DISTINGUISHING CLOSELY RELATED MODERN HUMAN POPULATIONS USING CRANIAL MORPHOMETRICS: A VIEW FROM KOREA AND JAPAN

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In loving memory of my papaw John F. Trotter, my nana Nobuko "Kay" Higa Trotter, and my dad Kenneth L. Broam.

For my mom Diana Trotter and the love of my life Michael P. Placher.

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ABSTRACT

One of the continuing issues in biological anthropology research on human variation is whether two closely related populations can be distinguished using skeletal methods. This dissertation uses morphological approaches to analyze 2D and 3D cranial data from Korean and Japanese skeletal collections dating to the historical early modern and modern periods. These two populations were selected as the subjects of this study due to their established shared population history and close genetic relationship. The cranium was chosen as the focus of this research because its form is the result of primarily neutral factors, but also to some extent environmental and developmental factors. The aim of this dissertation is to determine if two closely related populations can be differentiated, and to test whether directionality of gene flow can be detected in the cranium.

Traditional 2D craniometric and 3D geometric morphometric methods were utilized to analyze the data. For the 3D analyses, the cranium was divided into three components: the whole cranium, facial region, and cranial vault. This was done to test hypotheses about the neutrality of different parts of the cranium that have been presented in previous studies. Both 2D and 3D methodologies included principal component analysis, canonical variate analysis, and discriminant function analysis.

The results of the various analyses show that while the Korean and Japanese populations share cranial variation, there was enough between-group variation to be able to distinguish them. Overall, the whole cranium performed the best in this. In line with the existing neutral hypotheses that state the facial region is less congruent with genetic data, the face had the most landmarks that contributed to the variation between the groups. However, the temporal bone which is generally the most congruent with genetics had landmarks that contributed to the differences between the populations. This is likely a result of differential gene flow coming from populations not included in this study.

In terms of directionality of gene flow between the Korean and Japanese populations, the analyses provided some unexpected results. Contrary to expectations based on the historical evidence, there was more admixture in the early modern period than the modern period, and the

gene flow was in the direction from Korea to Japan. In addition to this, the modern period shows divergence between the two geographic populations while the Korean temporal groups have more continuity than the Japanese.

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CHAPTER 1: INTRODUCTION

The Problem

Understanding the nature of human morphological variation has been an integral component of biological anthropology research since the beginning of the field. While numerous studies of global and regional patterns of human variation have been conducted, a major debate that still exists is whether or not two distinct but closely related populations can be reliably distinguished using standard biological anthropology methods (e.g.: cranial linear and geometric morphometric methods; Manica et al., 2007; Relethford, 2001, 2004). The core problem with distinguishing two closely related human populations using skeletal methods is that it has been shown that most variation is due to genetic factors, such as genetic drift and gene flow, which lead to phenotypic variation (von Cramon-Taubadel, 2014). Indeed, 80-90% of the entire breadth of human cranial variation exists within any given population, mirroring the same phenomenon observed in human genetic variation (Lewontin, 1972; Lieberman, 2011; Relethford, 1994; Roseman and Weaver, 2004). However, research going as far back as the classic Boas (1912) study has shown that environmental factors will also influence phenotype to varying to degrees. While the validity of Boas' finding continues to be debated even into the twenty-first century (e.g.: Gravlee et al., 2003a, 2003b; Relethford, 2004; Sparks and Jantz, 2002, 2003), many studies have demonstrated that there are various factors outside of genetics that contribute to cranial form, including climate, environmental pressures, natural selection pressures, and developmental factors (e.g.: Lieberman, 2008, 2011; Lieberman et al., 2000, 2002; Relethford, 2010; Roseman, 2016; von Cramon-Taubadel, 2014). In cranial studies conducted on a global scale, researchers have found that some portions of the cranium adhere more to genetic (neutral) factors while other portions better reflect the non-genetic (non-neutral) pressures (e.g.: Harvati and Weaver, 2006; Hubbe et al., 2009; Smith, 2009; von Cramon-Taubadel, 2009; see the Neutral Theory section below). Since these patterns were found on a global scale, it is unknown how these patterns play out on a smaller, intra-regional scale. By analyzing crania restricted to one particular geographic region, it might be possible to determine whether or not the neutral and non-neutral factors are affecting different populations to different extents as von Cramon-Taubadel (2014) has suggested, in addition to investigating the problem of identifying non-neutral effects on cranial form. Thus, the primary aim of this research project is to determine if closely related populations can be distinguished using cranial morphometric methods and if so, what combination of data and what components of the cranium may best accomplish this.

The reason these questions are important is because in forensic anthropological and bioarchaeological investigations genetic methods are not always feasible, either due to a lack of usable genetic material from skeletal remains or due to cultural, legislative, or other prohibitions against the destruction of human remains. This dissertation presents research that differs from previous studies in that two distinct, yet closely related populations, Korean and Japanese, are utilized whereas most previous studies used global populations. It also differs from the few studies that have used single populations in that those studies were mapping clines of variation without identifying specific measurements that contributed to the observed variation; this research investigates whether specific cranial components can be reliably used to distinguish two related populations.

Many of the large regional or global studies have generally focused on population origins, human origins, the patterns of variation observed across large geographic regions, and the potential causes for the patterns observed (e.g.: Hanihara, 2006; Harvati and Weaver, 2006; Hennessy and Stringer, 2002; Howells, 1973; Konigsberg, 1990; Pietrusewsky, 2010; Relethford 1994, 2004; Roseman, 2016; von Cramon-Taubadel, 2009). The use of large geographic regions can be problematic due to the high variability that is likely to exist among a large number of populations in such a large region (Eller, 1999). For example, Relethford (2001) demonstrated this using global regions in the Howell's database (1989) and found that there is considerable cranial variation within these regions that can skew statistical results for genetic and phenotypic variation studies. The aggregated regional populations are often genetically distinct as many genetic studies have begun to show, including populations in East Asia (e.g.: Di and Sanchez-Mazas, 2011; Eller, 1999; The HUGO Pan-Asian SNP Consortium, 2009; Jeong et al., 2019; Kim et al., 2005; Listman et al., 2007; Tanaka et al., 2004; Xue et al., 2006; Yao et al., 2002).

As an increasing number of more narrowly focused intra-regional skeletal studies are conducted, we are learning that a great deal of morphological variation is present even among the intra-regional populations; variation that is likely the result of complex population histories and historical events (e.g.: immigrations, emigrations, warfare, etc.). One example of these types of studies has been Relethford's work in Ireland where he has used anthropometrics to analyze the patterning of human variation in Ireland (Relethford, 2008; Relethford and Crawford, 1995). In that particular case, he found that the morphological variation present in coeval Irish populations was likely due to past invasions and military occupations. Another example in Asia has been Wu and colleagues' studies on the microevolutionary changes in the craniofacial morphology of the Chinese through time (Wu et al., 2012, 2017). Through their research they found that there are morphological changes from the Neolithic to modern period and between northern and southern Chinese in all periods. The changes through time they attribute to the changes in climate and diet, while the differences between north and south are likely the result of the Qinling Mountain Range and Yangtze River being barriers to population movement (Wu et al., 2012; 2017).

Similar results to these examples have been found to be the case in Japan and to some extent, in Korea. For example, studies on cranial variation between Hokkaido (Ainu population, historically modern time periods), the Ryukyu Islands (Okinawan population, prehistoric and historically modern time periods), and the main Japanese islands of Honshu, Shikoku, and Kyushu (prehistoric and historically modern time periods) have shown that these three groups of Japanese populations are distinct from one another and distinct between time periods in their cranial variation (e.g.: Dodo et al., 1998; Fukase et al., 2012; Ishida et al., 2009; Pietrusewsky, 2010). This is despite the fact that these populations generally cluster together in larger regional or global studies. These studies have also demonstrated that there has been change over time in cranial morphometric traits in the Japanese populations. As of yet, not many comparable studies of spatial or temporal cranial variation have been conducted in Korea. One morphometric study of two Late Pleistocene human crania from the Ryonggok site in North Korea was recently undertaken that included modern Korean samples in the comparative database (Bae and Guyomarch, 2015). Another study analyzed geometric morphometric cranial variation in the Joseon Dynasty from the 15th to the early 20th centuries which found that both males and females varied through time (Jung et al. 2015). Together, these studies on Korean and Japanese crania show that both spatial and temporal variation in cranial morphometrics can clearly distinguish between subpopulations.

I suggest that many of these same questions regarding population history and analytical approaches (morphometrics) can be answered by studying comparable human skeletal populations in eastern Asia. In particular, the population history of Korea and Japan, and how they relate to one another, is long and complicated with multiple instances of interaction between the two (see Chapter 2). The question remains as to how much each population is affected by the other phenotypically throughout this history, and in what ways. This dissertation contributes to answering such questions, much like Relethford's research aided in better understanding the effects of past migration history on the variation of the Irish populations.

The Neutral Theory and Biological Anthropology

The Neutral Theory will be the theoretical base of this dissertation. In this section, the first subsection discusses what the Neutral Theory is, the importance of the theory in evolution, and its use as a testable hypothesis. The second subsection addresses how these concepts are applied in biological anthropological studies, especially with regard to research on human cranial variation.

The Neutral Theory

While natural selection is a strong force of evolution, research spanning over half a century has shown that many of the mutations that occur in DNA over time do not come under selective pressures and are in fact evolutionarily neutral. This idea that much of DNA variation and new mutations do not affect individual organisms in either an evolutionarily positive or negative way is the basis of the Neutral Theory. Genetic drift and gene flow have been long recognized as important factors in evolution. Wright (1931, 1932) was one of the first researchers to point this out. However, it was not until the late 1960s that the Neutral Theory entered the discourse of evolution as a clearly defined concept with mathematical applications to the study of genetic and, later, phenotypic changes of species and populations. The theory was originally described in two seminal articles by Kimura (1968) and King and Jukes (1969) who observed that there were more nucleotide substitutions present in the genomes of mammals than is accounted for by traditional Darwinian Evolution (also termed adaptive evolution). Therefore, these authors deduced that other non-selective avenues of evolution were having a larger impact on the genetic make-up of mammals. Kimura (1991:370) succinctly defined the Neutral Theory as stating "that the overwhelming majority of evolutionary changes at the molecular level are not caused by selection acting on advantageous mutants, but by random fixation of selectively neutral or very nearly neutral mutants through the cumulative effect of sampling drift (due to finite population number) under continued input of new mutations." However, while genetic drift has been originally characterized as having a larger expected divergence in a single generation in smaller populations, this is not the case with the neutral model. Rather, the rate of drift in populations depends on the rate of mutation because when there is equilibrium (a balance between different evolutionary factors) the rate of genetic drift is not faster in small populations compared to larger populations (Kimura, 1968; King and Jukes, 1969; Weaver, 2018). Another aspect of the Neutral Theory is that many of the neutral mutations, in the form of DNA polymorphisms and proteins, are kept in a species through the balance of redundant mutations and random extinction through the deaths of individuals (Kimura, 1991; Kimura and Ohta, 1971). This is a result of the fact that mutations occur at higher rates in DNA regions that are evolutionarily neutral and therefore have higher heterozygosity or polymorphism. These are not yet fixed in the species, nor are they completely removed, but rather exist in a type of transitory phase of molecular evolution through genetic drift (Kimura, 1991; Kimura and Ohta, 1971). Though the Neutral Theory focuses on the neutral variants of genes, it is important to note that it does not state that all mutations are neutral. Researchers have explicitly acknowledged that there are mutations that are not neutral and are selectively fixed or removed from populations as they affect an organism's survivability and/or their ability to reproduce successfully (e.g.: Kimura, 1991; Kimura and Ohta, 1974; King and Jukes, 1969; Weaver, 2018). The Neutral Theory has since been expanded by various researchers to include gene flow as another means of introducing and fixing neutral genetic variants in a population when they demonstrated how migration and gene flow create a heterogenizing effect in the receiving populations and reduction of between population variation (e.g.: Kimura and Maruyama, 1971; Lynch, 1988; Weaver 2018). Lynch's (1988) study also shows that low rates of gene flow, as low as one immigrant per generation in small populations, over time will have these effects.

Up to this point, the discussion of the Neutral Theory has revolved around its use as a genetic theory. However, shortly after the theory was established in the 1960s and 1970s, researchers began to extend its application to physical (phenotypic) traits. While quantitative phenotypic traits had been studied for within and between population variation, it was not until after the Neutral Theory entered the discourse of evolution that these types of studies began to look at non-selective forces as a means of population divergence or speciation. Just as mathematical formulae and models had been developed for the application of the theory to genetics, they were also created for quantitative traits. Through this, researchers were able to demonstrate that for a majority of traits they studied, the neutral models could not be rejected as the rate of change was too slow to be consistent with directional selection and/or too fast to be consistent with stabilizing selection (e.g.: Lande, 1976, 1977; Lynch and Hill 1986; Turelli et al. 1988). Some authors also illustrated that they could utilize polygenic traits as well as single-loci traits or genes in evolution studies and in the reconstruction of phylogenies (e.g.: Lynch and Hill 1986; Rogers and Harpending 1983). These various studies generally used the fossil record or fast-generation species, such as the fruit fly (*Drosophila*), but others applied the new neutral models to other organisms, including humans and our hominin ancestors.

The mathematical formulae that have been developed by researchers have provided a way to test predictions about adaptive and neutral evolution by using the neutral models as the null hypothesis (e.g.: Lynch, 1988; Roseman and Weaver, 2007; von Cramon-Taubadel, 2014; Weaver, 2018). Not only are models of the Neutral Theory more easily testable due their explicit use of specific units, coefficients, and variance and covariance matrices, but also because adaptative evolution can be proffered as the explanation to nearly any evolutionary pattern (Kimura and Maruyama, 1971; Roseman and Weaver, 2007; von Cramon-Taubadel, 2014). With the clear definitions of the neutral models, if the results of any test using them rejects the null hypothesis of neutrality, then it clearly suggests that neutral factors do not play a strong role in the evolution of the gene or trait being studied and that natural selection may have had a larger influence on it. However, if it cannot be rejected, then it is likely that natural selection had no or little role shaping the evolution of a trait.

The Neutral Theory in biological anthropology research

As noted in the previous section of this chapter, the study of human skeletal variation, particularly cranial variation, has long been a focus of biological anthropological research. While much of this research was aimed at documenting the variation within and between human groups, a significant portion has also investigated which components or features of the human form are the result of environmental factors (i.e., which features are adaptive). As Chakraborty and Nei (1982) noted, it is not an easy task to develop mathematical models for evolutionary processes in phenotypic traits due to the fact that multiple factors affect them. It has been known that genetic, environmental, and developmental factors all contribute to the phenotypic variation of a species. While all traits are coded for in some way by our genes, some are thought to be more or less affected by these various factors. These factors also often interact with one another during growth and development of individual organisms, therefore making it even more difficult to parse out their effects in mathematical models. This is particularly true for the human head. As we know, the cranium is a complex system of bones that interact with each other and the tissues that surround them. Many of the individual bones in the skull are not independent, often interacting with surrounding tissues (other bones and soft tissues) and spaces to perform certain functions. Thus, the cranium can be viewed as a set of integrated modules that are themselves, in a way, composed of modules (Lieberman, 2011). Add in the influence of adaptive selection over our evolution history, developmental factors such as access to nutrition, and genetic controls of cranial development and the result is a highly complex system of interactions.

Nonetheless, the mathematical models allow us to test the neutrality of traits. Among the first to apply the neutral models to anthropometric data were Rogers and Harpending (1983), Lynch (1989), and Relethford (1994). Together, these studies have established three important aspects of the use of the Neutral Theory in the study of the human skeleton and its variation and evolution. First, Rogers and Harpending (1983) demonstrated that polygenic traits can be used to investigate the relationship between populations and species just as single-locus markers in genetics are used in neutral models. Second, Lynch (1989), using craniometric data from Howell's database (1973), showed that the human cranial form conformed to the neutral models and that due to the ability to reject the neutral hypothesis it is a better model with which to test phenotypic diversification. This is because, as already noted above, adaptive forces and selection can always be used to explain variation as they are rarely able to be rejected as a hypothesis. Third, Relethford (1994), also using Howell's database (1973, 1989) in his study where he analyzed the among-group cranial variation and compared the results with previously published genetic studies, illustrated that craniometric variation co-varied with genetic variation for within and between population variation. The co-variation of these two types of data indicate that the Neutral Theory can be applied to craniometric data to test the hypothesis that cranial variation is primarily the result of genetic drift, which Relethford's (1994) results suggest is the case.

Compared to the genetic models where researchers have addressed gene flow, most of the anthropological studies of phenotypic variation using the Neutral Theory have only included genetic drift. As discussed above, gene flow is another aspect of the theory that is important in neutral evolution. Among some of the first researchers to adapt genetic neutral models of gene flow to human phenotypic characteristics were Relethford and Blangero (1990). Their study illustrated how hypotheses of neutrality can be utilized to test for gene flow, especially deviations from expected rates of heterogeneity that could suggest more or less admixture from within or outside of the tested geographical region (Relethford and Blangero, 1990). More recently, studies of gene flow, or hybridization, in hominin species have become popular as the development of ancient DNA (aDNA) techniques has allowed for the acquisition of aDNA samples from recent hominin species. In particular, the Neanderthals and Denisovans, the admixture between the two groups, and the admixture between them and *Homo sapiens* has been the focus of this recent research (e.g.: Kuhlwilm et al., 2016; Sankararaman et al., 2016; Vernot et al., 2016; Wall et al., 2013; Wolf and Akey, 2018). While the majority of the studies analyze the genetic evidence for hybridization, some studies are looking at how morphological traits can be used to do the same (e.g.: Ackermann et al., 2006; Ackermann, 2010; Ackermann et al., 2016; Bae et al., 2017; Martinon-Torres et al., 2017; Warren et al., 2018). These studies have shown that there are morphological trends (including size and shape differences) between the hybrid offspring and their parents, suggesting that these patterns could be used to analyze the hominin fossil record for evidence of hybridization between hominin species.

This group of research was an important step in biological anthropological comparative research that took the field from simply describing differences as a result of adaptive evolution toward more hypothesis driven research where the null hypothesis could now be falsified. Prior to this, and to some extent afterward, comparative studies of humans and their phenotypic traits "rarely consider the possibility that the differences among groups could be a simple consequence of population structure and history driven by random genetic drift and gene flow" (Roseman and Weaver, 2007:1185). As research utilizing the Neutral Theory continued, the main aspects of the theory's application to human physical traits described in the above two paragraphs became central to many of the studies as they became more frequent in the 2000s. While these studies were not the first to illustrate that human skeletal (and in particular cranial) variation is the result of both genetic and environmental factors, and that signatures of both can be seen in the analysis of the skeleton, they have reaffirmed this biological fact and have built upon it. Indeed, Relethford (2004) has demonstrated that both neutral and non-neutral influences can be seen in the analysis of human crania and that one set of influences does not necessarily erase or obscure the other set. Beyond this, the body of literature has served to further refine our understanding of the interaction between genes and environment by showing that certain parts of the cranium are more neutral than others.

The early studies that developed and applied neutral models to human crania typically compared populations using the entire cranium and genetic data. Various researchers have established that craniometric data largely conforms to the Neutral Theory, which has since been further demonstrated using newer models and methodologies (e.g.: Relethford, 1994; Roseman and Weaver, 2007; von Cramon-Taubadel, 2009, 2014). In addition, many of these studies have also shown that cranial variation is correlated with geographic distance in a similar pattern to genetic data (e.g.: Betti et al., 2009; Konigsberg, 1990; Relethford, 2004, 2016). These results are not surprising considering the history of human population movements, how geographically closer groups will admix more than those that are further away, and the nature of the skull and how it grows, develops, and functions. With this extensive background research, the stage was set for researchers to begin to explore which bones, cranial modules, and components of the cranium are more or less congruent with neutral genetic data.

Several studies in recent years have conducted tests of the cranium to identify which sections of it are more influenced by non-neutral (or adaptive) factors. These studies utilized cranial data and genetic data from modern human populations from various regions of the world. They all attempted to match the cranial and genetic data for each population, but due to these being acquired from different (often previously published) datasets, it was not always possible to do so and thus sometimes the populations were not exactly the same for the two types of data. One potential problem that von Cramon-Taubadel (2014) has pointed out for these types of studies is that different populations are likely to be affected by non-neutral factors to differing extents. Another potential confounding factor is that not all researchers divide the cranium in the same way. Most of these studies have divided the cranium into functional components or morphological units (for example: the facial region, the cranial vault, and the basicranium; or bone groupings based on function such as the orbital, nasal, masticatory, oral, and frontal regions). A third manner in which researchers divvy up the cranium is by developmental modules (endochondrally ossifying versus intramembranously ossifying components). von Cramon-Taubadel (2011) tested the two developmental modules and found that the chondrocranium (endochondrally ossifying portion of the basicranium) was less consistent with neutral data than the dermatocranium (intramembranously ossifying vault and facial regions), which was not the expected result based on previous studies. What this particular study indicates is that the mode of ossification has less of an effect on the morphology of the cranial components than does the neutral genetics, function of the modules, or adaptive selection forces.

Even so, many of the cranial studies have shown that only a few cranial morphological features are subject to adaptive factors and/or that only a few populations in extreme environments have these adaptive changes (e.g.: Harvati and Weaver, 2006; Hubbe et al., 2009; Roseman and Harpending, 2004; Relethford, 2010; Smith, 2009). For example, in studies of modern human populations around the globe, it appears that populations living in extremely cold environments have distinctive adaptations in the facial region, especially in the nasal region, facial breadth, and facial height (e.g.: Harvati and Weaver, 2006; Hubbe et al., 2009; Roseman and Harpending 2004). Those features or cranial portions which have been identified as being relatively less congruent with neutrality when compared with other features are often the occipital bone, eye orbit, and maxilla, which are often associated with climatic adaptations (e.g.: Harvati and Weaver, 2006; Hubbe et al., 2009; Smith, 2009) even though it is not possible at this time to definitively identify the effects of climate on human cranial variation (von Cramon-Taubadel, 2014). The cranial vault, temporal bone, and basicranium minus the occipital are generally the most correlated with neutral genetic data and therefore better reflect biological distance (biodistance) and population history (e.g.: Harvati and Weaver, 2006; Hubbe et al., 2009; Smith, 2009; von Cramon-Taubadel, 2009, 2014).

Together, this large body of literature provides the theoretical and methodological applications of the Neutral Theory to biological anthropological questions about human variation. It reaffirms that the theory provides a way to test hypotheses of neutrality versus non-neutrality of traits, including with cranial morphology. As several researchers have demonstrated that the cranium conforms to neutral models, it is important to note that this means that in the absence of genetic data, we can use the cranium to answer questions of population history, dispersal events, and patterns of population affinity. These studies have thus far shown that while the entire cranium is overall neutral, certain components (such as the cranial vault, temporal bone, and basicranium minus the occipital) are more reflective of neutral genetic data than others, and thus those components should be better for answering such questions. On the other hand, the components (occipital, eye orbit, and maxilla) that are less congruent with neutral genetic data should align more with environmental or climatic conditions, and therefore better for testing hypotheses about adaptative evolution. As the current dissertation research is focused on the shared population history between the Korean and Japanese populations, it is expected that the more neutral cranial vault, temporal bone, and basicranium minus the occipital will be a better indicator of this history than those that are less neutral.

Research Questions and Hypotheses

As noted in the first section of this chapter, the primary research question of this dissertation is whether two closely related human populations can be distinguished using cranial morphometric methods and if so, what components of the cranium best accomplish this. Since cranial form is the result of both genetic and environmental factors, the neutral model will be utilized as the null hypothesis in this research. Because the Korean and Japanese populations are closely related (see Chapter 2) any differences found between the two should theoretically be due to either environmental influences or to different genetic factors that the populations do not share. While it might be difficult, if not impossible in this study, to differentiate between these two possibilities, the differences should provide us with an idea of what characters may be used to distinguish the Koreans and Japanese. Specifically, since the facial region and occipital bone have been shown to be the least correlated with genetic data (e.g.: Harvati and Weaver, 2006; Smith, 2009; von Cramon-Taubadel, 2009), it is hypothesized here that the facial cranium will best differentiate the two groups in this research. Alternatively, since the cranial vault region is more correlated with genetic data (e.g.: Harvati and Weaver, 2006; Hubbe et al., 2009; Smith, 2009; von Cramon-Taubadel, 2009), it is hypothesized here that this region will not do well to differentiate the closely related Korean and Japanese populations.

Furthermore, this research aims to test whether directionality of gene flow can be detected in cranial morphometric data. In order to test this, two main comparisons were made in this study: 1) between the compiled Japanese temporal populations and compiled Korean temporal populations; and 2) between the four temporal groups (Korean Joseon Dynasty, Modern Koreans, Japanese Edo Period, and Modern Japanese). These comparisons were conducted with sexes pooled and separated to control for sexual variation as a potential confounding factor. Comparison 2 allows for the control of temporal variation within the sample set that could affect the results while still allowing for a combined temporal comparison. It also allows for both the control of temporal variation within each population and the investigation of directionality of gene flow that has been documented in the various studies (see Chapter 2).

Organization

In this chapter, I have outlined the research problem, theoretical approach, and research questions and hypotheses. The remainder of this dissertation is divided into five remaining chapters (Chapter 2 through Chapter 6) and three appendices. In Chapter 2, I present the evidence (archaeological, genetic, and historical) for the close relationship between Korean and Japanese populations. While the shared population histories of Korea and Japan extend into deep prehistory (Bae, 2017), the early modern and modern periods will be the focus of this chapter and only a brief review of the former will be discussed. Chapter 2 provides the contextual setting for the biological anthropological study of the populations in this research, including the historical events that potentially contributed to the admixture between them as well as to their separation. In Chapter 3, I present a summary of the material and methods utilized in the current study. Each collection that was studied is described, including number of individuals sampled, their condition, and their archaeological or historical setting. The types of data collected, the methods used to collect the data, and the methods used to analyze it are discussed in this chapter. A discussion of the merits of each methodological and analytical approach is included. Chapter 4 presents the results of the analyses conducted. It is organized to present the results for each type of data collected and for each type of analytical approach used for them. In Chapter 5, I discuss the results in the context of the population histories of Korea and Japan. This discussion includes an interpretation of the results in terms of gene flow and admixture, how the results reflect the historical events discussed in Chapter 2, and how each methodology used in this research performed in distinguishing the two populations. Chapter 6 is the concluding chapter in which I summarize this study and suggest future steps in this line of research. Finally, is the Appendix containing the canonical coefficients for the canonical variate analyses conducted. The data collected for this research is not included the dissertation due to the large size of the database. It is available upon request to the author.

CHAPTER 2: THE INTERTWINED POPULATION HISTORIES OF KOREA AND JAPAN

The populations of Japan and Korea have been selected for this study due to their known shared population histories as evidenced by archaeological (Barnes, 2000, 2015; Hudson, 1999; Mizoguchi, 2013; Rhee et al., 2007), historical (Lewis, 2003; Morris-Suzuki, 2006; Robinson, 1996, 1997; Seth, 2016a, 2016b; Uchida, 2011), and genetic data (Hammer et al., 2006; Horai et al., 1996; Hudson, 1999; Jeong, 2019; Kim et al, 2000; Nakagome et al., 2015). The closeness between these two populations is in part due to a series of major and minor migration events between the Korean peninsula and the Japanese archipelago that resulted in various admixture events between the immigrating populations and the resident populations (Barnes, 2000; Hammer et al., 2006; Horai et al., 1996; Hudson 1999; Kang, 1997; Lewis, 2003; Nakagome et al., 2015; Rhee et al., 2007; Seth, 2016a, 2016b). Perhaps the most prominent and most well-known of the population history events between the Korean peninsula and the Japanese archipelago is the transition from the Jomon Period (15,000 BC – [700]300 BC[1]) to Yayoi Period ([700]300 BC – AD 300) in the archipelago. This heavily studied transition in Japanese pre-history is defined by a shift from a primarily hunter-gatherer society to one dominated by agriculture (Barnes, 2015; Hudson, 1999). The transition from the Jomon to the Yayoi Period was initially slow, beginning in Kyushu, but then quickly spread northeastward through Honshu (Barnes, 2015; Hudson, 1999). The literature generally agrees that the Yayoi population originated from the Korean peninsula (Figure 1; e.g.: Barnes, 2015; Hudson, 1999). The skeletal remains of the Jomon and Yayoi peoples are morphologically distinctive (Fukase et al., 2012; Fukumine et al., 2006; Hudson, 1999; Kudaka et al., 2013; Nakahashi, 1993; Okazaki and Nakahashi, 2011; Ossenberg et al., 2006; Shigematsu et al., 2004; Temple et al., 2008; Yamaguchi, 1982). Research on cranial variation has shown that there is also a southwest to northeast cline in Japan, which has been used as evidence that the Jomon and Yayoi did indeed admix, but that this admixture occurred differentially as the Yayoi expansion was slow in the southwest (more admixture) and faster into the northeast (less admixture) (Hudson, 1999;

[1] There is an ongoing debate regarding the exact dates for when the Jomon Period ended and when the Yayoi Period began based on different lines of evidence.

Nagaoka, 2003; Ossenberg et al., 2006). Genetic studies have also documented evidence for the migration of a new population into the Japanese archipelago at the time of the Yayoi Period. The majority of the genetic studies have utilized modern Korean and Japanese samples to demonstrate the shared population history of the two groups, as well as to determine the rates of admixture between the Jomon and Yayoi (e.g.: Hammer and Horai, 1995; Hammer et al., 2006; Horai et al., 1996; Jinam et al, 2015a, 2015b; Nakagome et al., 2015; Tanaka et al., 2004). However, the estimated rates of admixture is disagreed upon in the literature, which is likely the result of the studies using different samples and sample sizes, including different types of DNA (mitochondrial DNA, Y-chromosome DNA, nuclear DNA).

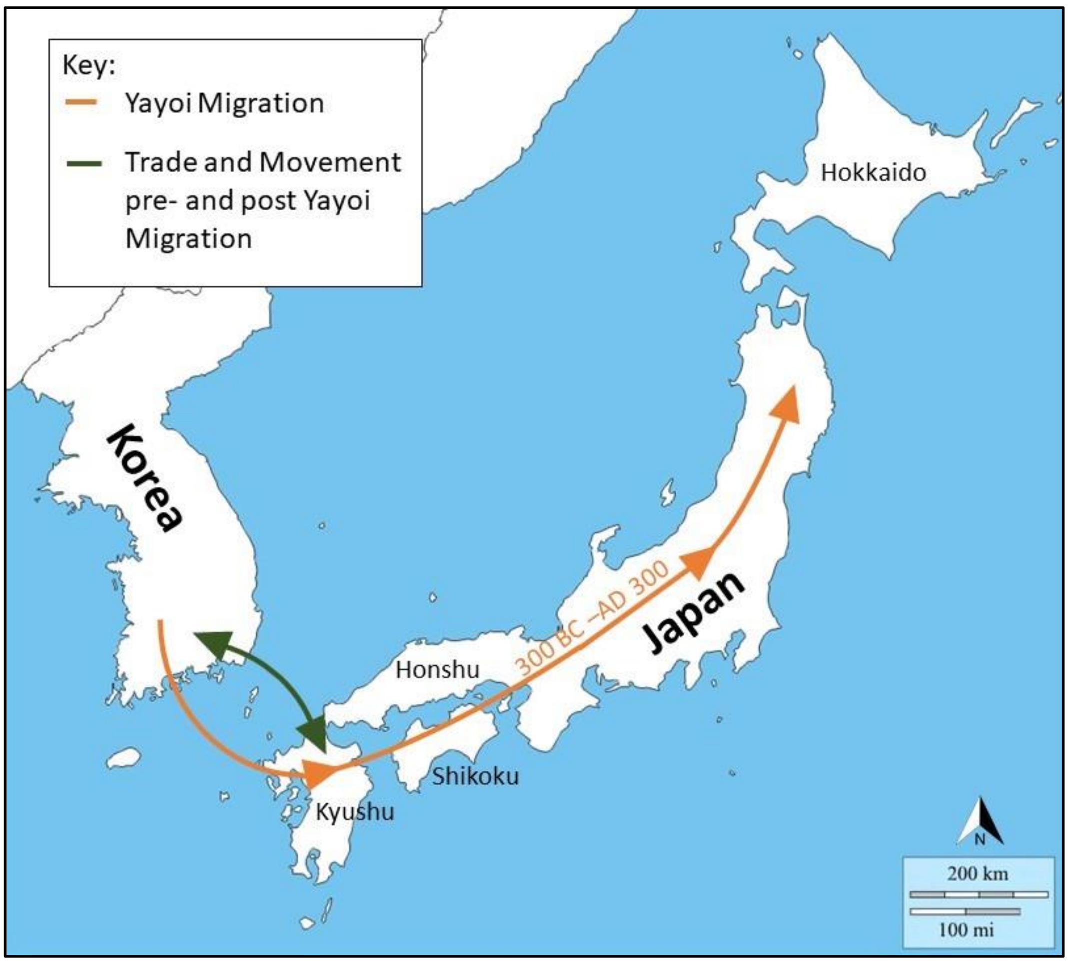

Figure 1: Map showing the migration of the Yayoi from the Korean peninsula to the Japanese archipelago.

There has been little formal skeletal or genetic research into post-Yayoi admixture between Japan and Korea. Many of the studies into population variation have been restricted to temporal variation or geographical variation within one or the other nation. In addition to this, there has been more population variation research conducted in Japan than there has been in Korea. Part of the reason for this is due to the better preservation of remains in Japan. Korea has primarily acidic soils that causes the destruction of skeletal remains at most sites within a few centuries, with the exception of shell middens and caves (Bae, 2014; Norton, 2000). In addition to this, Japan has had a longer history of skeletal research than Korea has had. When reviewing the published literature, research on Japanese skeletal remains date back to earlier than those on Korean skeletal studies by several decades.

Some of the biological anthropology and genetic studies on Japanese populations have been aimed at documenting secular trends through time, such as those in height and cranial form (e.g.: Nagaoka, 2003; Nakahashi, 1993; Okazaki and Nakahashi, 2011), or at determining the variation and population histories of the Ainu, Ryukyu, and main island populations (e.g.: Dodo and Ishida, 1990; Fukase et al., 2012; Ishida et al., 2009; Jinam et al., 2015a; Pietrusewsky, 2004; Yamaguchi-Kabata et al., 2008). Some of the latter studies are related to the Jomon-Yayoi transition as they attempt to determine how much the Yayoi admixed with the Jomon in Hokkaido (i.e. the Ainu population) (e.g.: Ossenberg et al., 2006; Shigematsu et al., 2004). Some of this research has also explored the potential origins of the Ainu or Ryukyu peoples, as well as the origins of admixture in these two groups that are different from the main island populations (e.g.: Dodo et al., 1998; Fukumine et al., 2006; Ishida et al., 2009; Matsumura, 1995, 2001; Pietrusewsky, 2010; Shigematsu et al., 2004; Tanaka et al., 2004).

In Korea, many of the skeletal and genetic studies published thus far have focused on paleoanthropology, paleopathology, health, trauma, and biological profile estimators of human skeletal materials (e.g.: Bae and Guyomarch, 2015; Beom et al., 2014; Han et al., 1995; Jeong et al., 2013; Kim et al., 2011; Pak, 2011; Woo and Pak, 2014). However, there are some that deal with secular trends and population variation (e.g.: Jung et al., 2015, 2016; Kim et al., 2018; Shin et al., 2012), and some that address the origins of the Koreans (e.g.: Jeong, 2019; Jin et al., 2003; Jin et al., 2009; Kim et al., 2000; Kim et al., 2011; Lee et al., 2008; Pang and Bakholdina, 2008).

In addition to the publications specifically on Japan or Korea, there are numerous pan-Asian studies that include Japanese and Korean samples, both modern and archaeological. Many of these studies, both skeletal and genetic, aim to document the variation of Asian populations, their origins, or their phylogeny (e.g.: Bae et al., 2017; Di and Sanchez-Mazas, 2011; Hanihara, 2006; Jeong, 2019; Kim et al., 2005; Listman et al., 2007; Matsumura and Hudson, 2005; Pietrusewsky, 2010; Shi et al., 2005; Sue et al., 1999; Xue et al., 2006; Yao et al., 2002). Overall, the research shows that while Koreans and Japanese are both within the East Asian population cluster, they tend to be close to one another, sometimes being statistically indistinguishable from one another on scatter plots. This indicates that the two populations are closely related.

While the Jomon-Yayoi transition is one of the most investigated admixture events in the population histories of Korea and Japan, it was not the last time the two populations experienced admixture. And while there is no formal skeletal or genetic research into many of the post-Yayoi admixture events, there are a plethora of archaeological and historical evidence to support them. These events, depicted on a map below (Figure 2), include the Mimana colony and Empress Jingu legend found in the *Nihon shoki* text which suggests that there was a Japanese colony in Gaya between the 4th century and 7th century A.D. (Barnes, 2001; Mizoguchi, 2013; Seth, 2016a). The Kwanggaet'o stele of A.D. 414 is used as evidence supporting an invasion of Gaya by Japan during the 4th century as it has been interpreted to testify to the defeat of a Japanese force invading Silla by a King Kwanggaet'o (Barnes, 2001; Lee, 1984). In the 4th to 6th centuries, there were also refugees from Baekje and Gaya moving to the Japanese islands (see Figure 2). Both the refugee populations were referred to in a 9th century A.D. elite account where it is said that 28% of families on an elite family registry are of Korean or had continental origins (Barnes, 2015). While this account does not represent the entire Japanese population, it does provide evidence that there were immigrants from the peninsula in Japan at the time. This account is supported by the archaeological evidence which shows that during the 4th to 9th centuries A.D. many new crafts and Chinese language and writing appeared in Japan (Barnes, 2015). Such evidence are good examples of how the relationship between Koreans and Japanese continued beyond the Jomon-Yayoi transition. Below, I present the historical events that would have likely had an impact on the populations of Korea and Japan in the time periods being studied in this dissertation, the early modern (Joseon Dynasty and Edo Period) and modern periods.

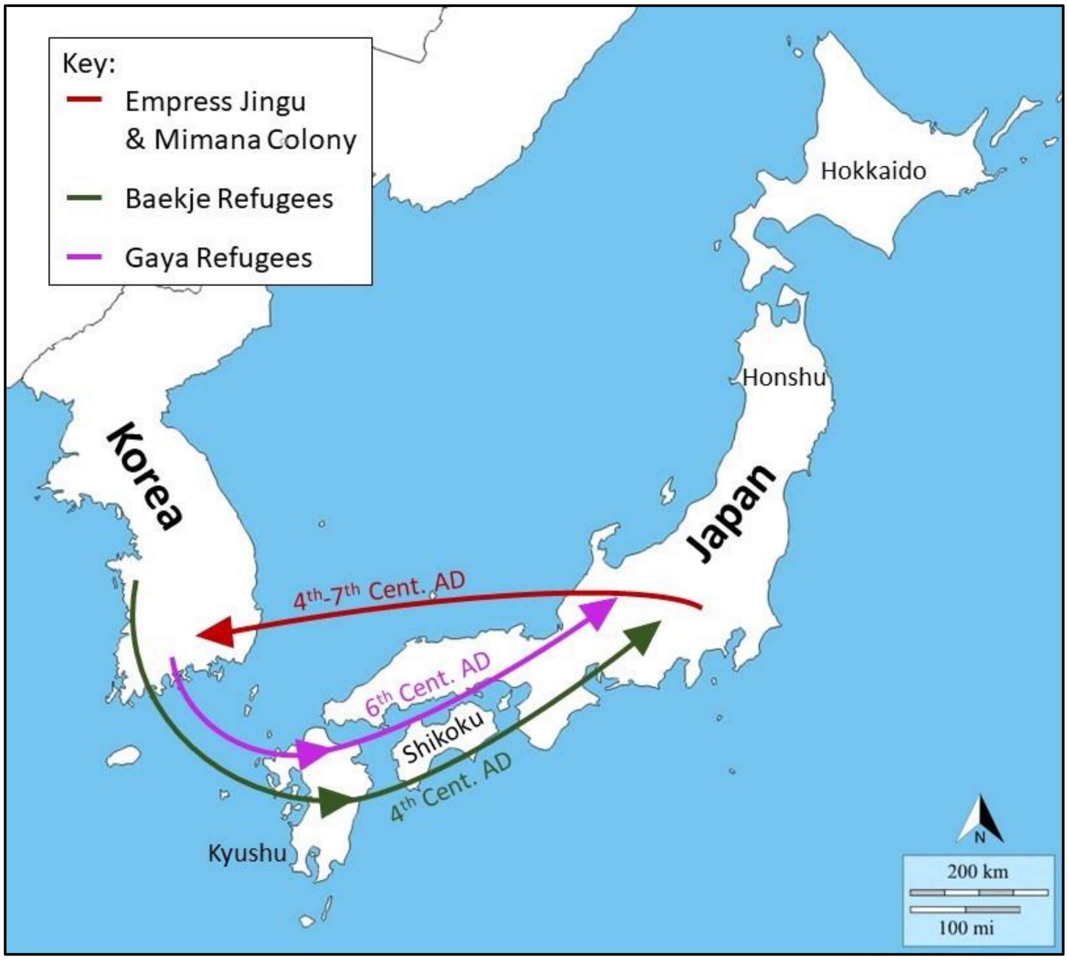

Figure 2: Map showing the events of the late pre-history and early history that likely contributed to admixture between the Korean and Japanese populations.

Relations during the Joseon Dynasty

In this section I will focus on the relationship between Korea and Japan during the Joseon Dynasty Period (A.D. 1392 to A.D. 1910). The reason for focusing on the Joseon Dynasty rather than the Japanese periods is the ease of discussing one period in Korea versus the four Japanese periods that occurred during the same time span (Figure 3). There are several aspects of this period which have led to gene flow between Korean and Japanese populations. The most prominent of these that have the best historical evidence are depicted in the map below (Figure 4) and discussed in this section.

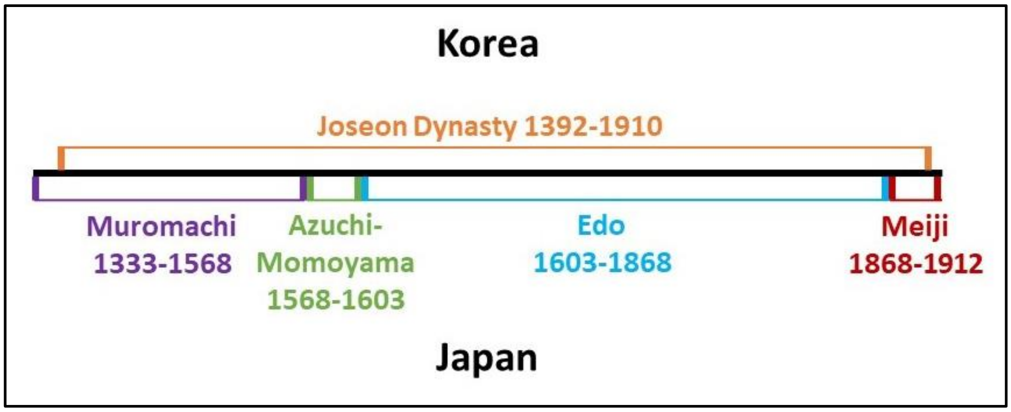

Figure 3: Timeline of the Japanese periods during the Korean Joseon Dynasty period.

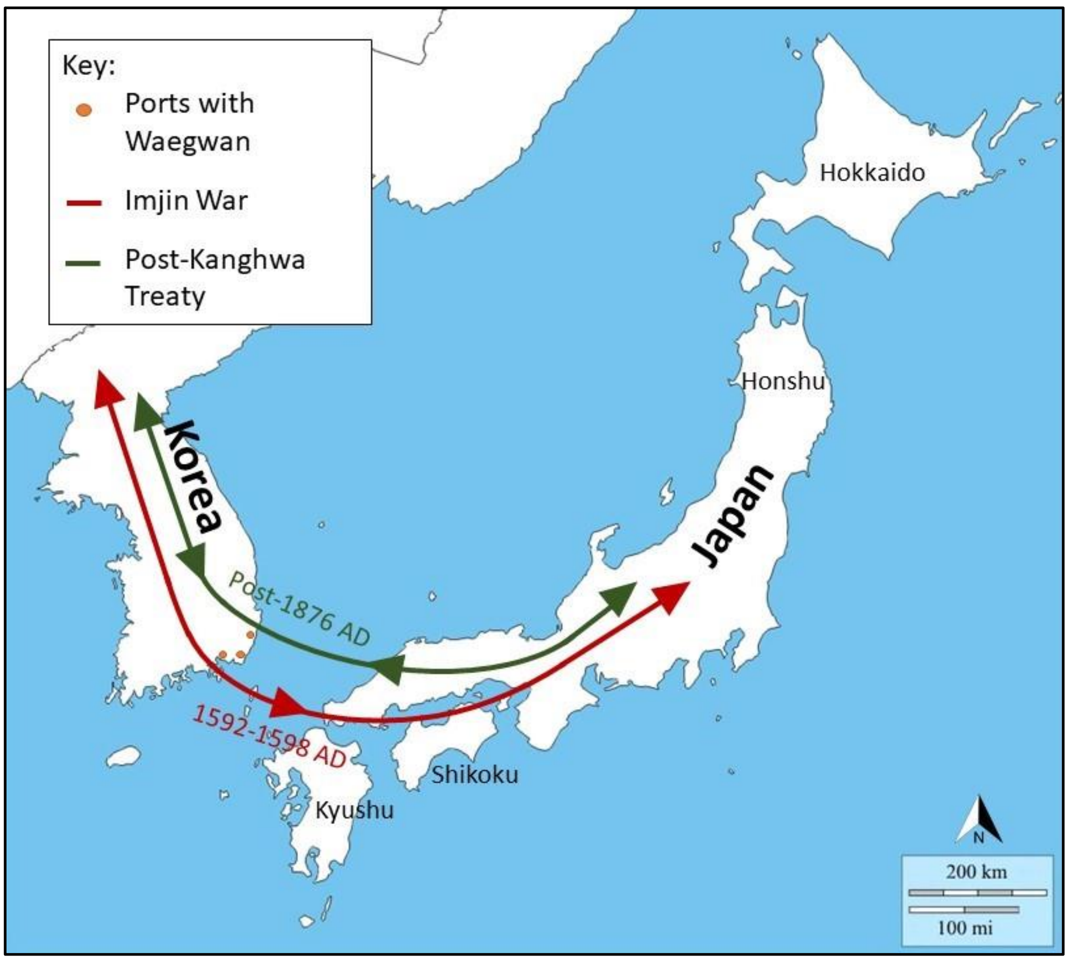

Figure 4: Map showing the events during the Joseon Dynasty that likely contributed to admixture between the Korean and Japanese populations.

Trade relations and the waegwan

After the Japanese allied with the other Korean Kingdoms against Silla, the relationship between Unified Silla (A.D. 668 to A.D. 935) and Japan was unsteady (Barnes 2001, 2015; Kang 1997; Mizoguchi 2013; Seth 2016a). Despite this, trade still occurred between the two, especially during the latter portion of the Unified Silla period (Seth, 2016a). However, during the Joseon Dynasty period (A.D. 1392 to A.D. 1910), the Korean courts restricted access to the peninsula in three main ways. First, they restricted trade to three ports (collectively known as the "Three *Po*" [Three Ports]) along the southern coast: Naeipo in the city of Ungcheon, Busanpo in the city of Dongnae (now part of the Busan metroplex), and Yeompo in the city of Ulsan (see Figure 4; Kang, 1997; Lewis, 2003). These ports are where *waegwan* (foreign trade districts) were specially constructed for Japanese merchants (Kang, 1997; Lewis, 2003). The *waegwan* was not only where the Japanese were allowed to trade, but also where they lived, whether temporarily or permanently. Second, starting in A.D. 1436-1438 Joseon Korea required formal passage permits, called *munin*, issued through Tsushima officials, in order to travel to the Three Ports (Kang, 1997; Lewis, 2003). And third, they placed a limit on the number of ships and number of passengers that could travel to the Three Ports (Kang, 1997).

Part of the reason behind the Joseon Dynasty courts restricting Japanese access to the peninsula was to reduce the government's costs of hosting the Japanese traders and diplomatic envoys (Kang, 1997). In addition to this, it was also in response to the increasing *wako* (pirate) raids that were primarily of Japanese origins (Kang, 1997; Lewis, 2003; Seth, 2016a). Tsushima was at the center of the *wako* problem as it was home to many of the pirates. The reason for this is due to Tsushima's environments being poor in food resources, thus residents found themselves taking up piracy in order to sustain themselves, especially in times of famine (Kang, 1997). The trade restrictions through Tsushima and the *waegwan* was a way to control the raids in two ways. First, it incentivized the *wako* to get official trade papers and conduct peaceful business rather than violently marauding coastal villages (Kang, 1997; Seth, 2016a). Second, it also put pressure on the Japanese *daimyo* to attempt to control the *wako* since the Korean courts used the trade restrictions to threaten them with severing trade relations all together (Kang, 1997). This eventually happened on several occasions, but not all of these instances were a result of *wako* raids. In A.D. 1510, when riots by the Japanese residents occurred at the Three Ports, the Joseon

Dynasty courts closed the ports temporarily (Lewis, 2003; Seth, 2016a). Following the Revolt of the Three Ports, as it is known, the 1512 Agreement led to a reduction in the number of ships and passengers that could travel to the peninsula, and the closing of *waegwan* in all but Naeipo (Lewis, 2003). Busanpo's *waegwan* was later reopened to the Japanese in A.D. 1521. In A.D. 1544, they closed the ports again after another revolt by the Japanese residents and a *wako* pirate raid at the ports (Kang, 1997; Lewis, 2003; Seth, 2016a). This led to the closing of the *waegwan* in Naeipo, thus restricting the Japanese to only Busanpo thereafter (Kang, 1997; Lewis 2003; Seth, 2016a). Finally, the longest and perhaps most well-known closing of ports to Japan was in A.D. 1598 following the Imjin War (A.D. 1592 to A.D. 1598; the war itself is discussed in the next subsection). Joseon Korea did not re-open ports to the Japanese for trade or diplomatic envoys (a few exceptions occurred, but those were mostly for negotiating purposes) until the Kiya Agreement of A.D. 1609 (Kang, 1997; Lewis, 2003). The Kiya Agreement allowed trade and diplomatic envoys to resume, but retained the limit of one port, Busanpo, and added that envoys could no longer travel up to the Joseon capital, but rather were restricted to Busanpo for the completion of all their business (Kang, 1997).

The importance of the *waegwan* rested not only in its role for cultural diffusion between Joseon Korea and Japan, but also in that there were many Japanese living in the *waegwan*. It is estimated that more than 3,000 Japanese residents were living at the *waegwan* in the Three Ports by 1494 (Lewis, 2003). This number dropped after A.D. 1544 when the Japanese were restricted to only Busanpo. It is estimated that approximately 500 Japanese lived in the Busanpo *waegwan* between A.D. 1609 and the 1870s (Lewis, 2003). However, their numbers remained high enough to cause problems for the local magistrates. These problems ranged from Japanese robbing Koreans in various situations to even murder (Lewis, 2003). In addition to these issues, there was prostitution and love affairs that occurred between Korean women and the Japanese men residing at the *waegwan* (Lewis, 2003); there is no mention of these relations being the other way around between Korean men and Japanese women. Historical documents refer to several incidents of sexual relations and also indicate that these interactions resulted in many Japanese-Korean offspring in Busan, which was seen as a problem for the "racial purity, social morality and state security" (Lewis, 2003:196). Thus, the Joseon Dynasty courts attempted to control the contact between the Japanese men and Korean women by instituting curfews and restricting freedom of movement outside of the *waegwan* (Lewis, 2003). Because these efforts did not fully prevent sexual relations from occurring, such events would have led to the contribution of Japanese biological variation into the Korean population, even if only initially in the port cities that had *waegwan*.

The Imjin War

In A.D. 1592, the *daimyo* Toyotomi Hideyoshi began his first invasion of the Korean peninsula with the goal of not only conquering Joseon Korea, but also to invade and conquer China, thus becoming the dominant power in East Asia (Hawley, 2005; Kang, 1997; Lewis, 2003; Seth, 2016a; Turnbull, 2002). Within four months, his military forces had effectively captured the majority of the Korean peninsula, including the capital of Hanyang (now Seoul) (Hawley, 2005; Turnbull, 2002). While the Korean military efforts on land were not successful, their naval forces were able to thwart Japan's naval efforts to transport and resupply troops already on the peninsula (Hawley, 2005; Seth, 2016a; Turnbull, 2002). This strategy affectively caused the Japanese to be unable to continue their efforts into China.

Japan's victory and occupation of Joseon Korea was short lived. The Joseon state had sent a request to Ming China for assistance in defeating Hideyoshi's forces. Based on the Chinese world order that they imposed in East Asia, Joseon Korea as a tributary state would have been entitled to Chinese assistance in times such as these. Once it became clear to China that the Japanese had intentions to continue on into their territory and that the Koreans could not expel the Japanese forces on their own, the Chinese dispatched military forces to recapture Korea (Hawley, 2005; Seth, 2016a; Turnbull, 2002). The Chinese forces eventually pushed the Japanese forces back to the southern coast of Korea where the Japanese were able to maintain a defensive line and territory on the peninsula (Hawley, 2005; Turnbull, 2002). However, as peace negotiations failed between Japan and China, Hideyoshi mounted a second invasion in A.D. 1597-98. The Japanese forces found it more difficult to re-capture the peninsula as the Korean forces were better equipped and prepared than the previous invasion in 1592 and had Chinese assistance early on the second time (Hawley, 2005; Seth, 2016a; Turnbull, 2002). With the death of Hideyoshi in late A.D. 1598, the Japanese forces were ordered to withdraw back to Japan (Hawley, 2005; Seth, 2016a; Turnbull, 2002).

During the Imjin War all three sides suffered casualties, but the Koreans suffered the most as they lost both soldiers and civilians (Hawley, 2005; Turnbull, 2002). In addition to this, both Japanese soldiers and Korean soldiers and civilians were captured by the opposing side. It is unknown how many captives were taken by the Korean forces or how many were repatriated to Japan after the war. The captives taken by the Japanese are estimated to be upwards of 60,000 to 100,000 people (Kang, 1997; Turnbull, 2002). Many of these captives were either forced into labor in Japan or sold to the Portuguese for the slave trade (Hawley, 2005; Kang, 1997; Turnbull, 2002). Between 3,000 and 7,500 were repatriated back to Korea after the war as part of peace negotiations and later trade negotiations (Hawley, 2005; Kang, 1997; Turnbull, 2002). Some of the captives that were brought to Japan were not repatriated and remained in Japan (Turnbull, 2002). The Koreans brought to Japan not only helped to revolutionize various aspects of Japanese culture, including pottery, art, agricultural practices, and typography (Hawley, 2005; Seth, 2016a; Turnbull, 2002). Those that stayed in Japan after the war and their descendants would have also contributed to the Japanese population genetically. However, it is unknown exactly how many Koreans stayed in Japan after the war as they were already absorbed into Japanese society by the time the Japanese government was repatriating Koreans after the war (Hawley, 2005).

Japan's influence on Korea in the late 1800s to 1910

Toward the end of the 19th century, not only was Joseon Korea facing pressure from Westerners to open up to foreign trade, but also from the newly reformed Meiji Japan (1868-1912) (van Dijk, 2015; Duus, 1995; Jin, In Press; Seth, 2016a, 2016b). Japan's interest in the peninsula was two-fold. First, Korea was viewed as a safety issue to Japan due to its proximity. If it should fall to western powers, including Russia, Japan would become more vulnerable to western influences and pressure even more so than they already were at the end of the 19th century (van Dijk, 2015; Duus, 1995). Second, Japan had already endured western nations forcing unequal treaties on them and wanted to ratify these (Duus, 1995; Jin, In Press). However, in order to be able to negotiate ratification, the Japanese saw that they needed to gain higher prestige and status on the international level following the western imperial paradigm. Therefore, Japan sought to extend its own influence over Korea to protect itself and to raise its own prestige in order to gain equal footing with western nations on the international playing field. Korea, on the other hand, sought to avoid economic dependency and colonization by attempting to pursue industrialization and institutional reforms (Jin, In Press). However, through these efforts, the monarchy and courts became more concerned with strengthening their own interests and little real progress was made toward economic stability (Jin, In Press). In fact, during this time period, there were foreign advisors from both Western and East Asian nations that attempted to influence Korea for their own interests, causing various factions to arise in the courts and xenophobia in both the public and courts (van Dijk, 2015; Jin, In Press). Hence, the Korean governments continued refusal to open up for trade and foreign diplomacy.

Japan sent envoys to the Korean courts to negotiate an unequal treaty, much like what the western nations had done to them, that would allow for open trade and for the Japanese to construct communications and rail lines in Korea. When Korea continually rejected the Japanese diplomats and their letters and requests, the Japanese became more aggressive and implemented gunboat diplomacy in 1875-1876 (Caprio, 2011; van Dijk, 2015; Duus, 1995; Jin, In Press; Seth, 2016a, 2016b; Uchida, 2011). This resulted in the Joseon monarch and court to cave to the Japanese demands and sign the Kanghwa Treaty in 1876 (Caprio, 2011; van Dijk, 2015; Jin, In Press; Seth, 2016b; Uchida, 2011). This treaty basically opened up Korea to trade and other diplomatic relations with Japan, which the Japanese began to take advantage of quickly. With the signing of the Kanghwa Treaty came many changes in Korea as a result of various provisions within the treaty. Some of these provisions had impacts on the Korean view of world order or on trade and economics, but of importance here are those that impacted the population in Korea. In particular, one of the provisions allowed for the residency of Japanese citizens in Korean ports that were a part of the Kanghwa Treaty (Seth, 2016b; Uchida, 2011). Initially, Busan was the only open port, but a few years later Wonsan (in 1880) and Incheon (in 1883) were added to the list of trade ports, and eventually more ports and cities were opened to the Japanese.

Shortly after the treaty was signed, Japanese people of varying occupations seeking opportunity moved to Korea, including, but not limited to, merchants, traders, prostitutes, journalists, teachers, general laborers, farmers, adventurers, and others (Uchida, 2011). In the early years, several of the people that moved to Korea returned to Japan after only a short time without having gained much, but others stayed and profited, mostly merchants. Between 1880 and 1910, the number of Japanese residing in Korea grew from 835 to 171,543 individuals (Uchida, 2011). The Japanese in Korea resided in numerous cities across the peninsula, but the majority were in major port cities, such as Busan, Mokpo, and Incheon. They also tended to live amongst other Japanese when they could, often forming their own districts within the cities they settled. Though there was tension between the colonial settlers and the Koreans, this did not preclude the Japanese and Koreans from interacting. They would patron each other's shops on occasion and would encounter each other in daily activities. The Japanese often hired Koreans to work around the house or as nannies (Uchida, 2011). In addition to this, Japanese and Korean prostitutes catered to both Japanese and Korean men (Uchida, 2011). This would have led to offspring of mixed ancestry in both populations living in Korea.

While the majority of the population migration was from Japan to Korea, there were also Koreans that traveled to Japan for short periods of time. For example, in the 1880s, Korea sent a handful of students to Japan to study military and technical trades (Seth, 2016b). However, between 1885 and 1894, Chinese intervention in Korea led to a ban on Koreans traveling abroad (Seth, 2016b). Despite this, the Japanese continued to have the largest foreign population in Korea as the Chinese presence did not interfere with the provisions of the Kanghwa Treaty, including the ability of the Japanese to settle in Korea. The Chinese intervention highlights the fact that both China and Japan wanted influence over Korea due to its strategic location in East Asia (van Dijk, 2015; Duus, 1995; Jin, In Press). In the case of China, their aim was also to maintain their influence over Korea that they had via the tributary system, especially since Japan was already weakening their sphere of influence by taking control of other tributary states (such as the Ryukyus and a few years later Taiwan).

The swift changes that were occurring in Korea as a result of the modernizing efforts of the Japanese resulted in a pronounced split between those that supported such efforts and those that were more conservative in both the court and the populace at large. During the Chinese intervention years, as the common people struggled with the changes, unrest became a regular occurrence. This unrest was a response to the changing economy, poverty conditions, and corrupt officials (van Dijk, 2015; Duus, 1995; Jin, In Press; Seth, 2016b). In response to the rebellious nature of the populace, the Korean government requested assistance from China, to which the Chinese responded by sending military assistance in 1893. Upon being informed of this development, Japan also sent military units to Korea to meet the Chinese presence. The military presence of China and Japan did not stop the eventual Tonghak Rebellions of 1894. While the Koreans managed to put down the rebellion and no longer needed China's assistance, the Chinese military remained in the Korean peninsula. With this, Japan decided that it was time to exert more direct control over Korea and attacked the Chinese forces in 1894, thus starting the Sino-Japanese War on Korea's doorstep (van Dijk, 2015; Duus, 1995; Jin, In Press; Paine, 2003; Seth, 2016b). The war did not last long, and China soon signed a treaty with Japan and left Korea.

Russia also attempted to exert some control over Korea in its bid to dominate Asia. Between 1895 and 1905, Russia was competing against Japan for greater involvement in Korean affairs and succeeded to a degree when King Kojong and the crown prince moved from the palace to the Russian legation in Seoul in 1896 to 1897 (van Dijk, 2015; Duus, 1995; Jin, In Press; Seth, 2016b). Eventually the tensions between Russia and Japan over Korea led to the Russo-Japanese War of 1904-1905. Once again, Japan emerged victorious. This victory over Russia led to the United States (U.S.) and Japan signing the Taft-Katsura Memorandum of 1905 in which the U.S. acknowledged that Korea was a protectorate of Japan (van Dijk, 2015; Duus, 1995; Jin, In Press; Seth, 2016b). The status of Korea was finalized with the Protectorate Treaty of 1905 between Japan and Korea (van Dijk, 2015).

While Japan now had active control over Korea, it was not without opposition from the Korean people. There were resistance groups protesting against the Japanese, as well as others', presence in Korea and the numerous changes that came with them (Jin, In Press). Riots broke out when the Japanese forced King Kojong to abdicate his throne to his mentally ill son in 1907 (van Dijk, 2015; Duus, 1995; Seth, 2016b). However, there were many Koreans who saw the opportunities that these changes could bring to Korea and took advantage of the situation. Japan became a popular choice for many Korean students to obtain more education in a variety of subjects (Seth, 2016b; Weiner, 1994). And just like the many Japanese who were seeking opportunities in Korea, Koreans were also moving to Japan for jobs (Weiner 1994).

Modern Japan and Korea

The modern history of Korea and Japan is a complex one with numerous factors influencing the course of historical events. There are many aspects of this history that are not addressed here due to the narrow scope of this dissertation project. These aspects, often having varying levels of impact on the two nations, ranged from the colonial and wartime policies of Japan to the post-war economic ups and downs in both Koreas and Japan. What is discussed in this section are the events that led to population contact and changes in residency of citizens in the past century.

In the modern period, Korea and Japan's relationship as nations is marked by the tensions caused by the Japanese imperialism and World War II (WWII). However, these events had two major impacts on their populations. First, during the Japanese colonial period in Korea, there was increased contact between their populations through people moving between the two countries that would have allowed for increased rates of gene flow. Second, WWII resulted in population loss for both nations, but also the division of Korea into separate countries, the return of Japanese to the archipelago, and the repatriation of Koreans in Japan to the two Koreas. These events are discussed below and are illustrated in Figure 5.

Japanese Occupation of Korea 1910-1945

In 1910, Korea was annexed by Japan after Korea's prime minister signed the annexation agreement presented to him by the Japanese resident general (Duus, 1995; Seth, 2016b). This completed the consolidation of Japanese power in the peninsula. As discussed above, part of the reasoning behind why Japan wanted to incorporate Korea into its territory was a sense of self-preservation through expanding its borders to protect its core. Interestingly, the Japanese used the argument that they and the Koreans were a related people with shared historical roots, including the intermarriage of Korean and Japanese nobles (Caprio, 2009; Weiner, 1994). Along with the annexation came many changes to Korea. Some of these changes were a continuation of those seen from the late 1800s up to the annexation, while others were novel. These changes affected the populace in varied ways, but perhaps the most noticeable was the increased poverty of the commoners, mostly farmers, as the political and economic changes upended centuries of established ways of life. This initially resulted in many Koreans fleeing to Manchuria, Russia,

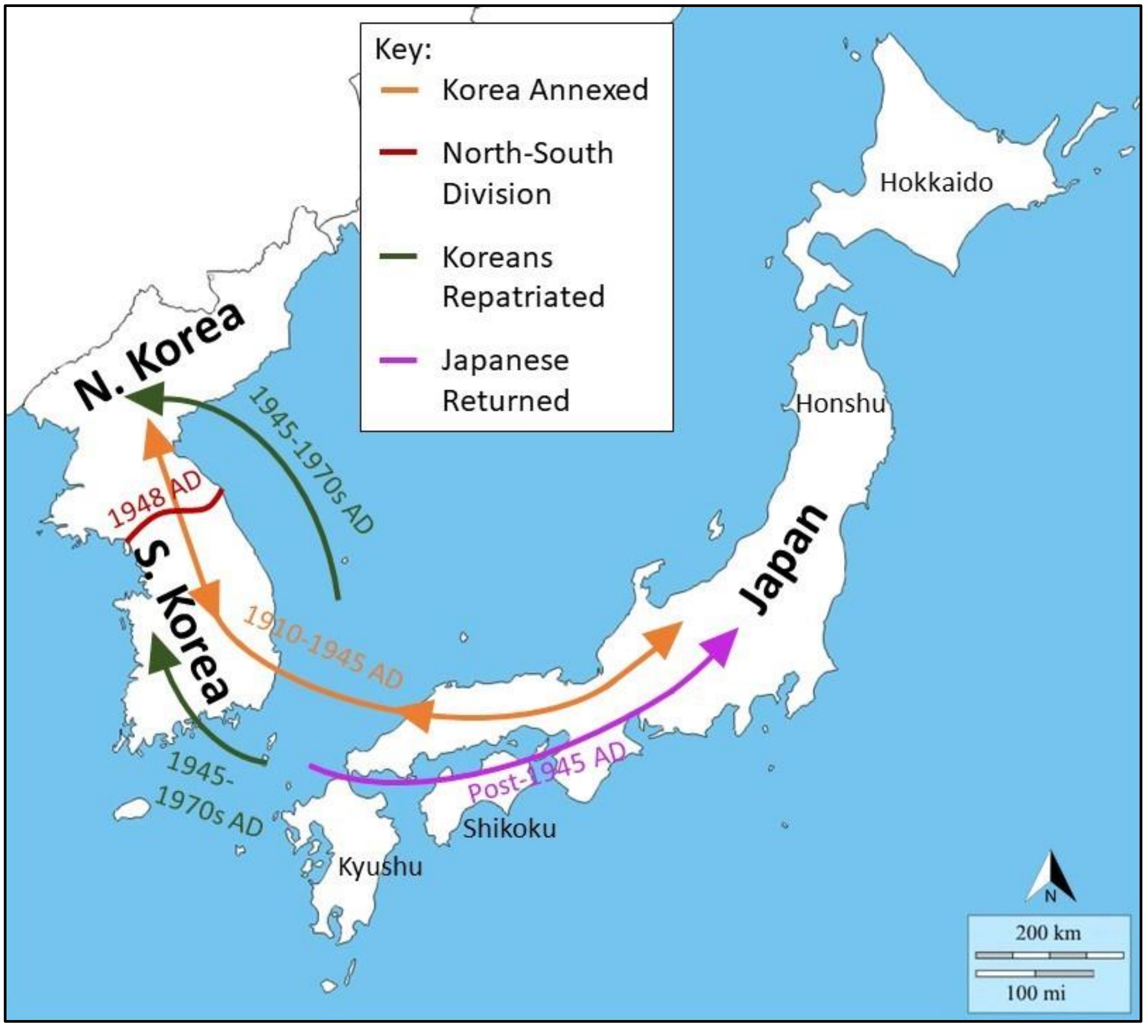

Figure 5: Map showing the events during the modern period that likely contributed to admixture between the Korean and Japanese populations.

Hawaii, and Shanghai for both political and economic reasons (Kim, 2010; Patterson, 1988; Seth, 2016b). However, some Koreans sought opportunity at home in the peninsula while others pursued it in the Japanese empire as they now had the freedom to move anywhere within it. Many seeking better fortunes within Korea went into new occupations that the new economic systems that opened up to them. Students began going to Japan for higher education where there were more and better schools (Seth, 2016b; Weiner, 1994). In addition, some workers were starting to move to Japan for better work opportunities, and Japanese companies began recruiting Korean workers as well (Kawashima, 2009; Morris-Suzuki, 2006; Weiner, 1994).

After 1910, the number of Koreans moving to Japan began to increase steadily rising up to a total of almost 4,000 migrants by 1915, and in 1917 began to increase almost exponentially (Kawashima, 2009; Weiner, 1994). The sharp increase is primarily due to the Japanese factories seeking laborers to work for them for cheap wages to combat the rise of wages demanded by unionized Japanese laborers (Kawashima, 2009). In 1917, the recruitment of Korean workers brought over 28,000 workers to Japan in that year alone, the largest number recorded for the colonial years (Kawashima, 2009). During this time period, Japan's economy was riding the wave of World War I (WWI), and with that wave came a lot of mine and factory jobs that needed to be filled. In addition to the official recruitments, there was also hiring of Korean workers through family and friend connections of the workers already employed in Japan (Weiner, 2994). After 1917, the recruitment rates began to drop precipitously with the anticipation of the end of WWI and with companies cutting back on the size of their labor forces to meet or get ahead of those anticipations (Kawashima, 2009). In addition to this, the Japanese government enacted travel restrictions on Koreans in 1919 to help not only regulate immigration between the peninsula and archipelago, but also to curb the growing Korean nationalist movements (Weiner, 1994). The fast pace at which layoffs were occurring, and of which the first and most people to be laid off were Koreans, led to a massive population of unemployed Koreans who either could not afford to or did not want to return to Korea (Kawashima, 2009).

Despite the dwindling number of jobs available to Koreans and the growing poverty of those living in Japan, the number of Koreans residing in Japan continued to increase during this time period (Weiner, 1994). This in part was due to the worsening economic conditions in Korea as well as the continuously increasing dependence of Japanese industry on the cheaper Korean labor (Weiner, 1994). In addition, as time went on more of the migrants came with their families and began settling in Japan in a more permanent fashion. It is estimated that by 1925 there were approximately 187,100 Koreans residing in various Japanese cities, and by 1945 this number reached 2.4 million (Seth, 2016b; Morris-Suzuki, 2006; Weiner, 1994). While not all of these resident Koreans worked in Japan (some were students at universities and some were children for example), the majority did and they accounted for about one quarter of the Japanese workforce by 1945 (Seth, 2016b; Weiner, 1994). Throughout the colonial period, resident Korean workers primarily lived in separate worker camps near mines or Korean districts around urban and industrial centers (Weiner, 1994). This segregation limited their contact with the Japanese populace. Nonetheless, contact between the two populations did occur. They encountered each other in the workplace and to a small extent in their daily lives outside the workplace. Intermarrying are known to have occurred on occasion (Baba 2019), although exact numbers are not reported in the literature.

While Koreans were immigrating to Japan in droves in hopes of finding more prosperous work opportunities, the Japanese continued to move to the peninsula, albeit in much reduced numbers compared to their Korean counterparts moving to Japan. The Japanese government attempted to incentivize immigration to Korea to establish Japanese communities there in hopes of not only establishing a buffer against other Asian nations, but also as a way of providing a cultural role model for their new subjects (Weiner, 1994). In particular, at various points during the colonial period, the Japanese government tried to incentivize Japanese farmers to go to Korea and farm in order to provide the empire with food. Their goal was to re-settle between 10,000 and 30,000 farmers per year, but they were not very successful (Duus, 1995; Uchida, 2011; Weiner, 1994). By the 1940s, the number of Japanese farmers in Korea equaled less than 5% of the Japanese population there (Uchida, 2011).

Nonetheless, Japanese people continued to immigrate to the Korean peninsula during the colonial period for business opportunities, much as they did in preceding decades. After annexation, the number of Japanese residing in Korea quickly rose to over 347,000 in 1920, over 501,000 in 1930, and by the early 1940s there were between 700,000 and 750,000 Japanese living in Korea (Seth, 2016b; Uchida, 2011), with an additional 300,000 Japanese military personnel stationed in Korea (Uchida, 2011). The Japanese workers in Korea comprised approximately 10-11% of the Korean workforce by 1937, but this number dropped to about 7% after that. Most of the workers were skilled workers or merchants (Seth, 2016b; Uchida, 2011), but by the late 1930s nearly 250,000 Japanese were bureaucrats, police, state bank employees, and school employees (mainly teachers) (Seth, 2016b; Weiner, 1994).

The patterns of residence in segregated Japanese districts in cities were maintained after the annexation. As before, this did not preclude them from interacting with the Korean population.

The Japanese still hired Koreans as house workers and nannies, individuals of both populations continued to patron the other's establishments, and they still encountered each other during their daily activities. There is evidence of intermarrying between the Japanese and Koreas, although this number was not large. According to the historical records, of the Japanese residents in Korea, roughly 1,000 to 1,500 married Koreans (McWilliams, 1988; Seth, 2016b). In addition to this, there was the continual practice of prostitution in which both Japanese and Korean prostitutes catered to men from both populations. Furthermore, it seemed that Japanese men sought out Korean prostitutes and female companions more often than they did for their Japanese counterparts (Uchida, 2011). Such behavior became so frequent that at Japanese business parties, Korean female entertainers became a common component of the events (Uchida, 2011). These sexual encounters would have led to Japanese-Korean offspring being born largely in the Korean communities and some in the Japanese communities.

WWII in the Pacific

Japan's interest in expanding its dominance in Asia led to the start of Asia's entrance into WWII in the Pacific. What initiated the war in Asia was the Manchurian Incident in 1931 when Japan invaded the region in an effort to expand its colonial empire and solve its own economic recession (Gruhl, 2007; Seth, 2016b). In all of Japan's wars during this time period, both the Korean and Japanese populations were affected. During the wartime, there were three major themes to the population histories of Korea and Japan. The first is one of loss of life, both in terms of military personnel and civilians. The second is one of comfort women and sexual slavery on the part of the Japanese military. And the third is one of returning to one's nation of origin toward the end of WWII and after. While these themes overwhelmingly did not create much gene flow between the Korean and Japanese populations, they are important events that led to the reduction of their populations that likely impacted the current variation through the loss of some of it.

As Japan's war industries ramped up again, Koreans were once again being heavily recruited to work in factories, mines, and other jobs, in part to fill the new open positions needed and in part to replace Japanese who went to serve in the military (Seth, 2016b; Weiner, 1994). After 1942, there was a sharp increase in the number of Koreans being brought to Japan for labor

(Weiner, 1994). The number of Korean residents living and working in Japan steadily increased as a result of these recruits, and by the beginning of 1945 there were over 2.4 million Koreans in Japan (Seth, 106b; Morris-Suzuki, 2006; Weiner, 1994). It has been estimated that during the war period, the number of Korean laborers who died in Japan is approximately 400,000 (Gruhl, 2007). One area in which Koreans were not initially allowed to serve was in the Japanese military. However, starting in 1938 the Japanese government opened up military service to Koreans (Seth, 2016b; Uchida, 2011). Though the Japanese officials were hoping for higher educated and higher status Koreans to join the military, the majority of volunteers were from the lower class, usually tenant farmers (Uchida, 2011). Between 1938 and 1943, only 17,000 Korean applicants were accepted into the Japanese military despite over 800,000 Koreans volunteering for service (Seth, 2016b). By the end of the war, a total of 116,294 Koreans were enlisted as soldiers and an additional 126,047 worked as civilian laborers for the army and navy (Ishikida, 2005). Of these, it is estimated that over 22,000 were killed in the war (Ishikida, 2005).

The Japanese exploitation of Koreans was not relegated to only labor and military service, but extended also to sexual slavery for brothels and comfort stations during both pre-war and wartime periods. Prior to the annexation of Korea in 1910, the Japanese military and brokers had established pleasure quarters in various cities and ports in Korea to service the expanding military presence as Japan entered war with China (Sino-Japanese War 1894-1895) and Russia (Russo-Japanese War 1904-1905) (Soh, 2008). At first these brothels would recruit women from Japan, albeit deceptively, but then the pleasure quarters began to expand to recruit Korean women, which then increased significantly after annexation in 1910 (Soh, 2008). Prior to WWII, traffickers would deceptively recruit or kidnap Korean women, both prostitutes and non-sex workers, to work at comfort camps for laborers in Japan (Norma, 2016; Soh, 2008). These systems that were in place for prostitution in Korea were easily co-opted by the Japanese military. When WWII in the Pacific began, the Japanese military extended the existing system to include comfort stations for troops, primarily those stationed and fighting outside of Japan (Norma, 2016; Soh, 2008). While the girls and women who were enslaved at these comfort stations were of several nationalities, including Japanese, the vast majority of them (upwards of more than 80%) were Korean (Gruhl, 2007; Kwon, 2019; Norma, 2016; Seth, 2016b; Weiner, 1994). Of the estimated total of 300,000 to over 400,000 comfort women that serviced the military between 1937 and 1945, approximately 100,000 to over 200,000 were Korean (Norma, 2016; Seth, 2016b). However, it should be noted that different sources provide different numbers that range as low as 50,000 comfort women (Ishikida, 2005; Soh, 2008). Part of the reason for this discrepancy is that there are not many records that document the number of comfort women, or necessarily where they came from (Ishikida, 2005).

The conditions of the comfort stations and treatment of the women varied from place to place (Soh, 2008). This is in part due to some stations being owned by the military and some by civilians, and in part due to where they were located, both in terms of geography as well as in relation to the front lines of battle (Soh, 2008). Those that were closer to the front lines and closer to the end of the war had the worst conditions and became known as ‘rape stations’ as the women were forced to service upwards of 50 men a day (Gruhl, 2007; Norma, 2016; Soh, 2008). It is unknown how many of these women got pregnant or were able to carry to term and give birth. One reason for this is that the military provided its soldiers with condoms for use at the comfort stations (Soh, 2008). However, they did not always use them as there are known instances of pregnancies (Gruhl, 2007; Norma, 2016; Soh, 2008). If a woman was able to give birth, we do not know what happened to the baby as it appears that they were not raised by their mothers in most cases based on survivors’ stories (Norma, 2016). Many of the women who were enslaved died from the conditions of the comfort stations or committed suicide (Gruhl, 2007; Norma, 2016; Seth, 2016b, Soh, 2008). Many of the survivors also contracted venereal diseases from the men they were forced to service at these comfort stations and were left unable to have children due to the physical damage their bodies endured (Gruhl, 2007; Norma, 2016; Soh, 2008). The use of comfort women has been argued as a method of controlling the reproductive abilities of the Korean population by the Japanese government (Norma, 2016; Soh, 2008). While it is not within the scope of this research to discuss whether or not this is the case, there is the potential for this to reduce some of the population’s variation through the removal of young women of reproductive age as a result of their deaths or subsequent inability to have children. Biologically speaking, this would have reduced the amount of variation in the population since these women were no longer able to contribute to it. However, the percentage of Korean women that were forced into this is relatively low compared to the total population. Therefore, in reality it is difficult to say how much this affected the overall variation of Koreans.

The impact of WWII on the populations of Korea and Japan were significant in terms population movement and loss of life. Not only were hundreds of thousands of people moved between the archipelago and peninsula as discussed above, but during the last year of WWII and the year after the war ended, there was massive population movement of Koreans and Japanese living abroad back to their homelands. Over 800,000 Koreans in Japan fled back to the peninsula in 1945 due to the war escalating in Japan (Weiner, 1994). After the war ended, an additional one-half to three-quarters of the remaining Koreans returned to Korea either on their own or as part of the repatriation efforts, but many stayed in Japan (Ishikida, 2005; Morris-Suzuki, 2006). The estimates of those that returned and those that stayed in Japan vary, but approximately 1 to 1.7 million Koreans were repatriated from Japan and approximately 600,000 to 980,000 remained (Heung, 2004; Ishikida, 2005; Koo, 2019; Lee, 2012). Those that stayed in Japan likely did so because their spouse was Japanese or their children were Japanese-born and Japanese-speaking (Lee, 2012). In Korea, the situation was more complicated due to the Allied powers and the Soviet Union dividing the peninsula into two separate nations at the arbitrarily chosen 38th parallel. The U.S. and Allies forced the Japanese to return to Japan, and thus by the end of 1946, the vast majority of Japanese in South Korea were repatriated (McWilliams, 1988; Uchida, 2011). In North Korea, where the Soviet Union was in control, the situation was more chaotic and repatriations did not conclude for several years with most Japanese civilians and military personnel being repatriated either through South Korea or directly to Japan by June 1948 (McWilliams, 1988). Many of those who were returned via South Korea had fled the north and crossed into the south on their own or with Soviet papers permitting them to cross the 38th parallel. In addition to those who had lived in North Korea, many Japanese who were living in Manchuria fled into Korea, adding to the number of Japanese being returned to Japan through the peninsula. It is estimated that a total of 914,000 Japanese were repatriated from Korea back to Japan, including those that fled from Manchuria (McWilliams, 1988). However, an unknown number died in North Korea during the harsh winter of 1945-1946 and an estimated 1,500 (mostly women married to Korean men) remained in Korea (McWilliams, 1988).

Post-War Relations

After WWII, the populations of Korea and Japan were more separated than before in terms of politics. While there was a drastic reduction in the movement of people between the Korean peninsula and Japanese archipelago compared to earlier periods, there was still immigration between the two. At first, the immigration was primarily one way, from South Korea to Japan. However, as the two nations recovered from both WWII and the Korean War (1950-1953) and began to have positive political relations, people were freer to travel, especially today. Since the sample composition for this research includes only a few individuals born after WWII and the Korean War, I will primarily focus on the years directly after the Korean War and end the discussion there.

Despite more stringent emigration and immigration controls in both South Korea and Japan, after the Korean War many Koreans continued to illegally migrate to Japan. Some of these migrants were reentering Japan after having been returned to Korea due to the harsh living conditions in Korea, including the unavailability of basic resources such as food, or to reunite with their families that remained in Japan (Morris-Suzuki, 2006). Many of the undocumented immigrants into Japan were arrested if they were caught. In 1946, over 17,000 people were detained, by 1951 over 48,000 had been captured, and by 1974 the number reached a total of over 77,000 (Morris-Suzuki, 2006). While it is difficult to estimate the total number of Koreans who entered Japan illegally due to the unknown number of those who were not caught, some researchers estimate that approximately 50% of illegal migrants were captured (Morris-Suzuki, 2006). Many of those who were able to escape detection were able to stay in Japan.

Historical events in the context of biological anthropology

This chapter highlighted the historical events that led to the Korean and Japanese populations admixing. While it is not comprehensive, the events discussed here illustrate the ways in which migration, trade, politics, and war put the two populations into contact with one another. With the exception of the Jomon-Yayoi transition, many of the historical events led to localized or small-scale admixing. However, as discussed in the previous chapter, it only takes a low rate of gene flow from one population to another population each generation to have a heterogenizing effect and increasing the population's variation. Thus, we can conclude that the events presented in this chapter would have had an impact on the variation of both the Korean and Japanese populations in a cumulative fashion over time. While these were greater in early modern and modern times, the long history of contact, despite being periodic and at lower levels in earlier periods, would have made the two populations more similar to one another as their variation increased to create greater overlap between the two.

Another theme in the historical record is the loss of life during times of war. Even though the Korean-Japanese conflicts were primarily covered here, it should be noted that wars with other nations also caused loss of life for the Korean and Japanese populations (e.g., Mongol Invasion of the mid-1200s, Manchurian Invasions of the early 1600s; Seth, 2016a). While some of the earlier wars did not result in high rates of mortality, the modern wars did result in a significant loss of life. This would have resulted in the reduction of variation in the populations. In particular, with the high mortality rate in Korea as a result of the Korean War (estimated to be over 3 million deaths; Cumings, 2010; Seth, 2016b; Wada, 2014) and the division of the country into two separate polities, the Korean population effectively experience a small bottleneck event. While it is not the aim of this study to address whether or not this bottleneck event would have caused the Korean population to become more or less phenotypically similar to the Japanese population, this is an important factor when analyzing variation. The reason this is not addressed here is that, as will be discussed in the Materials and Methods chapter, the sample composition does not include many individuals that were born after WWII, especially in the Korean sample.

Based on the historical evidence discussed here, there are several hypotheses that we can posit for what the results might show. First, it is anticipated the cranial morphology will demonstrate continuity in both groups, but that there will be some differences between the early modern and modern samples for each geographical population (i.e., the Joseon Dynasty and Modern Koreans will be similar enough to indicate continuity, but there will be differences between them such that they are segregated in the results, and the same with the Japanese). Second, it is hypothesized that the results will reveal admixture between Korea and Japan, but that the gene flow will be heavier from the Japanese into the Koreans during the early modern period. Finally, since there was greater movement between the peninsula and archipelago during the Japanese occupation and annexation of Korea, the two modern populations will potentially show more similarities to one another than the early modern groups, thus signifying more gene flow during this time.

CHAPTER 3: MATERIALS AND METHODS

Collection and Material Descriptions

Two-dimensional and 3D cranial data were collected from 614 human crania that are curated in various institutions in South Korea and Japan. Only adult crania were utilized for this study to ensure that the measurements taken reflect fully developed crania that are no longer subject to changes due to ontogenic growth. Only complete, or as complete as could be obtained from the available collections, crania were measured to avoid incomplete data that can skew the statistical results (Lele and Richtsmeier, 2001; Slice, 2005). While complete data collection was attempted, several crania from each of the collections were not complete enough to be included. Thus, a few landmarks were culled from the datasets for certain statistical tests while in other cases some individuals were removed from the datasets for analysis (see the Methods subsection below).

The crania utilized for this study are housed at various institutions that have human skeletal collections available for teaching and/or research purposes. Below is a table summarizing the location of these collections, the time periods they represent, and the number of individuals from each collection utilized for this study. Each of these collections is described below, including the composition of the collections and the condition of the remains. It should be noted that as far as is it is known, the Korean samples do not contain any North Korean individuals. However, given the amount of movement by people (e.g., refugees) up and down the Korean peninsula, particularly after World War II and up through the Korean War, it cannot be discounted that some people originally born in the North are actually present in these modern Korean samples. There is also a smaller sample size for the Korean groups than there are for the Japanese. In addition to these, 21 unknown individuals and one Korean individual from Jikei University were also utilized for this study. The data from these 22 individuals were utilized to test the feasibility and reliability of the regression formulae created to distinguish Korean and Japanese populations. When discussing the condition of the remains in the assemblages, they are described as either good or moderate. Good condition is when the collection has a large proportion of specimens that are mostly complete and thus retain the majority of cranial landmarks. Moderate condition is when the collection has approximately half of the specimens that retain more than half, if not most, of the cranial landmarks, but that the rest are too damaged to be utilized in this study. Examples of the damage observed are shown below in Figure 6 and Figure 7.

The catalogue identification (ID) labels for many of the collections were lengthy and the archaeological collections had catalogue IDs that included the site names. Since these long catalogue IDs are difficult to work with in the statistical analysis of the data, all individuals were re-coded in the database with temporary IDs that consists of a two-letter abbreviation for the institution followed by a number three digits in length and going in numerical order for that institution (example: Catholic University samples were relabeled as CU001, CU002, etc.). The abbreviations utilized for each institution is included in Table 1.

Table 1: Collection information and sample size

Country	**Time Period**	**Institution**	**Number of Individuals**	**Total**	**Grand Total**
Korea	Modern	Catholic University of Korea (CU)	95	100	614
		Yonsei University School of Dentistry (YU)	5		
	Joseon Dynasty Period	Seoul National University (SU)	52	103	
		Hanyang University (HU)	17		
		Dong-A University (DU)	34		
Japan	Modern	Jikei University (JU)	189	189	
	Edo Period	National Museum of Nature and Science (NM)	200	200	
Korean in Japan	Modern	Jikei University (JU)	1	1	
Unknown	Modern	Jikei University (JU)	21	21	

Catholic University of Korea

The human skeletal assemblage at the Catholic University of Korea is a donated collection of modern Korean skeletal remains that is utilized for teaching skeletal anatomy to medical students at the university. The collection is composed of primarily dissected skulls and crania, but a few complete skeletons are present. The collection can be broken down into the several categories of completeness: intact crania with mandible (16), dissected crania with mandible

Figure 6: Examples of observed facial damage, anterior view (left is SU002, right is DU030).

Figure 7: Examples of observed damage to basicranium (left) and zygomatic arches (right), inferior view (left is CU017, right is DU008).

(50), intact crania without mandibles (11), dissected crania without mandibles (20), dissected crania with mandibles but without calvaria (3), dissected crania without mandibles and calvaria (31), and loose mandibles (58) and calvaria (50). These individuals were collected between 1970 and 2000 and do not have associated known biological information, such as age or sex. In addition to these, there are 11 complete skeletons and five intact skulls with known biological information. These specimens were collected post-2000 after new collection standards were implemented that required the documentation of the biological information for each individual.

In general, the individuals present in this collection are primarily lower class or homeless persons who died while at the St. Mary's Hospital associated with the university. They range in age from sub-adult to old adult, with most being middle age to old adult. The condition of the remains is variable, ranging from heavily damaged to pristine condition. The most commonly observed damage on the crania were to the zygomatic arches, mastoid processes, and the teeth and alveolar bone. The worst damage observed were crania that had large cracks in them or were broken into pieces. According to the collection managers, the damage is primarily from students mishandling the skeletal remains. Many of them also had pencil and pen marks on them, again primarily due to students. More than half of the crania were dissected or autopsied, and thus have separated calvaria. Only the specimens that were not damaged or only slightly damaged were included in this study; both intact and dissected/autopsied crania were utilized. The worst damage on a cranium that was utilized in this study was where the basicranium was damaged such that the area around the foramen magnum was missing. Data were collected from a total of 95 individuals (24 intact crania, 57 dissected crania, 14 intact crania with known biological information). For those that were dissected, I used paper clay to temporarily reattach the calvaria to the rest of the cranium (Figure 8). It should be noted that these dissections were conducted by anatomy and medical students, and as such the cuts were thick and uneven in most cases. The thickness of the clay corresponds to this and varied with each dissected cranium.

Because the majority of individuals in this collection do not have biological information, sex and age were estimated for them. Age was estimated to determine whether or not individuals were sub-adult or adult. Established age estimation techniques for the crania were utilized, including dental development and suture closure following Buikstra and Ubelaker (1994). Sex

Figure 8: Crania CU025 showing the use of paper clay to reattach the calvaria to the rest of the cranium, anterior view.

was estimated using the non-metric characteristics of the skull (Buikstra and Ubelaker, 1994). In some cases, when characters were indeterminate, sex could not be estimated. In these cases, the sex of those individuals was left as indeterminate.

Yonsei University School of Dentistry

The skeletal collection at Yonsei School of Dentistry is primarily comprised of modern Korean mandibles with a few mostly complete skeletons and crania. All of the crania except one were dissected. Many of the dissected crania do not have calvaria. Due to the absence of calvaria, only five individuals from this collection were utilized (four dissected, one intact). The four dissected crania were associated with known post-crania and the one intact cranium was not. The sex of the skeletal remains was estimated using established skeletal sex estimation methods (Buikstra and Ubelaker, 1994; Phenice, 1969). The collection was obtained approximately 30 years ago and the individuals in this collection were between the ages of 60 and 80 years old. Thus, the birth years for the persons comprising the assemblage are in the first half of the twentieth century with some potentially in the last decade of the nineteenth century. The crania did have some damage to them but were overall in reasonably good condition. The majority of the damage observed was to the alveolar bone and mastoid processes.

Seoul National University

The Seoul National University Department of Anthropology has skeletal collections from several archaeological sites in South Korea. Of these, three sites were utilized for this study (Table 2). The largest of these is the Eunpyeong collection from an archaeological site in Seoul, which dates to the Joseon Dynasty. Eunpyeong contained a variety of burials types, most of which were either wooden coffin burials or pit burials; limestone burials were present but rare (Central Institute of Cultural Heritage, 2009). The wooden coffin and pit burials contained commoners with little to no burial goods, making it difficult to accurately date the burials to specific typological periods within the Joseon Dynasty. However, two individuals were recently directly dated using accelerator mass spectrometry radiocarbon dating to 1780-1920 AD and 1800-1865 AD (calibrated) (Woo et al., 2015, 2018). Thus, Eunpyung should be dated to the middle to late Joseon Dynasty.

Two additional smaller archaeological collections housed at Seoul National University were also included in this study. They are the Yang Giri collection and the Gyeonggi Pyeongtaek collection. Only two individuals from the Yang Giri collection and one individual from the Gyeonggi Pyeongtaek collection were utilized. Both of these collections are from archaeological sites located in Gyeonggi Province (the province surrounding Seoul) and date to the Joseon Dynasty.

Table 2: Seoul National University site collection information

Site Name	**Location**	**Period**	**Types of burials**	**Class**	**References**
Eunpyeong	Seoul	Middle to Late Joseon Dynasty	Mixed	Mixed	Central Institute of Cultural Heritage, 2009
Yang Giri		Joseon Dynasty	Unknown	Unknown	--[2]
Gyeonggi Pyeongtaek	Pyeongtaek, Gyeonggi	Joseon Dynasty	Unknown	Unknown	--

The general condition of the skeletal remains in the collections at Seoul National University is moderate with significant weathering and damage present on the remains. This is primarily due to generally acidic soils in South Korea that causes the complete destruction of osseus materials at most open-air sites (excluding shell middens) within only a few centuries (Norton, 2000). A majority of the crania are not complete, and many in fact are in several pieces. However, there are several that are intact, if not without damage. The damage observed on the intact crania ranges from slight to heavy and includes, but is not limited to, damage to zygomatic arches, dentition and alveolar bone, mastoid processes, basicranium and the foramen magnum region, facial bones, and some crania have evidence of root etching and rodent gnawing. While many of the crania contained little damage, some individuals were missing several facial landmarks or basicranium landmarks. Data were collected from a total of 52 individuals (49 from the Eunpyeong collection, 2 from the Yang Giri collection, and 1 from the Gyeonggi Pyeongtaek collection).

These collections have been heavily utilized in past research on a variety of topics, including but not limited to stature, health, degenerative diseases, facial asymmetry, work load, and sexual dimorphism (e.g.: Jung et al., 2016; Pak, 2011; Pak et al., 2011; Woo and Pak, 2014; Woo et al., 2014). Due to the extensive previous research, sex and age have already been estimated by the department staff and independent researchers. While the estimates were provided, these were verified using skeletal age and sex estimation methods (Buikstra and Ubelaker, 1994; Phenice,

[2] The -- indicates that there are no known publications for the archaeological sites. All information on these sites were provided by the Seoul National University.

1969). No noticeable differences were determined between the new estimates and those previously calculated.

Hanyang University Museum

The skeletal collection housed at the Hanyang University Museum include Joseon Dynasty material from several different sites around the greater Seoul area. There were skeletal remains from 14 different sites available for this study. Of these, 10 included individuals that could be utilized (Table 3); the other four contained crania that were too damaged or fragmentary to be used. The skeletal remains consisted of mostly complete to partial skeletons, most of which included a cranium. The interments from these sites were mostly limestone and pit burials and primarily represented commoners, as most burials did not contain graves goods.

Table 3: Hanyang University Museum site collection information

Site Name	**Location**	**Period**	**Types of burials**	**Class**	**References**
Incheon Geomdan	Incheon Metropolitan City	Joseon Dynasty	Limestone	Commoner	Ahn and Jang, 2018
Gimpo Yuhyeon-ri	Gimpo-si, Gyeonggi-do	Joseon Dynasty	Limestone	Commoner	Ahn et al., 2017
Namyangju Pyeongnae	Namyangju-si, Gyeonggi-do	Joseon Dynasty	Unknown	Unknown	--[3]
Misari	Hanam-si, Gyeonggi-do	Joseon Dynasty	Limestone	Commoner	Bae and Yoon, 1994
Yeoju Botong-ri	Yeoju-si, Gyeonggi-do	Joseon Dynasty	Limestone	Commoner	Ahn et al., 2014
Icheon Jeungpo-dong	Icheon-si, Gyeonggi-do	Joseon Dynasty	Mixed (limestone, pit)	Commoner	Ahn et al, 2015
Hadong	Ansan-si, Gyeonggi-do	Joseon Dynasty	Mixed (limestone, pit)	Commoner	Kim and Choi, 1988

[3] The -- indicates that there are no known publications for the archaeological sites. All information on these sites were provided by the Hanyang University Museum.

Site Name	Location	Period	Types of burials	Class	References
Chungbuk Jungwon-gun Salmi-myeon Mureung-dong	Chungju-si, Chungcheongbuk-do	Joseon Dynasty	Limestone	Commoner	Kim and Choi, 1984
Hwaseong Suhwa-dong	Hwaseong-si, Gyeonggi-do	Joseon Dynasty	Limestone	Commoner	Ahn et al., 2016
Hwaseong Yangno-ri	Hwaseong-si, Gyeonggi-do	Joseon Dynasty	Limestone	commoner	Ahn et al., 2018

The condition of the remains is similar to that of the individuals curated at Seoul National University and ranged from heavily damaged to very little damage. Again, this is primarily due to the acidic soils in South Korea. Most of the damage was observed on the zygomatic arches, dentition and alveolar bone, mastoid processes, facial bones, basicranium and foramen magnum region. Data were primarily collected from mostly complete adult crania, although some crania utilized were missing facial landmarks or portions of the cranial vault.

Since little research has been formally conducted on these collections beyond inventory for the archaeological site reports, sex and age of the individuals have yet to be estimated. From what I could determine, I was collecting these data on these specimens for the first time. Established skeletal sex and age estimation methods were used to estimate the sex and age of the individuals utilized in this study (Buikstra and Ubelaker, 1994; Phenice, 1969).

Dong-A University

Dong-A University houses archaeological assemblages, including skeletal remains. These collections are from archaeological sites across South Korea and from multiple time periods. They have several Joseon Dynasty Period sites represented in their collections, of which 11 sites contained crania that were utilized for this study (Table 4). The sites contained a variety of burial types ranging from commingled to limestone concrete tombs. Most of the individuals sampled were from limestone concrete tombs as they had the most complete crania, but other burial types are also represented in the sample. The limestone concrete tombs represent the Yangban class, an elite group who were able to read and write Chinese and either served the government or the military (Foundation of East-Asia Cultural Properties Institute, 2012; Gyeonggi Cultural Heritage Research Center, 2001; The Korea Archaeology and Art History Research Institute 2018; Korea Research Institute of Military Heritage, 2010; Lewis 2003). The pit burials represent commoners, and the commingled burials are of unknown class. Most burials did not contain enough burial goods for accurate dating to specific typological periods within the Joseon Dynasty, although some sites included burials that spanned most of the Joseon Dynasty Period and one site could be accurately dated.

Table 4: Dong-A University site collection information

Site Name	**Location**	**Period**	**Types of burials**	**Class**	**References**
Busan Dong-nae Eupseong Haeja	Dong-nae, Busan	Late 16th Century; 1592	Commingled	Unknown	Park et al., 2010
Busan Saenggok	Saeonggok, Busan	Joseon Dynasty	Unknown	Unknown	--[4]
Gyeonggi-do Hwaseong Dongtan 2 District	Dongtan, Hwaseong	Joseon Dynasty	Mixed (pit burials, limestone concrete tombs) – only cement tomb in sample	Commoner, Yangban – only Yangban in sample	--
Gyeonggi-do Goyang Tanhyeon	Tanhyeon, Goyang	Joseon Dynasty	Mixed (pit burials, limestone concrete tombs) – only cement tomb in sample	Commoner, Yangban – only Yangban in sample	The Korea Archaeoogy and Art History Research Institute 2018
Gyeonggi-do Namyangju Hopyeong 3 District	Hopyeong, Namyangju	Joseon Dynasty	Mixed (pit burials, limestone concrete tombs) – only cement in sample	Commoner, Yangban – only Yangban in sample	Gyeonggi Cultural Heritage Research Center, 2001
Gyeonggi-do Namyangju Pyeongnae 4 District	Pyeongnae, Namyangju	Joseon Dynasty	Mixed (pit burials, limestone concrete tombs) – only cement in sample	Commoner, Yangban – only Yangban in sample	Gyeonggi Cultural Heritage Research Center, 2001

[4] The -- indicates that there are no known publications for the archaeological sites. All information on these sites were provided by the Dong-A University.

Site Name	Location	Period	Types of burials	Class	References
Gyeonggi-do Paju Wollong High-Tech Industrial Complex	Wollong, Paju	Joseon Dynasty	Limestone concrete tombs	Yangban	--
Gyeonggi-do Yongin Gongsedong	Geongsedong, Yongin	Joseon Dynasty	Limestone concrete tombs	Yangban	Korea Research Institute of Military Heritage, 2010
Gyeonggi-do Yongin Shingal-Suji	Shingal-Suji, Yongin	Joseon Dynasty	Limestone concrete tombs	Yangban	--
Hadong Heungryong-ri	Heungryong-ri, Hadong	16^{th} Century	Limestone concrete tomb	Yangban	Foundation of East-Asia Cultural Properties Institute, 2012
Incheon Wondang	Wondang, Seogu	Joseon Dynasty	Limestone concrete tomb	Yangban	--

The condition of the skeletal remains at Dong-A University is similar to those at Seoul National University and Hanyang University Museum. The skeletal remains were in moderate condition, ranging from heavily damaged to very little damage. They consisted of partial to complete skeletons, some which were only represented by crania. The differential preservation observed is primarily due to the acidic soils in South Korea. Observed damage included breakage on the zygomatic arches, alveolar bone, facial bones, and basicranium. There was evidence of bone etching from plant roots on several of the skeletal remains. Mostly complete crania were primarily used in this study, although some crania utilized were missing a few facial or cranial vault landmarks.

A few of these collections have been utilized in past research or have appeared in archaeological reports for the sites. Due to this previous research, sex and age have already been estimated by the department staff for most of the individuals used in this study. While the estimates were provided, these were verified using skeletal age and sex estimation methods (Buikstra and Ubelaker, 1994; Phenice, 1969). No noticeable differences were determined between the new estimates and those previously calculated.

The Busan Dong-nae Eupseong Haeja site is a unique site which is thought to represent the first battle of the Imjin War (1592-1598; also known as Hideyoshi’s Invasions) when the

Japanese forces attacked the Dong-nae Eupseong fortress in 1592 (Park et al., 2010). The skeletal remains discovered at this site consist of primarily skulls and crania. They were found with Korean weapons in what is thought to have been the moat of the fortress. Many of the crania have holes or other battle-related damage on them.

Jikei University

Jikei University's Anatomy Department houses an extensive skeletal collection with the remains of over 1,000 individuals. The assemblage contains both intact and dissected crania that are in good condition with little damage observed. Damage was observed on some of the dentition, alveolar bone, and mastoid processes. In some cases, the calvaria were missing from dissected specimens. The individuals who comprise this collection were self or next-of-kin donated and had died while at the Jikei Hospital. As such, nearly all persons in this collection have known biological information recorded for them, including date of birth, date of death, age, sex, and cause of death. Most of the biological information was obtained from their government issued identification. Some individuals had unknown identities at the time of their death, and thus age was sometimes estimated or was self-reported prior to death. While most individuals in this collection are Japanese, there are some known Korean individuals as well. In addition, there are approximately 100 skulls in the collection that do not have associated known biological information due to either lost records or lost specimen identification. Most individuals in this collection were lower to middle class or were homeless, similar to the collection at Catholic University of Korea.

The collection was started in 1908 and continued accepting skeletal remains until the year 2000. Due to changes in the Japanese laws regarding human remains, it has since become more difficult to continue the donated skeletal program, and thus Jikei University has stopped the program; although cadavers are still donated and accepted for the purpose of teaching dissection anatomy courses (personal communication with Professor Yoshikatsu Negishi). The range of birth years for the individuals utilized in this study is from 1857 to 1941, with the majority being in the late 1800s up to 1930; there were only a few individuals with birth years after 1930. The range of ages for the individuals utilized in this study is 20 to 72. There are two trends through time that was observed for this collection. The first is that there are more younger individuals in the earlier collection years and older individuals in the later collection years. This trend is expected as advancements in modern medicine and the rise of the standard of living has been improving the quality of health in the past few centuries. The second trend is that there are more dissected crania in the later years of the collection than in the earlier years. Therefore, it seems that they were utilizing more of the donations for both dissection courses or study as well as for the skeletal collection. For this study, only intact and mostly complete adult crania were utilized; no dissected crania were used due to the availability of intact crania and time constraints. Data were also collected on 21 of the unknown specimens and 1 known Korean individual in order to test the reliability of the regression formulae created to be able to distinguish Japanese and Korean crania.

The National Museum of Nature and Science

The National Museum of Nature and Science stores numerous skeletal collections at their Tsukuba collections facility. The assemblages range in time and from all over Japan, as well as a few smaller collections from other places, such as Southeast Asia. Five of their Edo Period archaeological skeletal collections were utilized in this study: the Ikenohata-Shichikencho site, Kozukahara Execution Place site, Hoshoji site, Hachobori 3 Chome site, and Sumida-ku No. 21-2 site. All of these localities are from the greater Tokyo area. Hachobori 3 Chome dates to the seventeenth century, Kenohata-Shichikencho and Hoshoji date to the eighteenth century, and the remaining two sites are only dated to the Edo Period (century unknown). Ikenohata-Shichikencho and Hoshoji generally contained a mix of different burials types. Hachobori 3 Chome contained wooden coffin burials, and Sumida-ku No. 21-2 burial types are unknown. The Kozukahara Execution Place is an exception to the normal types of burials and is considered a special situation. Kozukahara is one where crania were discovered in a well-like structure as a secondary burial (Ohtani and Baba, 2001). It is unknown why the crania were placed in the well-like structure, but it does appear to be a special circumstance. The authors state that it is perhaps related to executions, prison deaths, or death on the street as evidenced by the unique trauma observed on the remains and the fact that nearly all of the crania were estimated to be male (Ohtani and Baba, 2001). With the exception of Kozukahara, these assemblages generally represent commoner townspeople and samurai based on the burial types and burial goods or lack thereof. See Table 5 for a summary of the provenience information for these different sites.

Table 5: National Museum of Nature and Science site collection information

Site Name	**Location**	**Period**	**Types of burials**	**Class**	**References**
Ikenohata-Shichikencho	Taio-ku, Tokyo	After 18th Century	Mixed	Townspeople and Samurai	Nagaoka, 2007
Kozukahara Execution Place	Arakawa-ku, Tokyo	Edo	Secondary burial, special	Unknown	Ohtani and Baba, 2001
Hoshoji	Shinjyuku-ku, Tokyo	After 18th Century	Mixed	Townspeople and Samurai	--[5]
Hachobori 3 Chome	Chuou-ku, Tokyo	17th Century	Wooden Coffin Burials	Unknown	--
Sumida-ku No. 21-2	Sumida-ku, Tokyo	Edo	Unknown	Unknown	--

The general condition of the remains housed at the National Museum of Nature and Science's repository is good. There is typical damage to the remains as expected from archaeological sites. Damage was primarily observed on the zygomatic arches, mastoid processes, facial bones, alveolar bone, dentition, and basicranium around the foramen magnum. Some crania were in pieces, but many were intact. There was some evidence of root etching and rodent gnawing, but these were minimal. Only intact crania with little damage were utilized in this study.

The Ikenohata-Shichikencho and Kozukahara collections have been previously studied and published; thus, the sex of the individuals has been previously estimated. The other three assemblages, however, have not, to my knowledge, been previously published and thus do not have available estimates for sex. Therefore, sex was estimated for all individuals using skeletal and cranial methods (Buikstra and Ubelaker, 1994; Phenice, 1969). Sex estimates for the individuals from Ikenohata-Shichikencho and Kozukahara were then checked with the previously available estimates. No discrepancies were found for these individuals. In addition, in

[5] The -- indicates that there are no known publications for the archaeological sites. All information on these sites were provided by the National Museum of Nature and Science.

order to assure that only adult crania were utilized in this study, age was estimated using skeletal and cranial methods (Buikstra and Ubelaker, 1994).

Methods

The analysis of the crania was conducted using 2D linear craniometric and 3D geometric morphometric (GM) approaches. 2D linear craniometrics are the traditional morphometric methods that have long been in use while the 3D GM techniques are a relatively newer method that has quickly become well accepted. These two methodological approaches were selected due to their non-destructive nature and because they are well established methods in biological anthropology (Bass, 1995; Buikstra and Ubelaker, 1994; Lele and Richtsmeier, 2001; Martin and Saller, 1957; Slice, 2005, 2007).

Traditional Morphometric and Geometric Morphometric Methods

Traditional morphometric data, also known as craniometrics, are captured using sliding and spreading calipers to acquire inter-landmark distances (ILDs) from the cranium. The ILDs provide size measurements, such as cranial height, width, and length that allow researchers to analyze the various size and shape components among a series of crania for multiple research interests, including ancestry estimation (e.g.: Howells, 1973; Relethford, 1994, 2001; Slice, 2005; Spradley and Jantz, 2016). More recently, 3D GM methods that utilize 3D digitizers and computer software to capture the coordinates of each cranial landmark and to calculate ILDs, including those that cannot be captured with calipers, are also being used in statistical analysis of size and shape (e.g.: Adams et al., 2004; Baab et al., 2012; Lele and Richtsmeier, 2001; Rohlf and Marcus, 1993; Spradley and Jantz, 2016).

In this study, both traditional (calipers) and 3D digitizing methods were utilized in order to directly test the two methods of capturing shape and size measurements for reliability purposes. Few studies have compared the potential user error and machine error of these two methods against each other. The majority of error studies tend to focus on inter-observer or intra-observer error rates rather than inter-method error rates; albeit those are also important factors to investigate in this type of research as von Cramon-Taubadel et al. (2007) expressly state.

Fortunately, a recent study has investigated inter-method error rates in morphometric methods (Robinson and Terhune, 2016). This particular study utilized four different methods: 2D morphometric (caliper) method, 3D landmark digitizer method, 3D laser scanner method, and 3D microCT scanner method. While the results of the intra-observer, inter-observer, inter-method, and machine error tests demonstrated that of the methods, 3D scanning methods have lower error rates than 2D traditional or 3D digitizer methods, they also showed that inter-observer error was a little higher than inter-method error (Robinson and Terhune, 2016). The authors note that the differences between the methods was not substantial enough to preclude researchers from utilizing any of the methods tested in their study, and that the larger problem identified was the use of data from multiple observers (Robinson and Terhune, 2016). While their study is an important one for the analysis of inter-method error, more reliability and validation studies need to be conducted. Thus, in addition to the 2D craniometrics and 3D calculated ILDs being used in the analysis of the populations, these data will also be used in an inter-method error test.

Electric metric sliding calipers and metric spreading calipers were used to collect craniometric measurements. A total of 30 measurements were collected and are listed and defined below in Table 6 and depicted in Figure 9 through Figure 12. These measurements were chosen because they were considered key traits to explore shape and size variation. Some measurements that were excluded from this study, primarily from Howells (1972), were excluded due to the required use of specialized or modified equipment that is not standard in an osteology lab and that few have access to, including myself. For example, Howells' (1972) various subtense measurements were not collected due to the necessity of using coordinate calipers.

Table 6: Craniometric measurements and calculated ILDs, angle, and subtenses

Hand-taken craniometrics and calculated ILDs from 3Skull		
Measurement	**Abbreviation**	**Definition**
Basion-Bregma height	BBH	The direct distance between basion and bregma (Howells, 1973).
Basion-Prosthion length	BPL	The direct distance between basion and prosthion (Howells, 1973).
Biasterionic breadth	ASB	The direct distance between the left and right asterion (Howells, 1973).

Biauricular breadth	AUB	The least external breadth across the left and right roots of the zygomatic processes (Howells, 1973).
Biorbital breadth	EKB	The direct distance between the left and right ectoconchion (Howells, 1973).
Bistephanic breadth	STB	The direct distance between the left and right stephanion (Howells, 1973).
Bizyogmatic breadth	ZYB	The direct distance between the left and right zygion (Howells, 1973).
Cheek height	WMH	The minimum distance between the lower orbital border and the inferior margin of the maxilla, medial to the masseter muscle attachment (Howells, 1973).
Cranial base length	BNL	The direct distance between nasion and basion (Howells, 1973).
Foramen Magnum breadth	FOB	The maximum distance between the left and right margins of the foramen magnum, an interior measurement (Lahr, 1992).
Foramen Magnum length	FOL	The direct distance between basion and opisthion (Howells, 1973).
Frontal chord	FRC	The direct distance between nasion to bregma (Howells, 1973).
Interorbital breadth	DKB	The direct distance between the left and right dacryon (Howells, 1973).
Malar length	IML	The direct distance between zygomaxillare anterior and zygotemporale inferior on the same side of the cranium (Howells, 1973).
Mastoid length	MDH	The length of the mastoid process below and perpendicular to the Frankfort Horizontal Plane, measured from porion to mastoidale (Howells, 1973).
Minimum Frontal breadth	WFB	The direct distance between the left and right frontotemporale (Buikstra and Ubelaker, 1994; Martin, 1957)
Maxillo-Alveolar breadth	MAB	The maximum distance across the alveolar border perpendicular to the sagittal plane (Howells, 1973).
Maxillo-Alveolar length	MAL	The direct distance between Howells prosthion and alveolon (rubber band) (Bass, 1995; Buikstra and Ubelaker, 1994).
Maximum cranial breadth	XCB	The direct distance between the left and right eurion (Bass, 1995; Buikstra and Ubelaker, 1994).
Maximum cranial length	GOL	The direct distance between glabella and opisthocranium (Howells, 1973).
Maximum frontal breadth	XFB	The direct distance between the left and right maximum frontal point (i.e., the greatest breadth of the frontal bone along the coronal suture and perpendicular to the sagittal plane) (Howells, 1973).
Nasal breadth	NLB	The direct distance between the left and right alare (Howells, 1973).

Nasal height	NLH	The direct distance between nasion and in the inferior-most point on the lower border of the nasal aperture on either side (Howells, 1973).
Nasio-occipital length	NOL	The direct distance between nasion and opisthocranium (Howells, 1973).
Occipital chord	OCC	The direct distance between lambda and opisthion (Howells, 1973).
Orbital breadth	OBB	The direct distance between ectoconchion and dacryon of the same orbit (Howells, 1973).
Orbital height	OBH	The direct distance between the lower orbital border point and the upper orbital border point (Howells, 1973).
Parietal chord	PAC	The direct distance between bregma and lambda (Howells, 1973).
Upper facial breadth	UFBR	The direct distance between the left and right frontomalare temporale (Buikstra and Ubelaker, 1994).
Upper facial height	NPH	The direct distance between nasion and prosthion (Howells, 1973).
Additional calculated ILDs, angles, and subtenses from 3Skull		
Measurement	**Abbreviation**	**Definition**
Basion angle (na-pr)	BAA	The angle between the sides of basion-nasion and basion-prosthion (Howells, 1973).
Basion angle (na-br)	BBA	The angle between the sides of basion-nasion and basion-bregma (Howells, 1973).
Bifrontal breadth	FMB	The direct distance between the left and right frontomalare anterior (Howells, 1973).
Bijugal breadth	JUB	The direct distance between the left and right jugale (Howells, 1973).
Bimaxillary breadth	ZMB	The direct distance between the left and right zygomaxillare anterior (Howells, 1973).
Bregma angle	BRA	The angle at bregma whose two sides are basion-bregma and nasion-bregma (Howells, 1989).
Dacryal angle	DKA	The angle formed at dacryon by the orbital breadth from ectoconchion and the subtense from dacryon to biorbital breadth, left and right angles added (Howell, 1973).
Dacryon subtense	DKS	The mean subtense from dacryon to the biorbital breadth, average of the two sides (Howells, 1973).
Maximum Malar length	XML	The direct distance between zygotemporale inferior to zygoorbitale on the same side of the cranium (Howells, 1973).
Mid-Orbital width	MOW	The direct distance between the left and right zygoorbitales (Woo and Morant, 1934).
Nasio-Frontal angle	NFA	The angle at nasion whose two sides reach from this nasion to frontomalare anterior, left and right (Howells, 1973).
Nasio-Frontal subtense	NAS	The subtense from nasion to bifrontal breadth (Howells, 1973).

Nasion angle (ba-pr)	NAA	The angle at nasion whose two sides are basion-nasion and nasion-prosthion (Howells, 1973).
Nasion angle (ba-br)	NBA	The angle at nasion whose two sides are basion-nasion and nasion-bregma (Howells, 1973).
Prosthion angle	PRA	The angle at prosthion whose two sides are are basion-prosthion and nasion-prosthion (Howells, 1973).
Zygomaxillary angle	SSA	The angle at subspinale whose two sides reach from subspinale to zygomaxillare anterior left and right (Howells, 1973).
Zygomaxillary subtense	SSS	The subtense from subspinale to the bimaxillary breadth (Howells, 1973).

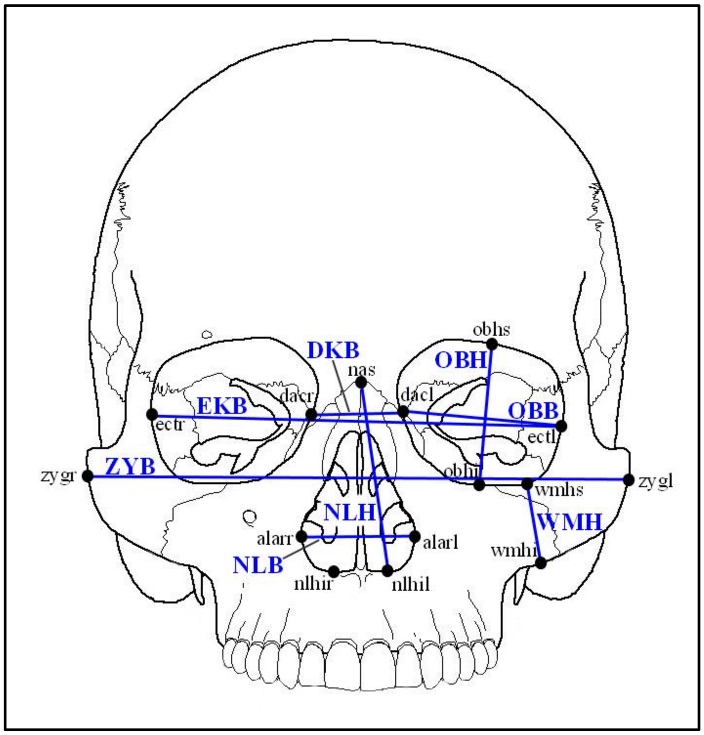

Figure 9: Facial measurements of the eye orbits, nasal aperture, and cheek, anterior view.

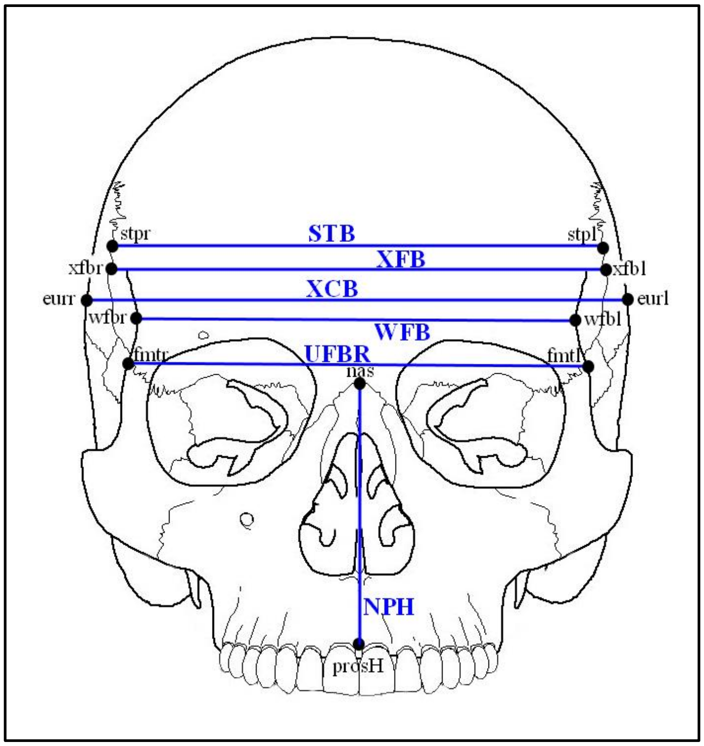

Figure 10: Facial measurements of breadth and height, anterior view.

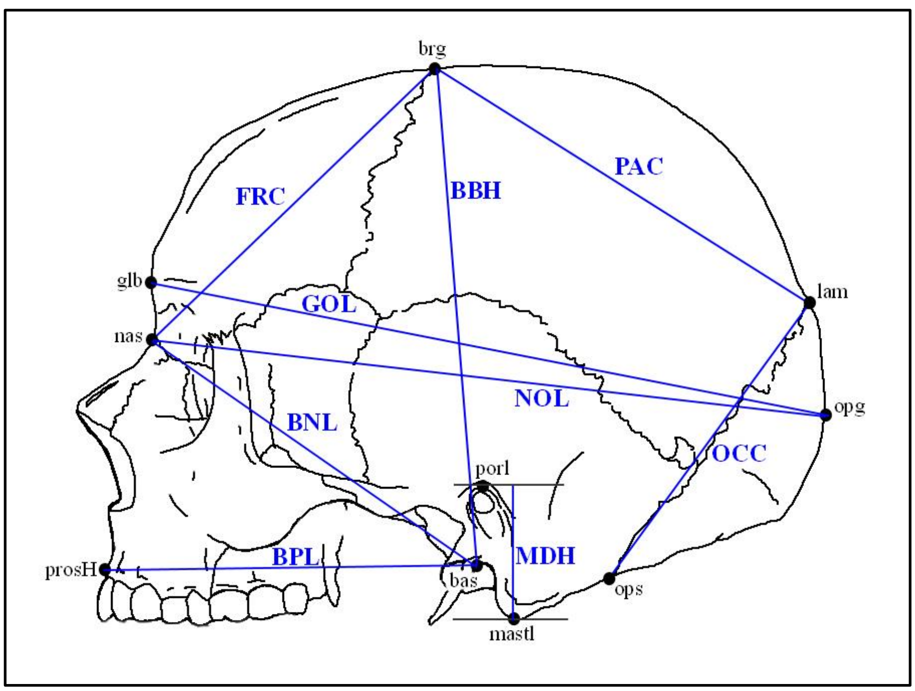

Figure 11: Lateral measurements of the cranium, note that basion and opisthion are not viewable from the lateral view and are located on the inferior side of the cranium.

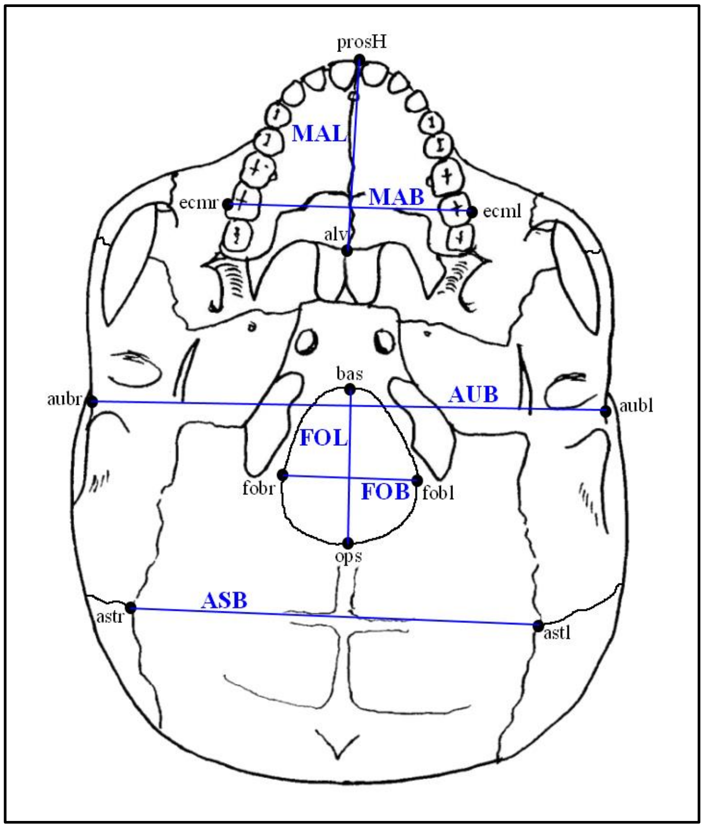

Figure 12: Inferior measurements of the cranium.

A few of these measurements were utilized in calculating several standard indices of the cranium (Table 7). These indices were included in the analysis of the ILDs as they have traditionally been included in the study of cranial morphology. They are used to provide some information on the shape of the cranium, such as how long the cranium is relative to its width or height.

Table 7: Indices of the Cranium

Index	Abbreviations	Definition	Equation
Cranial Index	CI	The ratio of the cranial breadth to the cranial length	$\frac{XCB}{GOL} * 100$
Length-Height Index	LHI	The ratio of the cranial height to the cranial length	$\frac{BBH}{GOL} * 100$

Index	Abbreviations	Definition	Equation
Breadth-Height Index	BHI	The ratio of the cranial height to the cranial breadth	$\frac{BBH}{XCB} * 100$
Mean Basion-Height Index	MBHI	The ratio of the cranial height to the cranial length and breadth	$\frac{BBH}{\frac{GOL + XCB}{2}} * 100$
Fronto-Parietal Index	FPI	The ratio of the minimum frontal breadth to the cranial breadth	$\frac{WFB}{XCB} * 100$
Upper Facial Index	UFI	The ratio of the facial height to the bizygomatic breadth	$\frac{UFBR}{ZYB} * 100$
Nasal Index	NI	The ratio of the nasal breadth to the nasal height	$\frac{(NLB)}{NLH} * 100$
Orbital Index	OI	The ratio of the orbital height to the orbital breadth	$\frac{OBH}{OBB} * 100$

In addition to the collection of craniometric measurements with calipers, a MicroScribe G2X series 3D digitizer along with 3Skull software were used to collect 3D coordinates of landmarks, from which ILDs were calculated. The MicroScribe G2X digitizer was selected by default as it was the equipment available from the University of Hawaiʻi at Mānoa, Department of Anthropology. While it would have been ideal to use a laser scanner or a CT scanner, the high costs and lack of access to such equipment prohibited the use of those technologies for this study. In addition, digitizers are usually present in many anthropology departments and forensic anthropology labs, and thus may be considered accessible standard equipment. The 3Skull software was selected to capture the 3D landmark data with the digitizer because this software is often used in forensic anthropology. 3Skull was specifically designed to capture 3D landmarks and calculate the 2D ILDs (Ousley and McKeown, 2001). It uses adt/adi files that list the landmarks to be included and the landmark pairs by which to calculate the ILDs from the coordinates. These files can be adjusted as need to include or remove landmarks and ILDs by the researcher. The reason for the preference of the 3Skull software is its compatibility with FORDISC 3.1 (Jantz and Ousley, 2005), which forensic anthropologists use to help estimate sex, ancestry, and stature in forensic cases involving skeletal remains. FORDISC 3.1 will be used in this study (see below) to test the unknown individuals collected at the Jikei University anatomy collection.

There are three types of landmarks on the cranium: Type I, Type II, and Type III. Type I landmarks are those that are specific to the anatomy, such as the juxtaposition of tissues (e.g.: bregma). Type II landmarks are those that are the maximum curvature points along tissue boundaries or with biomechanical forces (e.g.: jugale). Type III landmarks are ones which are external points dependent on the location of another landmark (e.g.: maximum cranial breadth). It should be noted that the Type III landmarks captured via digitizing require calipers to locate them. Therefore, even if one were to only utilize digitizing as a form of data collection, sliding and spreading calipers are still required if these landmarks are included. This is an important factor to recognize as Type III landmarks are more difficult to locate due to their reliance on something other than an easily identified bony entity, a problem well recognized by researchers (Robinson and Terhune, 2017; von Cramon-Taubadel et al., 2007). In the case of the landmarks used in this research, the Type III landmarks required calipers to find maximum or minimum cranial dimensions. This required placing the cranium in a specific orientation depending on which landmark is being located, and then holding the calipers to be horizontally level and moving them up, down, forward, backwards, and diagonally until the maximum or minimum was found, and then marking the location of the caliper tips on the cranium with a pencil (see Howells [1973] for a description of how to find these types of landmarks). This often required repeating the process a few times to make sure that the calipers were held in the correct position and that the pencil marks were in the correct location. Moreover, in comparison with the sharper digitizer stylus tip, the spreading caliper tips are more rounded which caused more difficulties in pinpointing the specific location of Type III landmarks.

In addition to the 3D landmark coordinates being utilized for the calculation of ILDs, the landmark data were also utilized for morphometric and geometric morphometric analyses of the samples. These analyses are further described below. A total of 58 landmarks were collected, and from these 3Skull calculated 47 ILDs (see Table 6). The landmarks are listed and defined below in Table 8 and are depicted in Figure 13 through Figure 15. These landmarks were chosen for their inclusion in the craniometric measurements and for their importance in representing cranial morphology. As noted above, the software can calculate more ILDs than be acquired with calipers; hence, the reason why there are more ILDs from 3D landmarks than from the craniometric measurements.

Table 8: Cranial landmarks

Landmark	Abbreviation	Definition and measurement
Alare (left and right)	alarl; alarr	The most lateral points on the nasal aperture; instrumentally determined in the transverse plane (Bass, 1995; Buikstra and Ubelaker; 1994)
Alveolon (rubber band)	alv	The meeting point of the midsagittal plane and a line connecting the posterior borders of the alveolar crests; location determined with the use of a rubber band around the alveolar crest (Buikstra and Ubelaker, 1994).
Asterion (left and right)	astl; astr	The sutural meeting point where the temporal, parietal, and occipital bones meet; if the meeting point includes a wormian bone, the lamboid suture was extended followed by the temporo-parietal and temporo-occipital sutures (Howells, 1973; Martin, 1957).
Basion	bas	The meeting point of the midsagittal plane and the anterior border of the foramen magnum; located on the anterior-inferior portion of the rim (Buikstra and Ubelaker, 1994; Martin, 1957).
Bregma	brg	The sutural meeting point of the coronal and sagittal sutures (Martin, 1957).
Cheek height inferior point	wmhi	The point on the inferior maxilla for the minimum cheek height, medial of the masseter attachment; instrumentally determined with sliding calipers, one caliper point on the inferior orbital rim and the other on the inferior maxilla where the minimum distance is located (Howells, 1973).
Cheek height superior point	wmhs	The point on the inferior orbital rim for the minimum cheek height; instrumentally determined with sliding calipers, one caliper point on the inferior orbital rim and the other on the inferior maxilla where the minimum distance is located (Howells, 1973).
Dacryon (left and right)	dacl; dacr	The meeting point of the lacrimal, frontal, and maxilla bones in the orbit at the apex of the lacrimal fossa (Buikstra and Ubelaker, 1994; Howells, 1973; Martin, 1957).
Ectomalare (left and right)	ecml; ecmr	The outside most lateral point of the alveolar border on the maxilla (Buikstra and Ubelaker, 1994; Martin, 1957).

Landmark	Abbreviation	Definition and measurement
Ectoconchion (left and right)	ectl; ectr	The intersection point of the anterior surface of the lateral orbital border and a line bisecting the long axis of the orbit; location determined by using a toothpick or similar object that is held parallel to the superior orbital border and moved down until it bisects the orbit in half, where the toothpick crosses the lateral border is where ectoconchion is located (Buikstra and Ubelaker, 1994; Howells, 1973).
Eurion (left and right)	eurl; eurr	The lateral-most point (left and right side) of the cranial vault comprising the greatest cranial breadth, located on the parietals or temporal bones superior to the zygomatic arch and external auditory meatus; instrumentally determined using spreading calipers to find the widest measurement of the cranial vault (Bass, 1995; Buikstra and Ubelaker 1994).
Foramen magnum breadth points (left and right)	fobl; fobr	The lateral-most point (left and right sides) of the foramen magnum rim (Lahr, 1992).
Frontomalare anterior (left and right)	fmal; fmar	The anterior-most point of the fronto-malar suture (Howells, 1973).
Frontomalare temporale (left and right)	fmtl; fmtr	The lateral-most point of the fronto-malar suture (Buikstra and Ubelaker, 1994).
Frontotemporale (left and right)	wfbl; wfbr	The anteriormedial-most point of the temporal line (Buikstra and Ubelaker, 1994; Martin, 1957).
Glabella	glb	The anterior-most point on the midsagittal plane on the frontal bone above the frontonasal suture (Buikstra and Ubelaker, 1994; Martin, 1957).
Jugale (left and right)	jugl; jugr	The point of the deepest curvature on the zygomatic bone between the temporal and frontal processes (Martin, 1957).
Lambda	lam	The meeting point of the sagittal and lambdoid sutures, when a wormian bone is present, extend the sagittal and lambdoid sutures with a pencil into the wormian and where the lines meet is the location of lambda (Buikstra and Ubelaker, 1994; Howells, 1973; Martin, 1957).

Landmark	Abbreviation	Definition and measurement
Lower orbital border	obhi	The intersection point of the lower orbital rim and a line that bisects the orbit and is perpendicular to the long axis of the orbit, this point is an inside measurement and is taken at the superior apex of the lower orbital rim; location is determined by using a toothpick or similar object that is held perpendicular to the superior orbital border and moved until it bisects the orbit in half, where the toothpick crosses the lower border is where the point is located (Howells, 1973).
Mastoidale (left and right)	mastl; mastr	The most inferior, lateral point of the mastoid process (Martin, 1957).
Maximum frontal point (left and right)	xfbl; xfbr	The point on the coronal suture where the frontal bone is at its maximum width, not on the temporal lines; instrumentally determine with spreading calipers, each caliper point on opposite sides of the frontal bone at symmetrical points, sliding them up and down along the coronal suture to find the maximum width (Howells, 1973).
Most inferior nasal border (left and right)	nlhil; nlhir	The inferior-most point on the lower rim of nasal aperture on either side, at the beginning of the nasal floor (Howells, 1973).
Nasion	nas	The meeting point of the fronto-nasal suture and the midsagittal plane (Buikstra and Ubelaker, 1994; Howells, 1973; Martin, 1957).
Opisthocranion	opg	The posterior-most point of the cranium on the occipital bone, farthest from glabella, the location should not be on the inion hook unless the it is on a well-developed crest; instrumentally determined with spreading calipers, one caliper point on the glabella, the other point on the occipital at the midsagittal plane and moved up and down until the maximum distance is found (Howells, 1973; Martin, 1957).
Opisthion	ops	The meeting point of the midsagittal plane and the posterior border of the foramen magnum; located on the inferior portion of the rim (Buikstra and Ubelaker, 1994; Howells, 1973; Martin, 1957).
Porion (left and right)	porl; porr	The superior-most point on the margin of the external auditory meatus (Martin, 1957).
Prosthion (Howells)	prosH	The anterior-most point on the midsagittal plane on the alveolar border, between the central incisors (Howells, 1973).

Landmark	Abbreviation	Definition and measurement
Roots of zygomatic processes (left and right)	aubl; aubr	The deepest incurvature of the roots of zygomatic process; measured to the outside of the roots, generally slightly anterior to the meatus (Howells, 1973).
Stephanion (left and right)	stpl; stpr	The meeting point of the coronal suture and the inferior temporal line (the superior limit of the temporal muscle) (Howells, 1973).
Subspinale	ssp	The deepest incurvature point below the anterior nasal spine when viewed in profile (Howells, 1973).
Upper orbital border	obhs	The intersection point of the upper orbital rim and a line that bisects the orbit and is perpendicular to the long axis of the orbit, this point is an inside measurement and is taken at the inferior apex of the upper orbital rim; location is determined by using a toothpick or similar object that is held perpendicular to the superior orbital border and moved until it bisects the orbit in half, where the toothpick crosses the upper border is where the point is located (Howells, 1973).
Zygion (left and right)	zygl; zygr	The lateral-most point on the zygomatic arch (Buikstra and Ubelaker, 1994; Martin, 1957).
Zygomaxilare (left and right)	zygoml; zygomr	The inferior, anterior point on the zygomaxillary suture, not on the masseter muscle attachment (Martin, 1957).
Zygoorbitale (left and right)	zygool; zygoor	The meeting point of the zygomaxillary suture and the inferior orbital rim, taken midway between the facial and orbital floor surfaces (Howells, 1973).
Zygotemporale inferior (left and right)	zytil; zytir	The inferior-most point on the zygo-temporal suture (Howells, 1973).
Zygotemporale superior (left and right)	zytsl; zytsr	The superior-most point on the zygo-temporal suture (Howells, 1973).

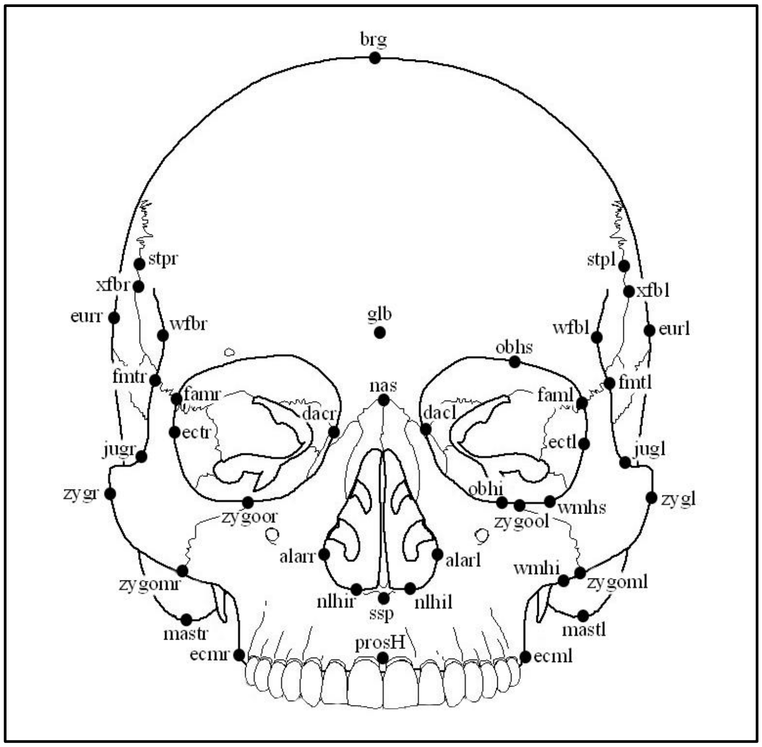

Figure 13: Anterior cranium showing landmarks

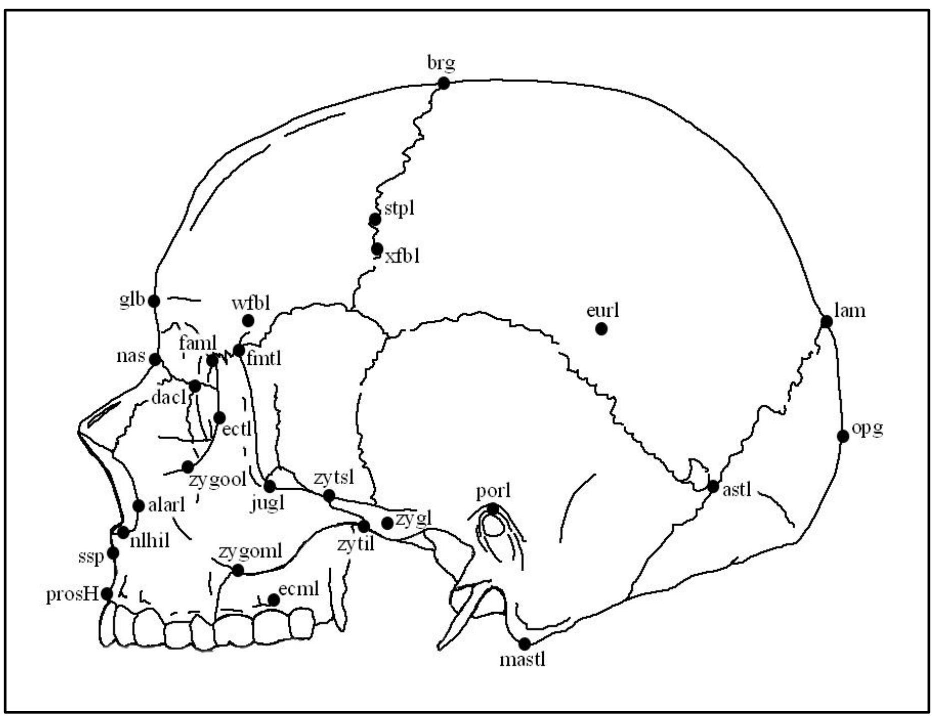

Figure 14: Lateral cranium showing landmarks

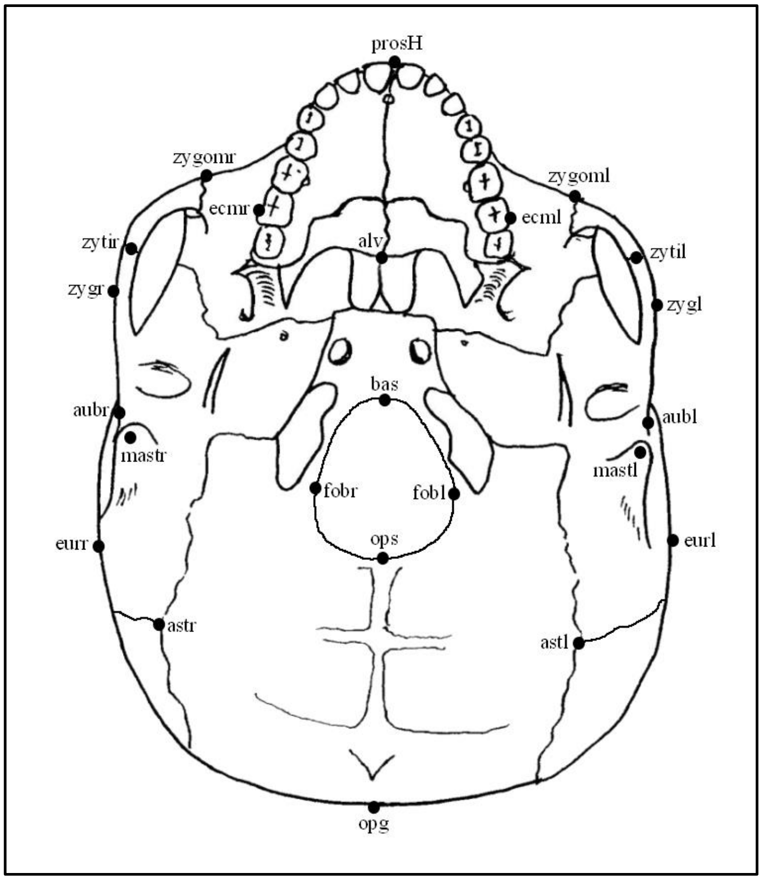

Figure 15: Inferior cranium showing landmarks

Statistical Analysis Methods

The application of morphometric and GM methods to analyze human cranial variation is not new to biological anthropology (e.g.: Boas, 1905; Cole, 1996; Richtsmeier et al., 2002; Slice, 2005). However, they have become more popular in recent decades thanks to advances in technology, especially those methods that use 3D coordinate systems. The main advantage of GM is that it retains the geometric information of specimens that are otherwise lost in traditional linear metric methods (Baab et al., 2012; Hennessy and Stringer, 2002; Rohlf and Marcus, 1993; Slice, 2005, 2007; von Cramon-Taubadel et al., 2007). This then allows for different types of analyses to be conducted to answer existing questions about shape variation, as well as raising new questions.

While traditional morphometrics (also referred to as craniometrics) are still utilized in studies today, it is not without its critics. There are significant limitations to 2D morphometrics. The main drawback of traditional morphometrics is that it does not retain the locational information of the endpoints of the cranial measurements (i.e., landmark coordinates), and thus they lack some of the shape information that cannot be recovered (Slice, 2005). Angles, subtenses, and indices, however, partially remedy this problem since they provide information that allows for the inferences of shape variability or differences. Still, the problem remains that these methods do not record the geometric relationships of the different shape components of the cranium (Slice, 2005). This is a large part of why GM methods have become more widely used in cranial studies.

The GM method utilized in this study is the generalized Procrustes analysis (GPA) The processing of crania for GPA involves removing location, orientation, and size differences by scaling the crania to the same size (scaling to a centroid) when calculating Procrustes coordinates (the resulting coordinates for the landmarks after the original coordinates have been corrected for rotation, translation, and scaling), thus only shape is analyzed (Slice, 2007; Richtsmeier et al., 2002). The removal of location and orientation is important since when collecting digitized data each crania is in a different position as needed to be able to access and collect the landmark coordinates with the digitizer's stylus. However, GPA has been criticized for what may be perceived as methodological flaws. One of the criticisms of GPA is its reliance on superimposition of visual representations that are dependent on coordinate systems that are arbitrarily defined, and thus must be corrected for reflection, rotation, and translation problems (Cole and Richtsmeier, 1998; Lele and Richtsmeier, 2001). GPA has been noted by some to not properly eliminate these problems, but rather constrains them based on a mean centroid that then is dependent on and changes with sample size (Lele and Richstmeier, 2001). Moreover, this leads to GPA being unable to correctly estimate the variance and co-variance matrices that statistical analyses rely upon as the removal of size differences eliminates some of the variation (Cole and Richtsmeier, 1998; Lele and Richtsmeier, 2001; Richtsmeier et al., 2002). Nonetheless, GPA remains one of the most used approaches in 3D GM studies.

Evaluating the differences between 2D morphometrics and 3D GM methods in the treatment of size differences is potentially important since Spradley and Jantz (2016) found that size variation was a factor in differentiating Hispanics from the other two ancestry groups (American Whites and American Blacks) in their study using both craniometrics and GPA methods. Along with this, their results demonstrated that American Whites and American Blacks were best differentiated by the non-standard ILDs rather than the GPA coordinates. However, since this was conducted on only three regional populations, the results may be limited to these specific groups. The results from Spradley and Jantz (2016) will be tested in this study to see if they also apply to populations on a small, intra-regional scale. Additionally, while previous studies examining closely related populations identified variations at the clinal level (Relethford, 2008; Relethford and Crawford, 1995), the current study is aimed at determining whether there are specific ILDs or shape components that may be useful in differentiating closely related populations and in population history reconstructions by using 3D morphometric methods which were not used in these earlier studies.

Both the 3D GM GPA and 2D craniometric methods were used in this study. The 3D landmark coordinate and 2D craniometric data were analyzed using two different software, one for each method. The MorphoJ software (Klingenberg, 2011) was employed to analyze the landmark data using the GPA method which creates Procrustes coordinates. MorphoJ is a software that was created for the geometric morphometric analysis of landmark data (two coordinate [x, y] and three coordinate [x, y, z] data) from biological samples. The Procrustes coordinates were then subjected to principal component analysis (PCA), canonical variate analysis (CVA), and discriminate function analysis (DFA) in the MorphoJ software. The 3Skull calculated ILDs were also analyzed with PCA, CVA, and DFA using the SAS software for academics (SAS Institute, Inc., 2015). The PCA method extracts a minimum number of components necessary to reproduce the observed variation in the dataset (Pituch and Stevens, 2016; O'Higgins, 2000; Slice, 2007; Spradley and Jantz, 2016). This allows for the identification of the number of components as well as to display the patterning of the variation. PCA does this without using the known or assigned *a priori* groups. Therefore, it is analyzing the variation of the coordinates and measurements across all individuals rather than the groups (i.e., it does not account for group differences). The resulting PCA coefficients (also known as eigenvectors) explain which variables are correlated to which principal component (PC). The higher the absolute value of the coefficient, the more the variable contribute to the PC. The PCs then represent a grouping of variables that contribute to the variation observed with each PC accounting for some percentage of the total variance. Since the PC coefficients range from -1 to 1 and are generally rather small, any absolute value greater than 0.3 ($\geq |0.3|$) is considered significant.

The CVA method analyzes the variation of the variables (measurements and landmark coordinates in this study) among the groups with membership known *a priori* (Pituch and Stevens, 2016; Klingenberg, 2011). This analysis maximizes the mean differences between the *a priori* groups and the correlations between the predictor (groups in this case) and variables. CVA results indicate which variables, or group of variables, best distinguishes the groups for each canonical variate (CV) produced. Thus, the CVs present the combinations of variables that represent the between-group variation. The CVA results include Mahalanobis distances between the groups for each CV. These distances indicate which populations are more or less similar in morphological variation; the smaller the Mahalanobis distance, the closer to one another they are (Ousley, 2012; SAS Institute, Inc., 2013). The canonical coefficients provide maximal separation between the groups for the variables and thus are part of the regressions, while canonical structures (commonly referred to as canonical loadings) are the correlation between canonical variables and the original variables (SAS Institute, Inc., 2013). The structures are thus a better indication of the variables that are contributing to the between-group variation. While the coefficients can have a large range of values, the structures range from -1 to 1. Since the structures have small value, any absolute value greater than 0.4 ($\geq |0.4|$) is considered significant. For both coefficients and structures, the higher the absolute value, the more the variable contributes to the variation in the CV. In this study, both of these are reported for the 2D data from the SAS software output for the CANDISC procedure. However, MorphjoJ only reports the canonical coefficients and does not provide the necessary information by which the structures can be calculate. Therefore, only the coefficients are reported for the 3D data, and these are used along with the CVs to compare the 3D and 2D CVA results.

The DFA method uses the variables in the dataset to predict which population each cranium classifies into based on the observed variation in those variables between the two populations (Pituch and Stevens, 2016; Ousley et al. 2009; Slice, 2007; Spradley and Jantz, 2016). DFA is based on the within-group variation rather than the between-group variation. DFA first discriminates the groups using the within-group variation of the *a priori* classifications. The discriminated groups indicate how many cases of a group can be classified correctly based on the within-group variation (i.e., how much of the population conforms to the observed variation of that group). DFA then cross-validates this over 1,000 iterations of the analysis. The cross-validation is conducted with each case or individual that is tested being left out of the reference sample for their test (leave-one out cross-validation). In the SAS software, DFA is conducted by comparing all groups at once, while in MorphoJ each pair of groups is tested individually.

For each of the population comparisons described previously (see Chapter 1), and for each of these statistical approaches, the 3D landmark data were divided into the complete cranium, facial cranium, and cranial vault (Figure 16 through Figure 18). This was done for two main reasons: one, because a number of the Korean crania were not in good condition and were missing different landmarks, dividing the cranium into specific components aided in maximizing the use of the data acquired; and two, to test specific hypotheses about the types of microevolution information the facial cranium and cranial vault provide. As noted in the materials section, many of the Korean crania, especially the Joseon Dynasty samples, were damaged and incomplete. This resulted in the necessity of removing several landmarks for the comparisons in which they were used, as well as the cutting of some of the individual crania from the different analyses. The division of the analysis into the different components of the cranium also allows for the testing of the specific hypotheses regarding the Neutral Theory outlined in Chapter 1. This division of the cranial components was not done for the 2D data as many of the craniometrics span the whole cranium.

Classifying Unknown Individuals with FORDISC 3.1

FORDISC 3.1 is a software program utilized by forensic anthropologists to help estimate three of the four categories of a biological profile (sex, ancestry, and height) for unknown, skeletonized individuals (Jantz and Ousley, 2005). The program uses DFA to classify unknown individuals using their cranial and skeletal measurements into groups represented in the reference databases. The databases included in the software are the Forensic Data Bank (FDB) and the Howells database, which together include numerous populations from around the globe (Jantz

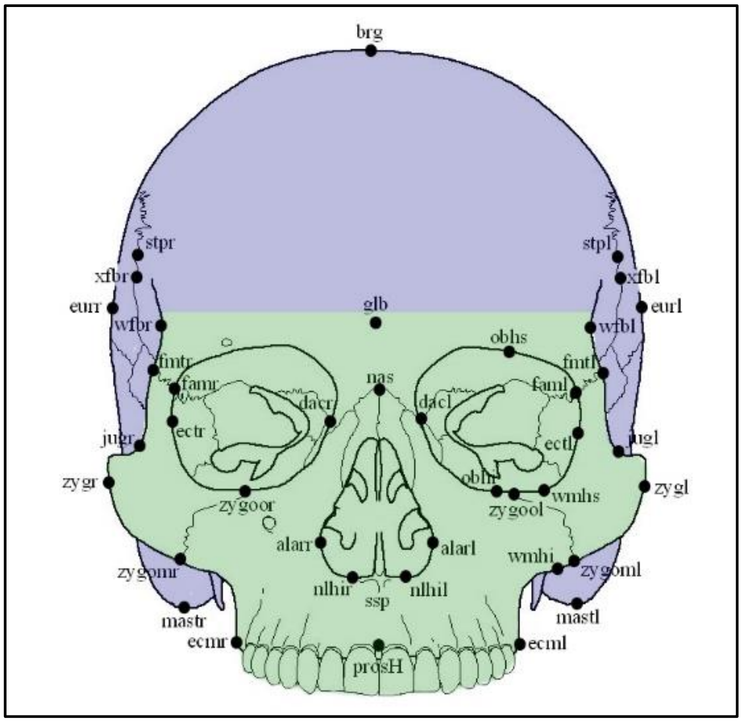

Figure 16: Anterior view of cranial divisions showing the facial region (green) and cranial vault (blue-gray).

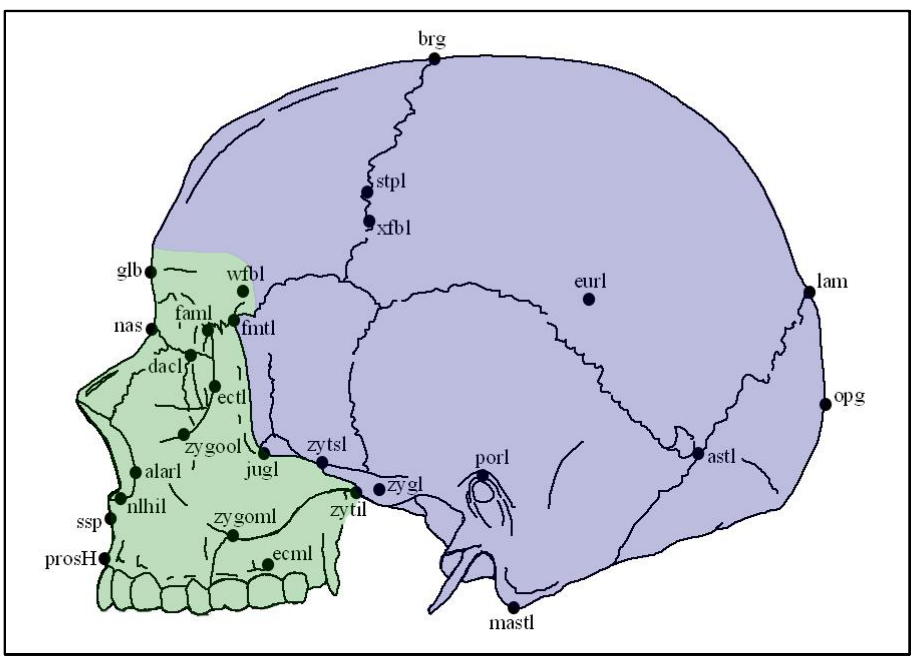

Figure 17: Laterial view of cranial divisions showing the facial region (green) and cranial vault (blue-gray).

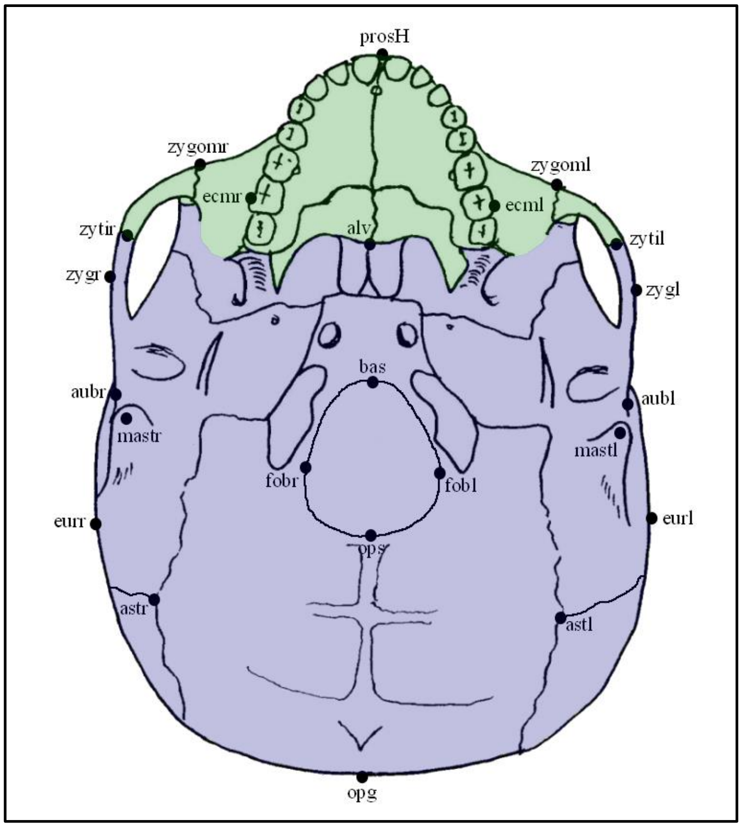

Figure 18: Inferior view of cranial divisions showing the facial region (green) and cranial vault (blue-gray).

and Ousley, 2005). However, their representation of Asian populations is small and disparate. The FDB has very few Asian individuals when compared with American Blacks and American Whites and only represents three national populations (Chinese, Japanese, and Vietnamese). The Howells database partially remedies this issue, but it is primarily composed of archaeological samples that span a large spread of time up to the 19th century (Howells 1973, 1989). These issues highlight the need for users to select proper reference samples (both by population and time period) when classifying unknown individuals with FORDISC 3.1. Another important aspect of the program to take into account is that it will force a classification into one of the reference database groups for which the individual is closest to even when they are not well represented by any of the groups. This is due to the fact that FORDISC 3.1 does not have an option for no classification if the individual is too dissimilar to the reference populations being used in the software. This requires the user to pay close attention to the posterior probabilities in the results as well as any statistical results that are highlighted by the program as being potentially problematic or outside the range of expected results (usually represented by bold black or red text for those particular results).

Despite these drawbacks, FORDISC 3.1 is still a useful tool. To test how well it performs with samples from Korea and Japan, the known Korean individual and unknown individuals from Jikei University were classified using this software. The FDB and Howells database were used as reference samples to investigate how well they performed with presumed eastern Asian individuals. In addition to this, the unknown individuals were classified using the Korean and Japanese samples collected in this research as the reference database in FORDISC 3.1. While users can import their own reference databases into the software, it cannot be combined with the FBD or Howells database. Therefore, the Asian groups in those databases could not be paired with my reference database for a more inclusive test.

Intra-Observer Error and Inter-method Error

As researchers have demonstrated, it is necessary to assess sources of error when conducting GM studies. In particular, they have emphasized the importance of inter- and intra-observer error (Robinson and Terhune, 2017; von Cramon-Taubadel et al., 2007), and more recently that of inter-method error (Robinson and Terhune, 2017). Both intra-observer and inter-method error will be analyzed here.

Generalizability (G) theory analysis in SAS software was conducted to assess the intra-observer and inter-method error. This method allows for the exploration of extent of variation in the sample that is explained by group (population in this case), specimen, observer-error, method-error, and trial-error (Marcoulides, 2000; Shavelson et al., 1989). This method relies on ANOVA with a nested design that exclusively groups specified measurement facets together in the analysis. This method has been used in previous GM studies that assess these types of error (Muñoz-Muñoz and Perpiñán, 2010; Robinson and Terhune, 2017).

To assess intra-observer error during the data collection process, 3D landmarks were collected from twelve individuals (two from Catholic University of Korea, two from Seoul National University, two from Dong-A University, four from the National Museum of Nature and Science, and two from Jikei University) three times each. Each digitization trial for each individual was completed on separate days. The resulting calculated ILDs, angles, and subtenses from these three trials were then analyzed using G theory analysis to assess the intra-observer error while still accounting for the variance in the group and specimen. To assess the inter-method error, the caliper measured and 3D calculated ILDs common between the two methods for each individual in the study were analyzed using G-Theory analysis while still accounting for the variance in the group and specimen.

CHAPTER 4: RESULTS

In this chapter, I present the results of the various analyses conducted on the data collected. The chapter is separated into five sections. The first two sections detail the results for the 2D craniometric analyses and 3D GM Procrustes analyses. The next section addresses FORDISC 3.1 results for the unknown individuals from the Jikei University collection. The last section reports the intra-observer error results that was conducted on a sub-sample of the 3D landmark data and the inter-method error for the comparison of the 2D and 3D methodologies. In order to minimize tables and for consistent formatting, throughout this chapter and the remainder of the dissertation, tables will utilize abbreviations for the populations. These are outlined in Table 9. However, in the text, the full terms will be used. Please refer to the tables in Chapter 3 for landmark, measurement, and indices abbreviations.

Table 9: Population abbreviations.

Term	**Abbreviation**
Japanese (pooled populations and sexes)	J
Japanese Female (pooled populations)	JF
Japanese Male (pooled populations)	JM
Korean (pooled population and sexes)	K
Korean Female (pooled populations)	KF
Korean Male (pooled populations)	KM
Edo Period (pooled sexes)	EP
Edo Period Female	EPF
Edo Period Male	EPM
Modern Japanese (pooled sexes)	MJ
Modern Japanese Female	MJF
Modern Japanese Male	MJM
Joseon Dynasty (pooled sexes)	JD
Joseon Dynasty Female	JDF
Joseon Dynasty Male	JDM
Modern Korean (pooled sexes)	MK
Modern Korean Female	MKF
Modern Korean Male	MKM

2D Craniometric Analyses

The results from the analyses conducted in SAS software are provided below in separate sections for each of the three statistical tests (PCA, CVA, and DFA). As a result of the incomplete nature of many of the crania, of the total 55 ILDs and indices, only 42 were included in the analysis to maximize the sample size. Despite dropping the variables with most missing data, several individuals were cut from the analysis due to them missing data for some of the variables retained. Each of the tests were conducted with the sexes pooled and separated for both the pooled geographic populations and the separated temporal populations. The Korean individuals whose sex could not be estimated were included for the pooled sex samples but were excluded for the analyses in which the sexes were separated. Both the pooled and separated sexes results are presented for each analysis. The sample sizes for the analyses are provided below in Table 10 and Table 11.

Table 10: Pooled geographic populations sample sizes.

	Population sample size				
	Japanese		Korean		
	Female	Male	Female	Male	Indeterminate
Sex Subtotals	142	242	39	96	5
Population Total	384		140		

Table 11: Four temporal populations sample sizes.

	Population sample size								
	Joseon Dynasty		Modern Korean			Edo Period		Modern Japanese	
	Female	Male	Female	Male	Indeterminate	Female	Male	Female	Male
Sex Subtotals	15	34	24	62	5	73	123	69	119
Population Total	49		91			196		188	

Principal Component Analysis

The results from the SAS software of the PCA show that the variation among individuals in the dataset is widespread, but that there is considerable overlap between the two geographical populations (pooled Korean and pooled Japanese) as seen in the PCA scatterplots (Figure 19; only the PC1-PC2 scatterplots are provided as the remaining PCs show similar results to PC1). The only PC to show any separation between the two groups is PC2 in which the Koreans are shifted toward the positive end and the Japanese toward the negative. As PCA does not take into account the *a priori* grouping, it is not surprising the results show significant overlap in the two closely related populations. The number of PCs the data was reduced to was 42 (the same of the number of variables in the analysis). The first five PCs account for over 60% of the total variation (Table 12). With the small amount of variation accounted for by each PC, the results indicate that the variation is spread across the measurements. The PC coefficients indicate which measurements are contributing to the variation observed among the individuals. These are presented in the Appendix. As indicated by the PC scatter plots and number of PCs, the coefficients show that the variation is spread across the measurements with no coefficients larger than |0.3| for PC1, which accounts for 26.9% of the variance. In PC2 which separates the two geographical populations, the cranial index and length-height index had high loadings, suggesting that these two indices are the primary contributors to the observed variation, accounting for 12.7% of the variance. For PC3 it was basion angle (na-br), breadth-height index, and mean basion-height index, for PC4 it was orbital height, dacryon subtense, dacryal angle, and nasal index, and for PC5 it was interorbital breadth, mid-orbital width, and nasal index. When the PCA was conducted with the sexes separated for the two populations, the results show little difference from when the sexes were pooled. Tables and graphs are not presented here due to the similarity with results already reported.

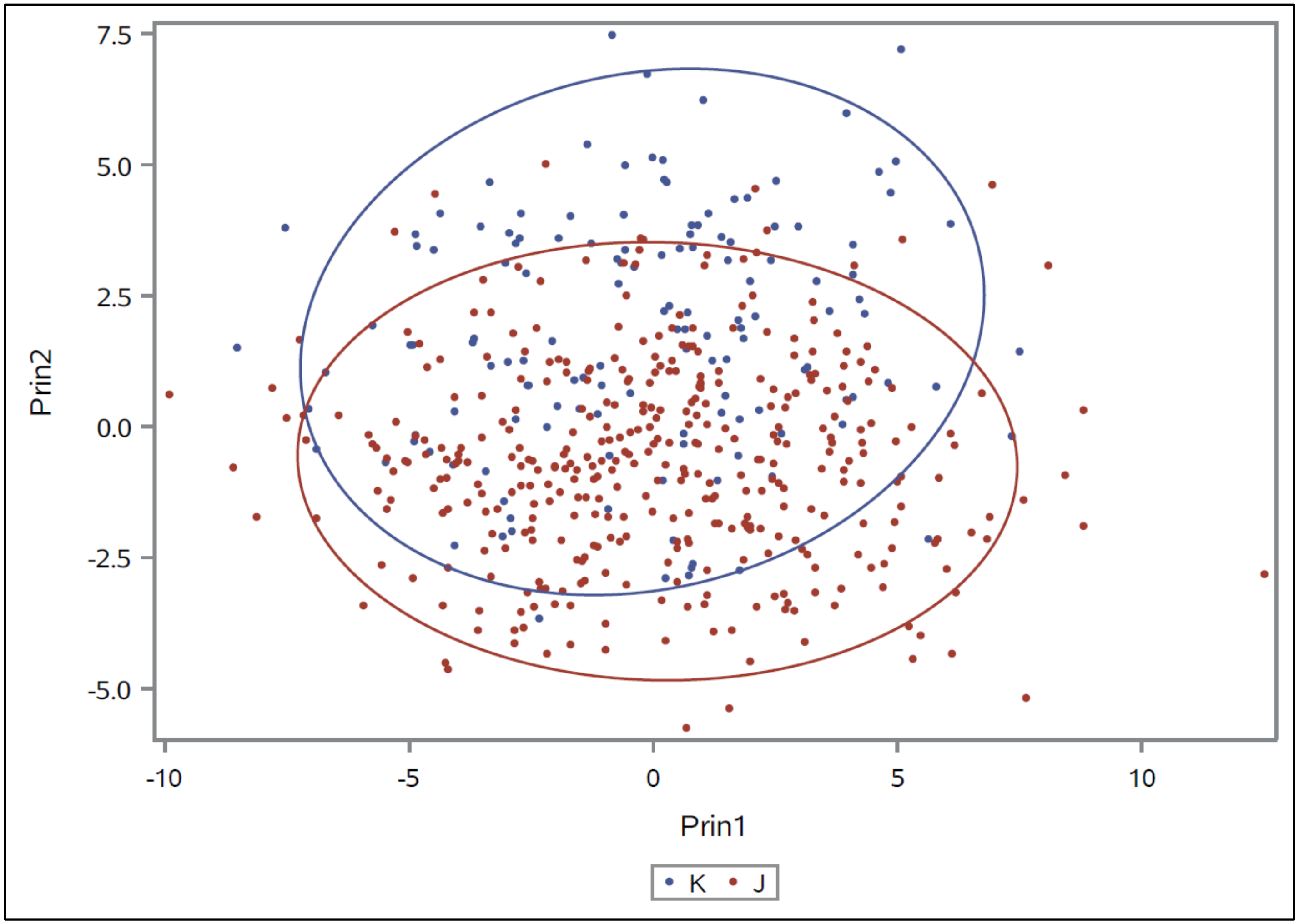

Figure 19: PCA scatterplots showing PC1 and PC2 for the comparison between pooled Korean and pooled Japanese populations.

Table 12: PCA results for the first five PCs for the comparison between the pooled Korean and pooled Japanese populations.

PC	Eigenvalue	% Variance	Cumulative %
1	11.3115675	26.93%	26.93%
2	5.3520357	12.74%	39.68%
3	3.6851434	8.77%	48.45%
4	2.9951745	7.13%	55.58%
5	2.4171796	5.76%	61.34%

The results for the comparison between the four populations (Joseon Dynasty, Edo Period, Modern Korean, and Modern Japanese) are similar for the two geographic populations reported above. There is a wide variation among individuals and the four populations overlap considerably (Figure 20; only the PC1-PC2 scatterplots are provided). The number of PCs the data was reduced to is the same as for the pooled populations and the first five PCs account for a little more than 60% of the variation in the dataset (Table 13). The PCA coefficients show that the variation is spread across the landmarks with no coefficients larger than |0.3| for PC1 which accounts for 26.8% of the variance. In PC2 which separates the geographic populations, the cranial index and length-height index had high loadings, suggesting that these two indices are the primary contributors to the observed variation, accounting for 12.7% of the variance. For PC3 it was basion angle (na-br), breadth-height index, and mean basion-height index, for PC4 it was orbital height, dacryon subtense, dacryal angle, and nasal index, and for PC5 it was interorbital breadth, mid-orbital width, and nasal index. When the PCA was conducted with the sexes separated, the results show little difference from when the sexes were pooled. Tables and graphs are not presented here due to the similarity with results already reported.

Table 13: PCA results for the first five PCs for the comparison between the four populations.

PC	Eigenvalue	% Variance	Cumulative %
1	11.2545858	26.80%	26.80%
2	5.3515010	12.74%	39.54%
3	3.6805982	8.76%	48.30%
4	3.0141952	7.18%	55.48%
5	2.4333019	5.79%	61.27%

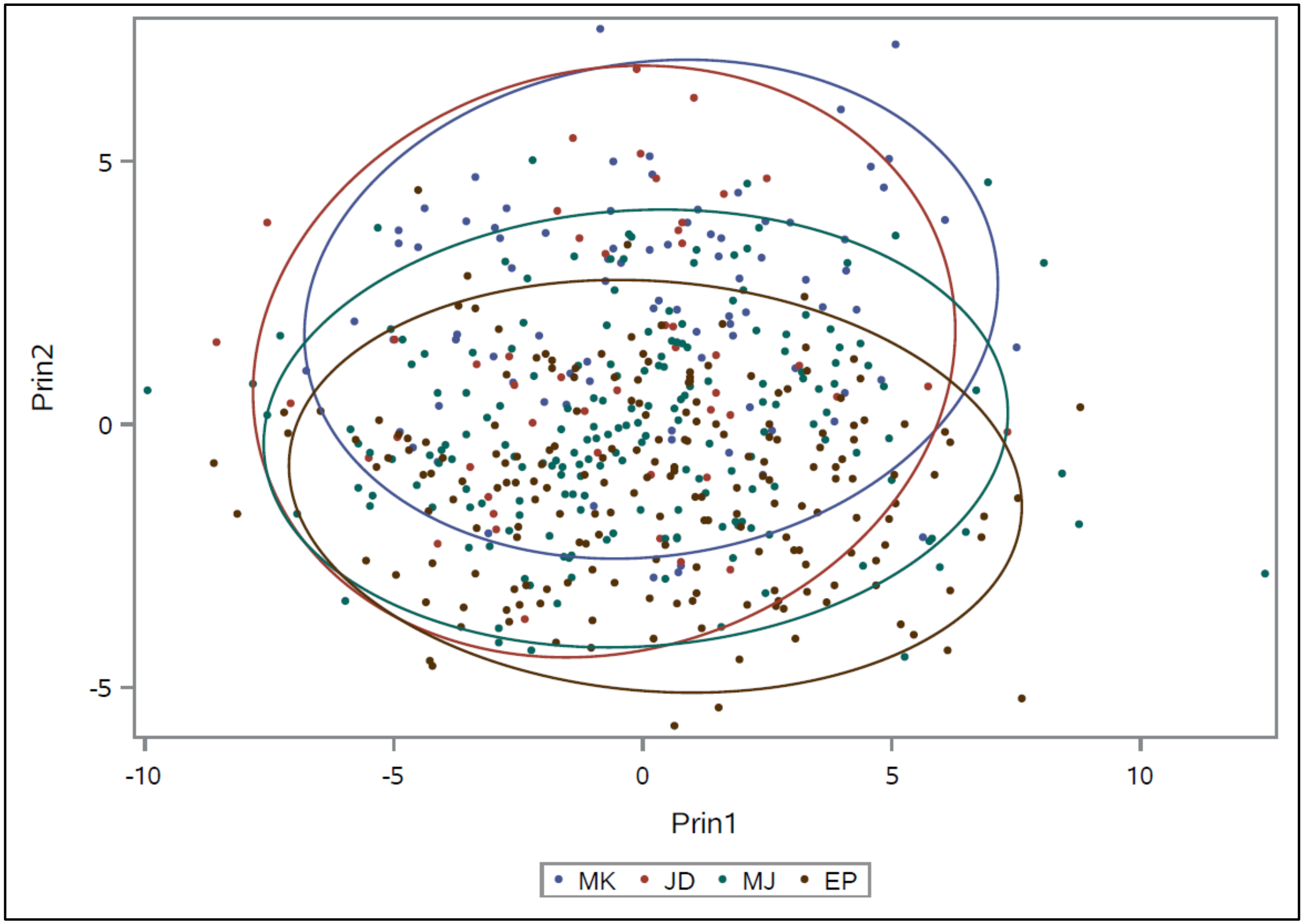

Figure 20: PCA scatterplots showing PC1 and PC2 for the comparison between four populations.

Canonical Variance Analysis

The results of the CVA from SAS software provide a clearer indication of the variation between the groups than PCA did. In the CVA for the pooled Korean and pooled Japanese populations, one canonical variate (CV) was produced. The eigenvalue for the CV is 0.7971. There is overlap between the pooled Korean and pooled Japanese populations in the histogram, but they are still somewhat distinguishable (Figure 21). The Mahalanobis distances indicate which populations are more or less similar in morphological variation; the smaller the Mahalanobis distance, the closer to one another they are (Ousley, 2012; SAS Institute, Inc., 2013). The Mahalanobis distance between the pooled populations is 4.05539. While this suggests that the two are close together in morphology, without additional populations to compare them to, it does not indicate more than this. The canonical coefficients and canonical structures indicate which measurements contribute to the variation that can be used to differentiate the two populations. The coefficients provide maximal separation between the groups for the variables and thus are part of the regressions, while the structures (commonly referred to as canonical loadings) are the correlation between canonical variables and the original variables and are thus a better indication of the variables that are contributing most to the between-group variation (SAS Institute, Inc., 2013). Both coefficients and structures are discussed here and are provided in tables in the Appendix. The coefficients that provided the maximal separation in the craniometrics are the nasal breadth, orbital height and breadth, nasio-frontal subtense, nasion angle (ba-br), cranial index, length-height index, breadth-height index, mean nasion-height index, and fronto-parietal index. The structures indicate that the maximum cranial length, nasio-occipital length, bregma angle, cranial index, length-height index, mean basion-height index, and fronto-parietal index contribute most to the between-group variation. Thus, half of the contributing variables to the between-population differences are measurements, both standard and non-standard, representing the size component and half are indices representing the shape aspects of morphological variation.

In the CVA for the pooled geographic population with the sexes segregated, the individuals whose sex was unknown and could not be estimated were removed from the analysis. When the sexes are separated out for the pooled geographic populations, the CVA results are somewhat similar to those for the pooled sexes above. The CVA resulted in three CVs for which the first

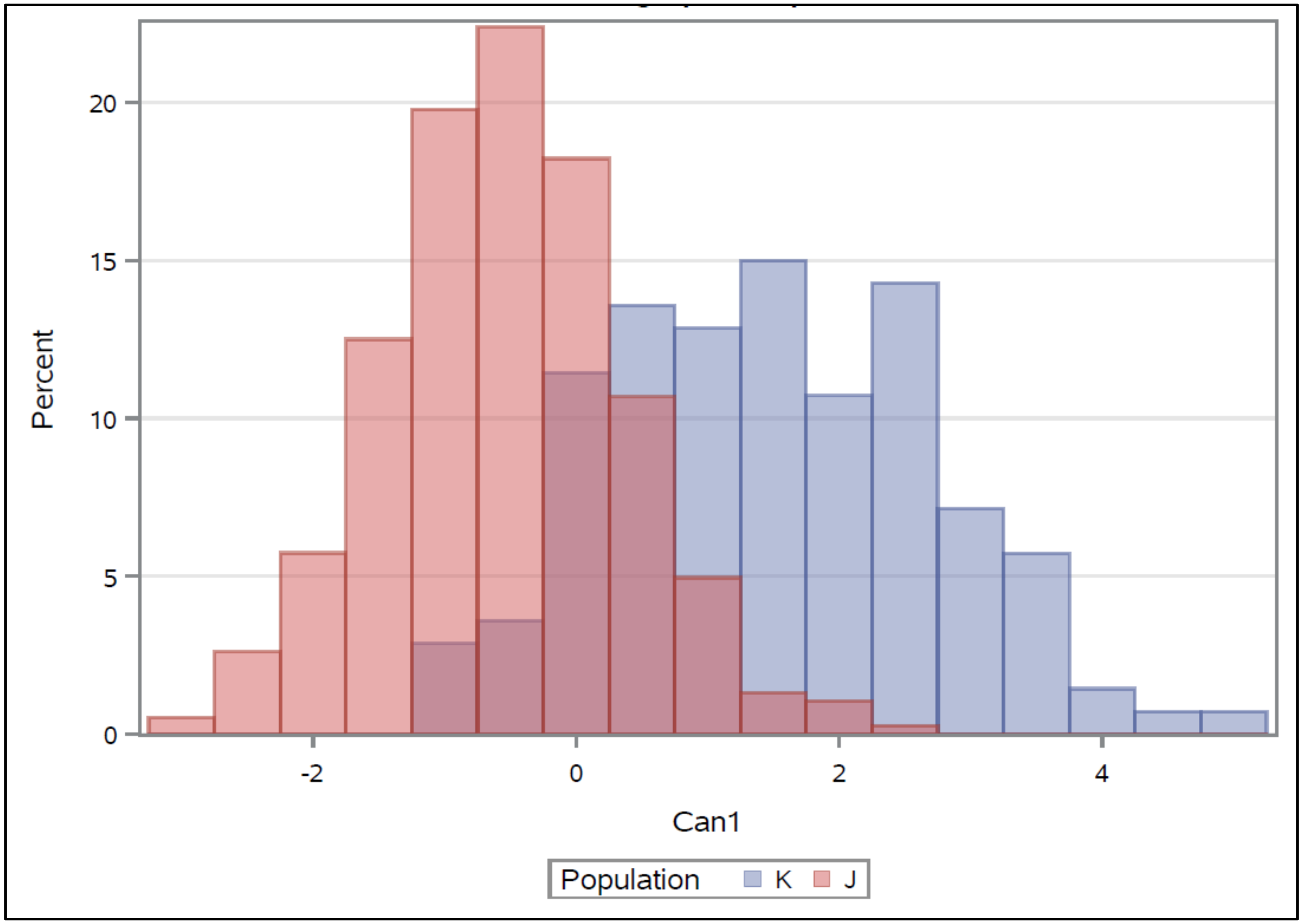

Figure 21: CVA histograms for the comparison of the pooled Korean and pooled Japanese populations.

CV accounted for about 59% of the differences between the groups and the first two CVs for just over 90% (Table 14). CV1 differentiates the sexes with the females toward the negative end and the males toward the positive, while CV2 separates the geographic populations with the Japanese on the negative side and the Koreans on the positive. CV3 shows differences in a portion of the Korean females from the other three groups. All four groups overlap in all three CVs. These results are depicted in Figure 22 and Figure 23 below. The Mahalanobis distances between each pair of the groups were significant with a p-value of less than 0.01 (Table 15). The Mahalanobis distances show that the two groups who were most distant were the Korean females and Japanese males. The two groups who were most similar were the Korean and Japanese males. This corresponds with the CV graphical results where CV1 segregates the sexes and CV2 the geographic groups.

The results for the canonical coefficients and canonical structures are provided in the Appendix. For the coefficients, CV1 had the mean basion-height index as the variable contributing the most to the separation between the sexes, meaning the overall cranial shape is the primary difference. In CV2, the orbital height and width, cranial index, length-height index, and mean basion-height index segregated the two geographic populations. CV3, which accounts for the lowest percentage of variance and which does not do well in differentiating between the groups, had the most variables contributing to it (cranial length and cranial breadth, nasal breadth, orbital height and breadth, nasio-frontal subtense, dacryon subtense, cranial index, length-height index, breadth-height index, and mean basion-height index). For the canonical structures, there is a flip in the number of significant variables for the CVs. In CV1, there were 19 variables with high loadings the separated the sexes, including standard and non-standard measurements but no indices, indicating that size was the primary differences between males and females. In CV2, the maximum cranial length, naio-occipital length, bregma angle, cranial index, length-height index, mean basion-height index, and fronto-parietal index contributed most to the differences between the geographic populations. The results for the CV2 structures are the same as that for the two geographic populations with the sexes pooled. In CV3, there were no variables that contributed to the slight differentiation of some of the Korean females, which reflects the general overlap of the groups observed on the scatter plot.

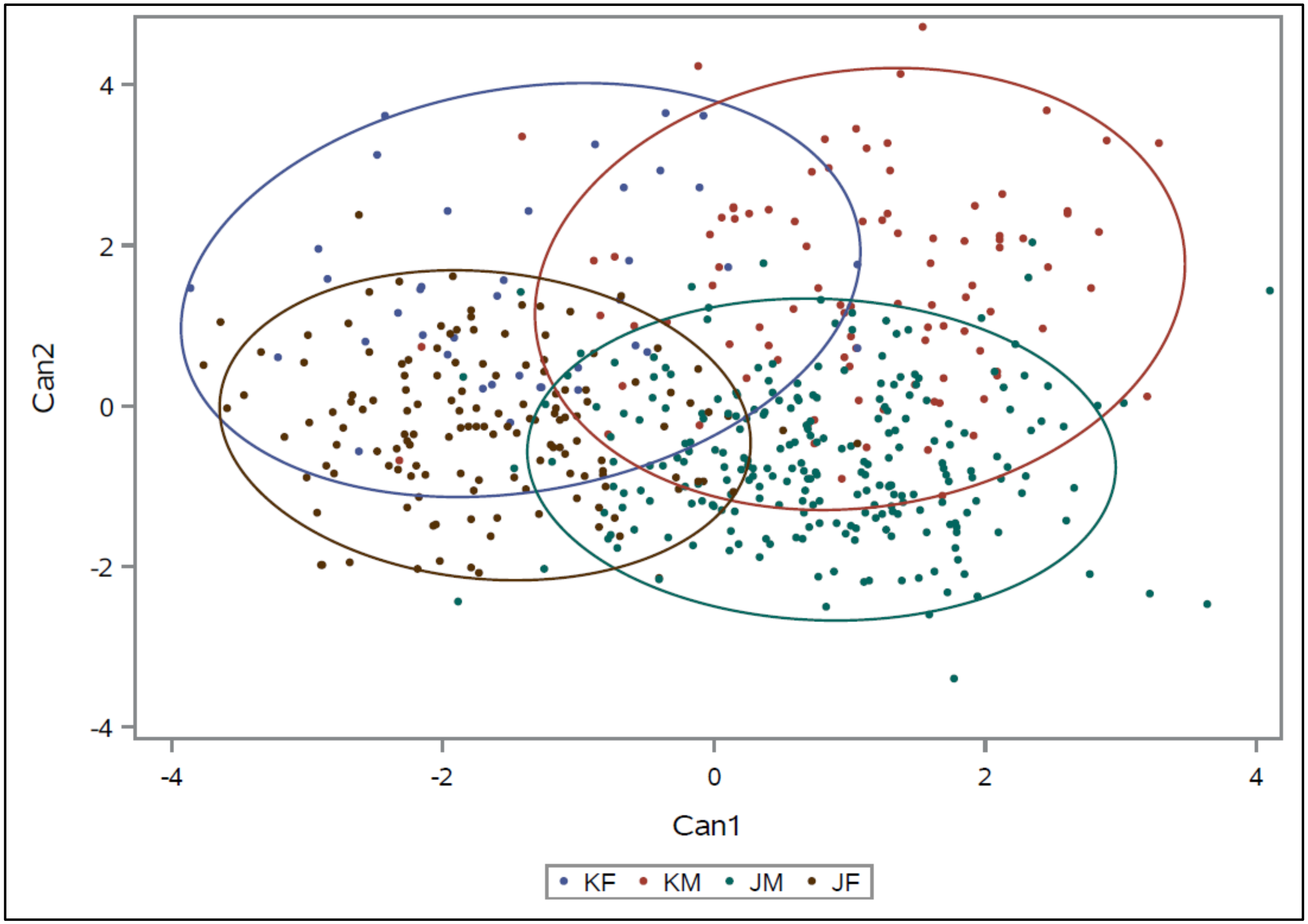

Figure 22: CV1 and CV2 scatterplot for the comparison of the pooled Korean and pooled Japanese populations with the sexes segregated.

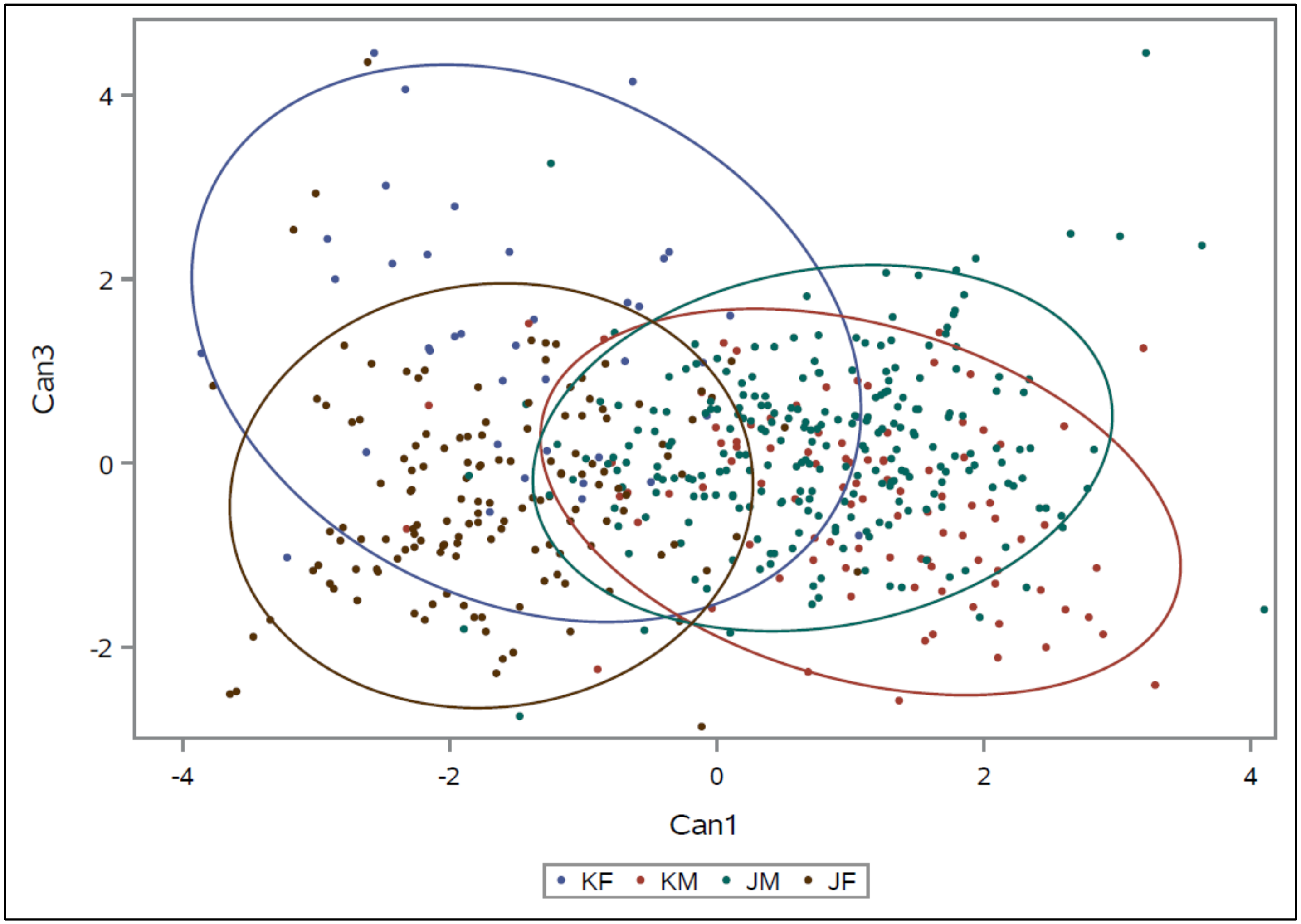

Figure 23: CV1 and CV3 scatterplot for the comparison of the pooled Korean and pooled Japanese populations with the sexes segregated.

Table 14: CVA results for the comparison between the pooled geographic populations with the sexes segregated.

CV	Eigenvalue	% Variance	% Cumulative
1	1.4506	59.53	59.53
2	0.7781	31.93	91.46
3	0.2081	8.54	100

Table 15: CVA results: Mahalanobis distances and p-values for the comparison between the pooled geographic populations with the sexes segregated.

	Mahalanobis distance		
	JF	JM	KF
JM	6.60047		
KF	5.63887	10.66771	
KM	10.52571	4.93093	9.22679
	P-values		
	JF	JM	KF
JM	<.0001		
KF	<.0001	<.0001	
KM	<.0001	<.0001	<.0001

The CVA for the comparison between all four temporal-geographic populations (Joseon Dynasty, Modern Korean, Edo Period, and Modern Japanese) produced three CVs. The first CV alone accounts for over 65% of the variation between groups and CV2 and CV3 for 18% and 15% respectively (Table 16). The scatterplots illustrate that CV1 differentiates between the geographic populations, but that CV2 and CV3 do not perform well in separating the groups (Figure 24 and Figure 25). The Mahalanobis distances indicates that the Edo Period and Modern Koreans are most distinct from one another while the Edo Period and Modern Japanese are closest followed by the Joseon Dynasty and Modern Koreans (Table 17). This illustrates both the similarities of groups from the same geography observed in the scatterplots for CV1, as well as the differences between geography. The canonical coefficients with the highest values for CV1 are cranial index, length-height index, and mean basion-height index. For CV2, the orbital height and breadth, cranial index, length-height index, and mean basion-height index contribute most to this CV, and for CV3 it is the basion-bregma height, dacryon subtense, length-height index, and mean basion-height index. For the canonical structures, CV1 had high loadings for maximum

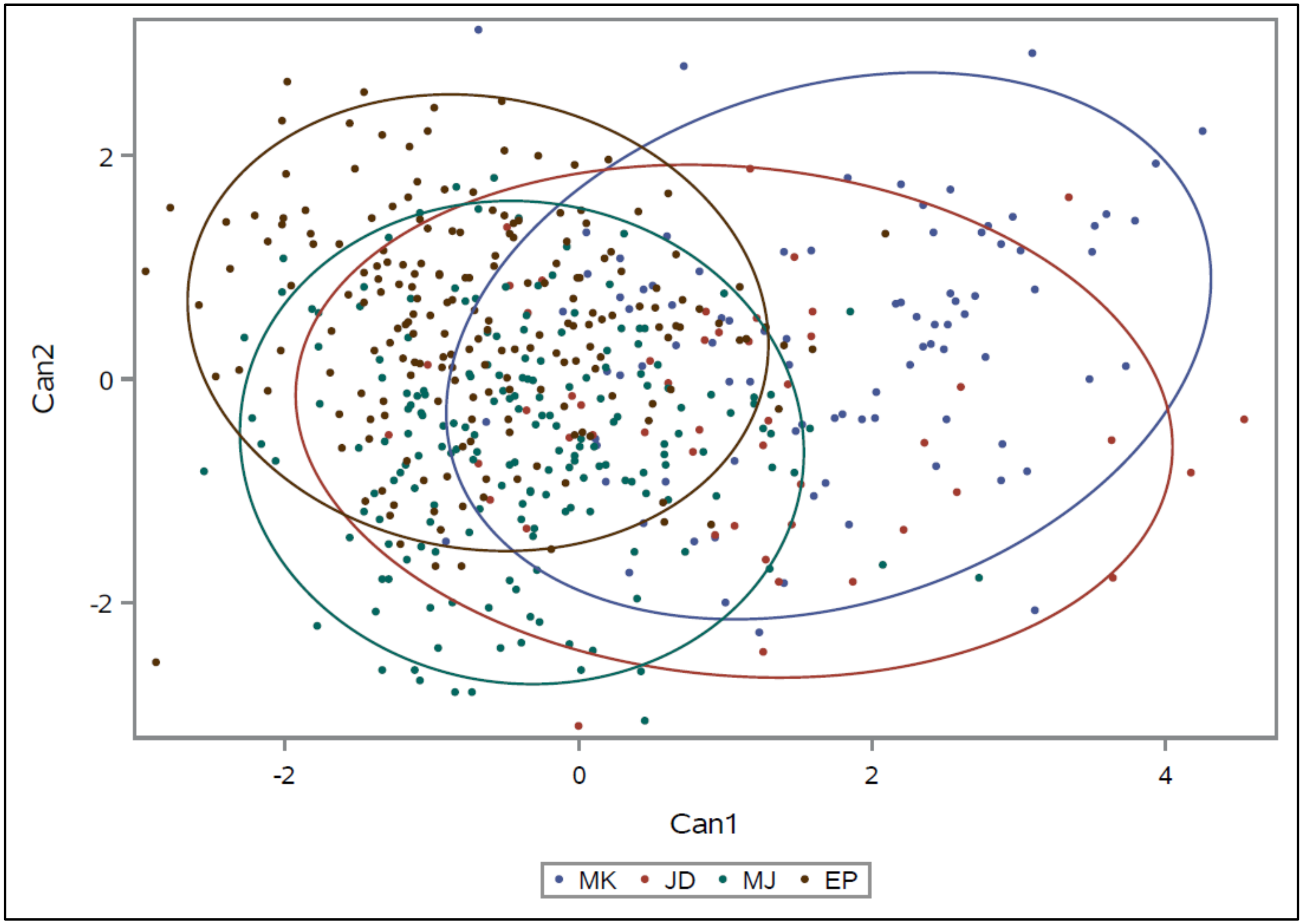

Figure 24: CV1 and CV2 scatterplot for the comparison of the four populations.

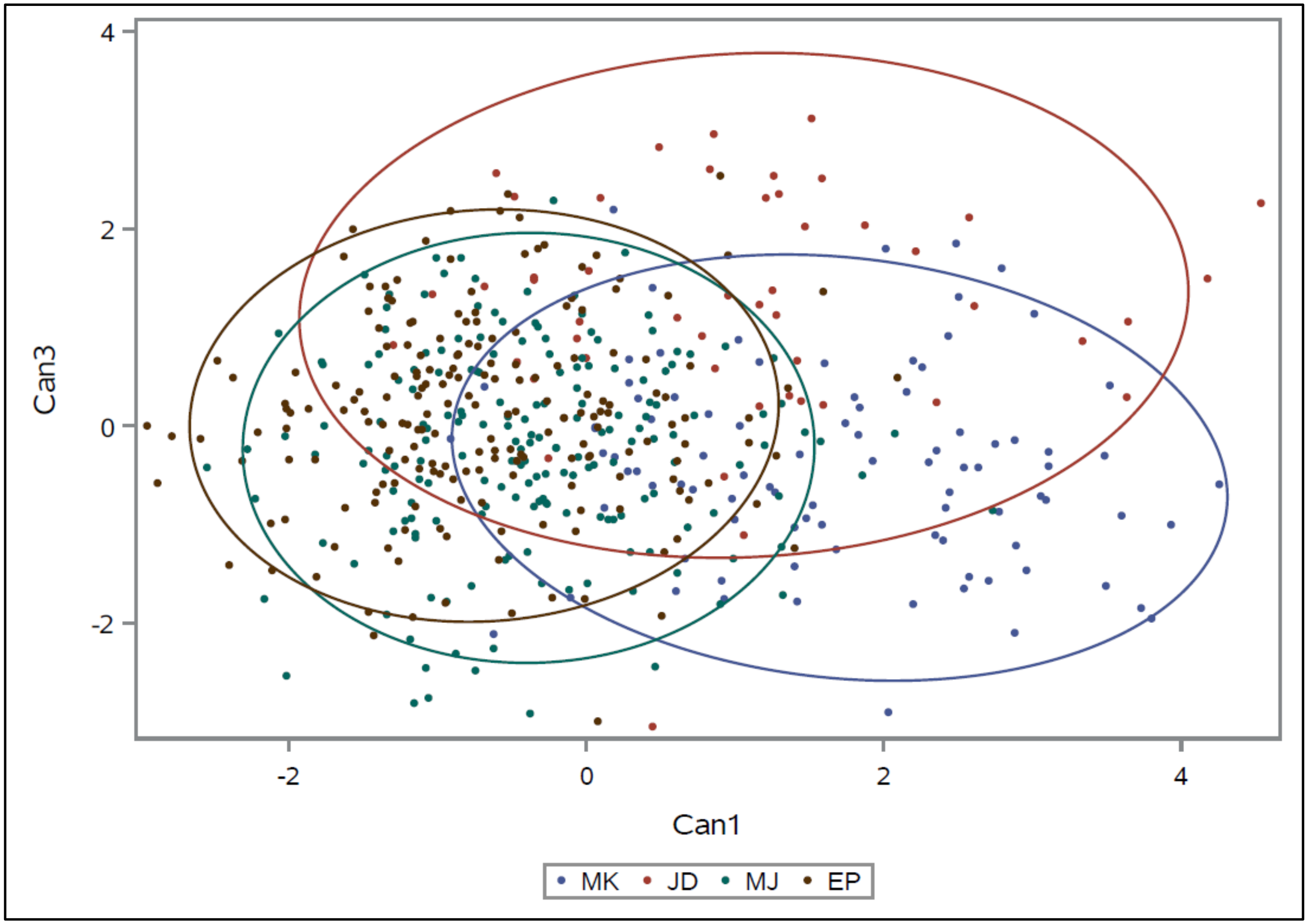

Figure 25: CV1 and CV3 scatterplot for the comparison of the four populations.

Table 16: CVA results for the comparison between all four populations.

CV	Eigenvalue	% Variance	% Cumulative
1	0.8450	65.98	65.98
2	0.2412	18.83	84.81
3	0.1945	15.19	100

Table 17: CVA results: Mahalanobis distances and p-values for the comparison between all four populations.

	Mahalanobis distance		
	EP	JD	MJ
JD	5.07543		
MJ	1.34536	4.21986	
MK	6.03035	3.58287	5.15819
	P-values		
	<.0001		
	<.0001	<.0001	
	<.0001	<.0001	<.0001

cranial length, nasio-occipital length, maximum cranial breadth, bregma angle, cranial index, length-height index, mean basion-height index, and fronto-parietal index. In CV2 it is maximum frontal breadth and in CV3 it is the occipital chord that have high loadings.

Three CVs were produced for the comparison between the females of all four populations. The first CV accounts for over 57% of the variation between groups, CV2 for 26%, and CV3 for 16% (Table 18). The resulting scatterplots show that CV1 differentiates between the geographic populations, CV2 the temporal periods, and CV3 indicated divergence between the Joseon Dynasty and Modern Korean females (Figure 26 and Figure 27). The Mahalanobis distances for the females have the Edo Period and Modern Japanese as the closest and the Modern Koreans and Modern Japanese as the most distinct followed by the Joseon Dynasty and Edo Period (Table 19). The canonical coefficients for CV1 with the highest values are the minimum frontal breadth, nasal breadth, nasio-frontal subtense, length-height index, breadth height index, and fronto-parietal index. For CV2, the minimum frontal breadth, nasal breadth, orbital height and breadth, cranial index, length-height index, breadth-height index, mean basion-height index, and fronto-

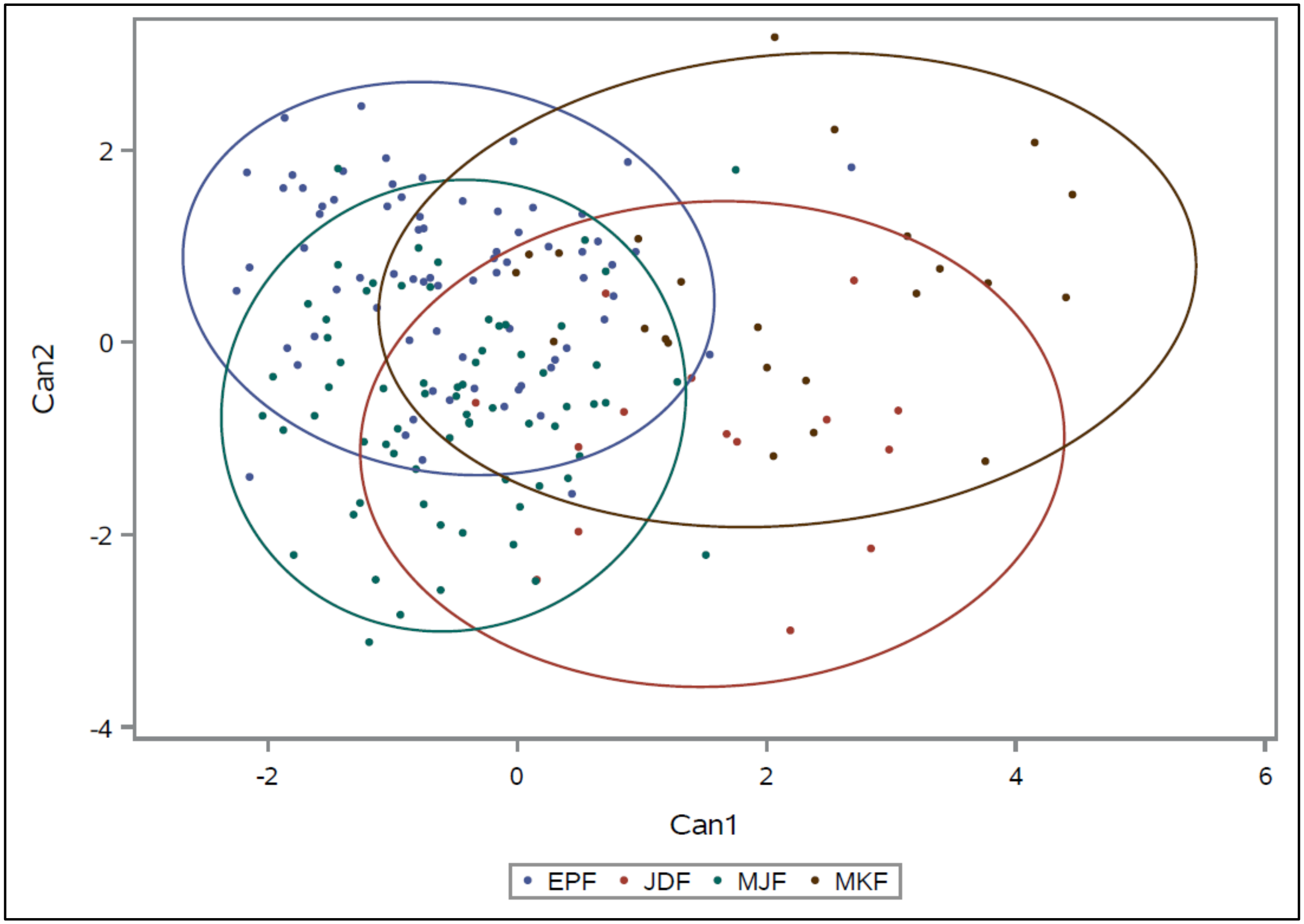

Figure 26: CV1 and CV2 scatterplot for the comparison of the four populations with females only.

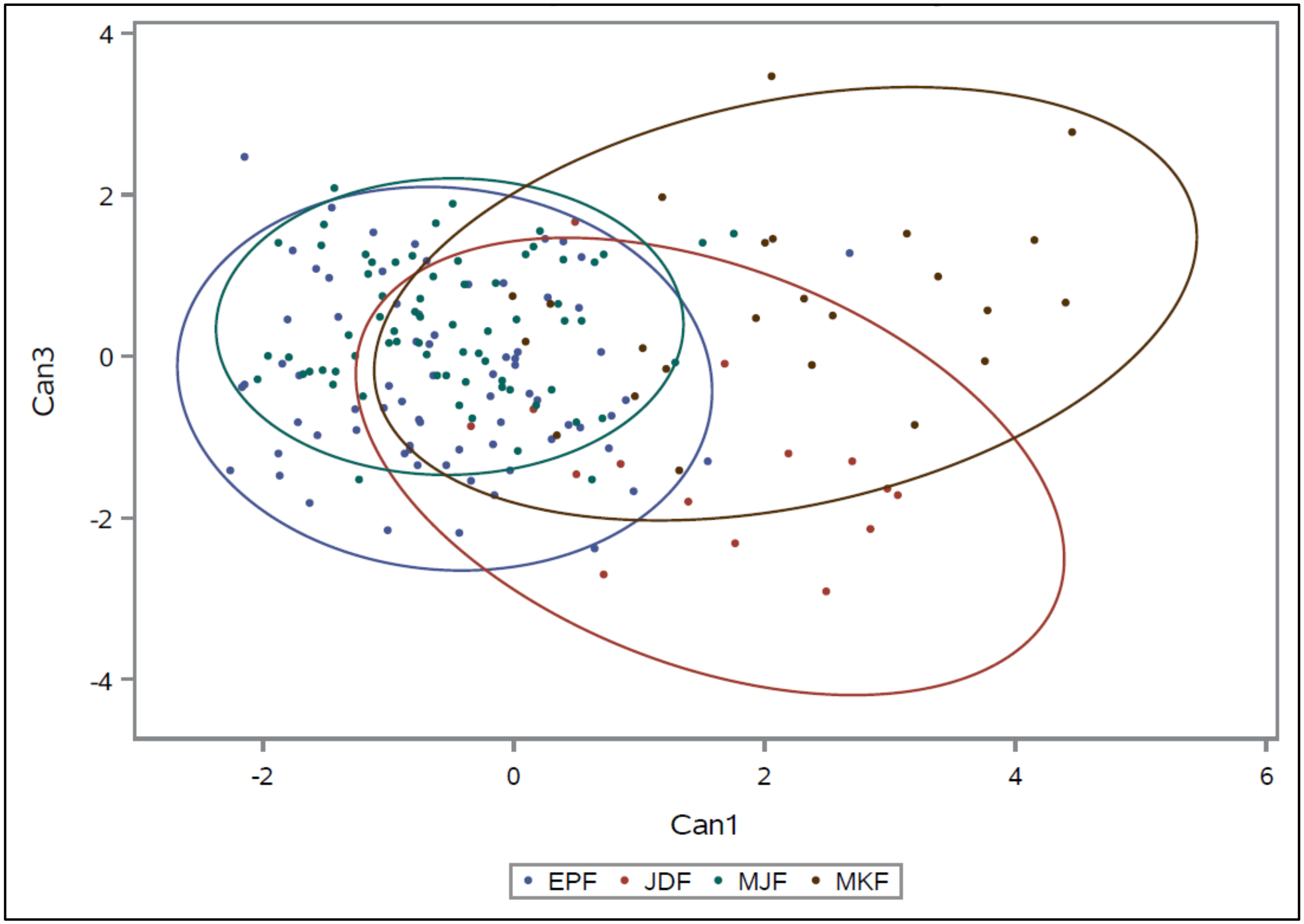

Figure 27: CV1 and CV3 scatterplot for the comparison of the four populations with females only.

Table 18: CVA results for the comparison between all four populations with females only.

CV	Eigenvalue	% Variance	% Cumulative
1	1.0715	57.73	57.73
2	0.4854	26.15	83.88
3	0.2992	16.12	100

Table 19: CVA results: Mahalanobis distances and p-values for the comparison between all four populations with females only.

	Mahalanobis distance		
	EPF	JDF	MJF
JDF	8.61959		
MJF	2.16426	7.46618	
MKF	8.26353	6.98304	8.69893
	P-values		
	EPF	JDF	MJF
JDF	<.0001		
MJF	<.0001	<.0001	
MKF	<.0001	<.0001	<.0001

parietal index best separate the groups. In CV3, it is the basion-bregma height, minimum frontal breadth, orbital height and breadth, cranial index, length-height index, breadth-height index, mean basion-height index, fronto-parietal index, orbital index that contributed to the variation between groups. The canonical structures this analysis only showed high loadings in CV1 and none for CV2 and CV3. The metrics in CV1 that contribute to the differences between the geographic populations are maximum cranial length, nasio-occipital length, maximum frontal breadth, bregma angle, cranial index, length-height index, and fronto-parietal index.

The CVA for the comparison between the males of all four temporal-geographic populations produced three CVs. The first CV accounts for 61% of the variation between groups, CV2 for 20%, and CV3 for 17% (Table 20). The resulting scatterplots show that CV1 differentiates between the geographic populations, CV2 between the Edo Period and Modern Japanese, and CV3 the Joseon Dynasty and Modern Korean males (Figure 28 and Figure 29). The Mahalanobis distances for the males have the Edo Period and Modern Japanese as the closest and the Modern Koreans and Edo Period as the most distinct from one another followed by the Joseon Dynasty and Edo Period as the next most differentiated pair (Table 21). The canonical coefficients for

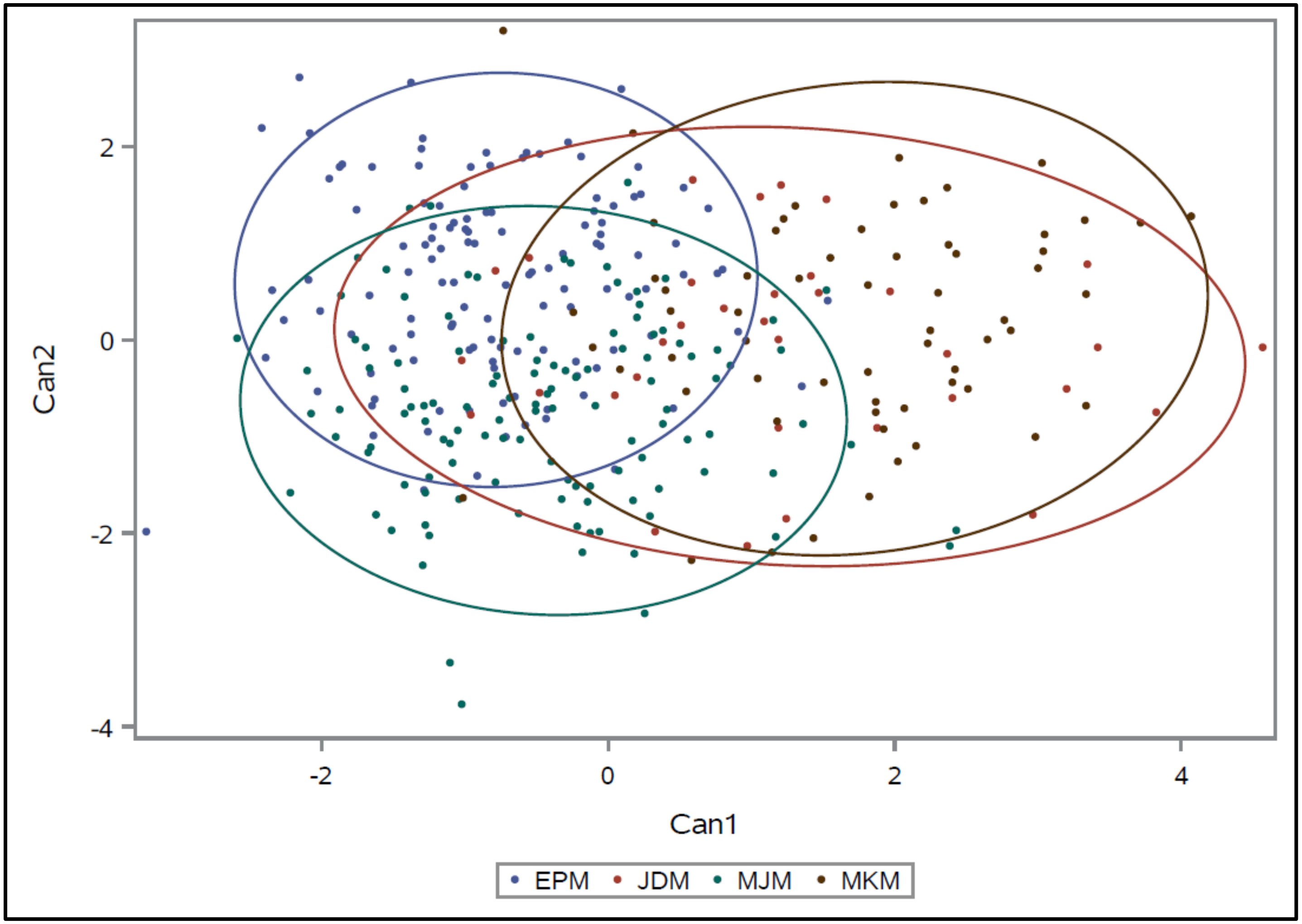

Figure 28: CV1 and CV2 scatterplot for the comparison of the four populations with males only.

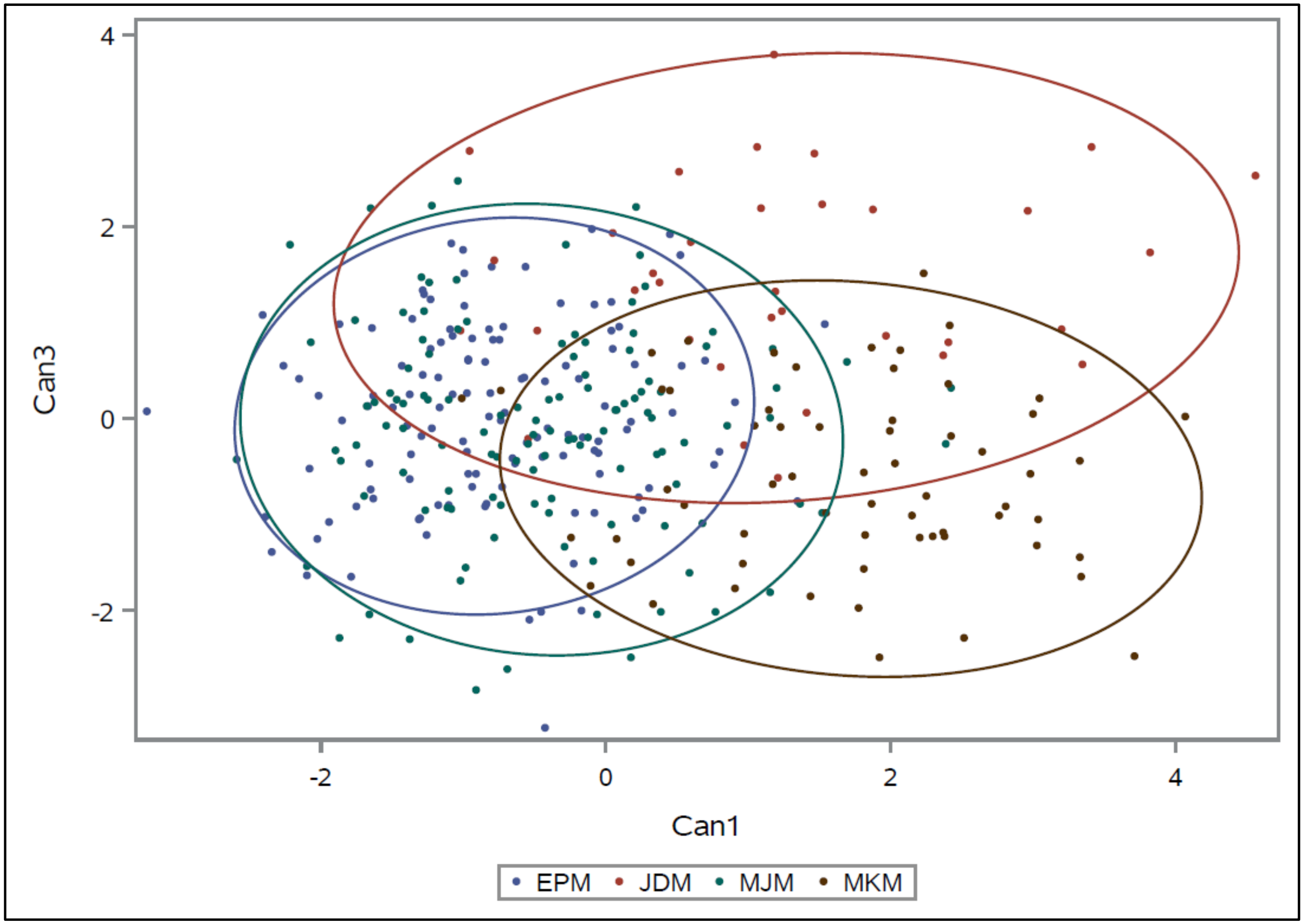

Figure 29: CV1 and CV3 scatterplot for the comparison of the four populations with males only.

Table 20: CVA results for the comparison between all four populations with males only.

CV	Eigenvalue	% Variance	% Cumulative
1	1.0111	61.32	61.32
2	0.3411	20.69	82.01
3	0.2967	17.99	100

Table 21: CVA results: Mahalanobis distances and p-values for the comparison between all four populations with males only.

	Mahalanobis distance		
	EPM	JDM	MJM
JDM	6.75037		
MJM	1.95329	5.89079	
MKM	6.85197	4.66866	5.88161
	P-values		
	EPM	JDM	MJM
JDM	<.0001		
MJM	<.0001	<.0001	
MKM	<.0001	.0001	<.0001

CV1 with the highest values are the nasal breadth, orbital height and breadth, cranial index, length-height index, breadth height index, mean basion-height index, and fronto-parietal index. For CV2, it is the nasal breadth, nasio-frontal subtense, cranial index, length-height index, mean basion-height index, and fronto-parietal index, and for CV3 it is the basion-bregma height, dacryon subtense, cranial breadth, breadth-height index, and mean basion-height index that contributed to the variation between groups. The canonical structures for CV1 that have high loadings are maximum cranial length, nasio-occipital length, nasion angle (NBA), bregma angle, cranial index, length-height index, mean basion-height index, and fronto-parietal index. For CV2, it was maximum cranial breadth, maximum frontal breadth, and cranial index. CV3 did not have any metrics with high loadings.

Discriminant Function Analysis

The results of the DFA for the four populations with the sexes pooled are presented below in Table 22. The DFA first discriminated the groups with the *a priori* groups, and then conducted a cross-validation to determine how many individuals classified correctly. The higher the missclassification percentages, the more similar the groups are in cranial variation, and the lower they are the more differentiated the groups are to one another (SAS Institute, Inc., 2013). The results of the initial discriminated groups show that the Edo Period had that highest correct classification rates, although this rate is 65.31%. The population with the lowest correct classification is the Modern Japanese at 61.7%. The Modern Japanese had the highest misclassification rate of 22.34% into the Edo Period, indicating that they are most similar to one another. The Edo Period had the lowest misclassification rate into the Joseon Dynasty, suggesting that they are distinct from one another. In the cross-validation analysis, the correct classification rates dropped, and thus the misclassification rates increased. Again, the Edo Period had the highest correct rate at 58.16%, but the Joseon Dynasty had the lowest at 42.86%. For misclassification in the cross-validation, the Modern Japanese had the highest rate into the Edo Period at 29.79%, and the Edo Period had the lowest into the Joseon Dynasty at 6.12%.

Table 22: DFA results for the comparison of the four populations.

True Group	**Discriminate Group**				**Cross Validated Group**			
	EP	JD	MJ	MK	EP	JD	MJ	MK
EP	65.31%	5.61%	21.94%	7.14%	58.16%	6.12%	27.04%	8.67%
JD	12.24%	63.27%	14.29%	10.20%	14.29%	42.86%	18.37%	24.49%
MJ	22.34%	7.98%	61.70%	7.98%	29.79%	11.70%	49.47%	9.04%
MK	9.89%	10.99%	14.29%	64.84%	14.29%	18.68%	16.48%	50.55%

The DFA results for the sexes separated (females only and males only analyses) are presented in Table 23 and Table 24 below. In the initial discriminated groups, the females had higher correction classification rates than the males, but the opposite was true for the cross-validated groups. This is potentially due in part to the males having a larger sample size. In both the females and males, the Joseon Dynasty had the highest percentage of correctly classified individuals for the discriminate groups (80% and 76.47% respectively), and the Modern Japanese had the lowest (69.75% and 65.55% respectively). The Joseon Dynasty females into Edo Period females had the lowest misclassification rate at 0%, indicating their strong distinctiveness. In the males it was the Edo Period into the Modern Koreans at 3.25%. The Modern Japanese females into the Edo Period the highest misclassification at 21.74%, while in the males it was the Edo Period into Modern Japanese had the highest at 21.95%. In the cross-validation analyses, the males had higher correct classification rates than the females. Modern Japanese females and Modern Korean males had the highest percentage for correct classification, while the Joseon Dynasty females and males both had the lowest rates. The highest misclassification rates were with the Joseon Dynasty into the Modern Japanese at 40% for females and the Edo Period into Modern Japanese at 30.08% for males. The Joseon Dynasty into Edo Period females (6.67%) and the Edo Period into Modern Korean males had the lowest misclassification rates.

Table 23: DFA results for the comparison of the four populations with females only.

True Group	Discriminate Group				Cross Validated Group			
	EPF	JDF	MJF	MKF	EPF	JDF	MJF	MKF
EPF	73.97%	2.74%	20.55%	2.74%	42.47%	13.70%	34.25%	9.59%
JDF	0%	80.00%	13.33%	6.67%	6.67%	26.67%	40.00%	26.67%
MJF	21.74%	5.80%	69.57%	2.90%	34.79%	8.70%	46.38%	10.14%
MKF	16.67%	8.33%	4.17%	70.83%	25.00%	29.17%	12.50%	33.33%

Table 24: DFA results for the comparison of the four populations with males only.

True Group	Discriminate Group				Cross Validated Group			
	EPM	JDM	MJM	MKM	EPM	JDM	MJM	MKM
EPM	69.92%	4.88%	21.95%	3.25%	56.91%	6.50%	30.08%	6.50%
JDM	8.82%	76.47%	5.88%	8.82%	14.71%	38.24%	20.59%	26.47%
MJM	19.33%	5.88%	65.55%	9.24%	26.89%	10.08%	52.10%	10.92%
MKM	8.06%	11.29%	11.29%	69.35%	12.90%	12.90%	14.52%	59.68%

3D Geometric Morphometric Analyses: Generalized Procrustes Analysis

The results from the analyses conducted in MorphoJ using GPA are provided below in separate sections for each of the three statistical tests (PCA, CVA, and DFA). Each of the tests were conducted for three separate analyses, the whole cranium, facial region, and cranial vault. As a result of the incomplete nature of many of the crania, of the total 58 landmarks, several had to be removed from the analysis to maximize the sample size. For each division of the cranium different landmarks were included with the whole cranium using 38, the facial region 26, and the cranial vault 19 of the landmarks. Despite dropping the variables with most missing data, several individuals were cut from the analysis due to them missing data for some of the variables retained. Each set of analyses were completed with the sexes pooled and separated. Both the pooled and separated sexes results are presented. The results for the pooled geographic populations (Korea and Japan) as well as the separated temporal populations are also reported for each set of analyses. Due to the differential preservation of each individual in the sample, different sample sizes were used for each of the three analyses. The sample sizes for each analysis are provided below in Table 25 through Table 28.

Table 25: Pooled geographic population sample sizes for each analysis.

	Population sample size	
Analysis	Japanese	Korean
Whole Cranium	383	148
Facial Region	383	144
Cranial Vault	387	170

Table 26: Pooled geographic populations with sexes segregated sample sizes for each analysis.

	Population sample size			
	Japanese		Korean	
Analysis	Female	Male	Female	Male
Whole Cranium	143	240	46	97
Facial Region	143	240	40	99
Cranial Vault	144	243	55	110

Table 27: Four temporal population sample sizes for each analysis.

	Population sample size			
Analysis	Edo Period	Joseon Dynasty	Modern Japanese	Modern Korean
Whole Cranium	194	56	189	92
Facial Region	194	50	189	94
Cranial Vault	199	76	188	94

Table 28: Four temporal populations with sexes segregated sample sizes for each analysis.

	Population sample size							
	Edo Period		Joseon Dynasty		Modern Japanese		Modern Korean	
Analysis	Female	Male	Female	Male	Female	Male	Female	Male
Whole Cranium	73	121	21	35	70	119	25	62
Facial Region	73	121	16	34	70	119	24	65
Cranial Vault	75	124	29	47	69	119	26	63

Principal Component Analysis

The results from MorphoJ of the PCA show that the variation among individuals in the dataset is widespread, but that there is considerable overlap between the two geographical populations (pooled Korean and pooled Japanese) as seen in the PCA scatterplots for all three analyses (Figure 30; only the scatterplots showing PC1-PC2 are provided here since the remaining PCs show similar results). As the two populations are closely related, it is not surprising the results show overlap for the two groups. The first five PCs account for approximately half or more of the total variation in each of the three analyses (50.5% for the whole cranium, 46.9% for the facial region, and 61.2% for the cranial vault) (Table 29). The number of PCs the data was reduced to varied with each of the analyses since each contained a different number of landmarks. In each analysis, the number of PCs reported by MorphoJ was only slightly less than the original number of coordinates (whole cranium: 38 landmarks [114 coordinates] to 107 PCs; facial region: 26 landmarks [78 coordinates] to 71 PCs; cranial vault: 19 landmarks [57 coordinates] to 50 PCs). With the small amount of variation accounted for by each PC, the results indicate that the variation is spread across the landmarks. This is generally confirmed by the PC coefficients which show that most landmarks have similar absolute values. The PC coefficients are provided in the Appendix. For the whole cranium, the landmarks that did have loadings larger than |0.3| were eurion for PC1, stephanion for PC2, cheek height landmarks for PC4, and eurion and lambda for PC5; PC3 did not have any significant landmarks. In the facial cranium, the significant landmarks were frontotemporale for PC1, zygoorbitale for PC2, jugale for PC3, and zygomaxilare for PC5; PC4 did not have any significant landmarks. For the cranial vault, the contributing landmarks were eurion for PC1, stephanion for PC2, eurion and lambda for both PC3 and PC4, and glabella and lambda for PC5. When the results from the whole cranium, facial region, and cranial vault analyses are compared, the landmarks of the cranial vault show greater variance accounted for in the first five PCs while those of the facial region accounted for the least (see Table 29). When the PCA was conducted with the sexes separated for the pooled geographic populations, the results show little difference from when the sexes were pooled. Tables and graphs are not presented here due to the similarity with results already reported.

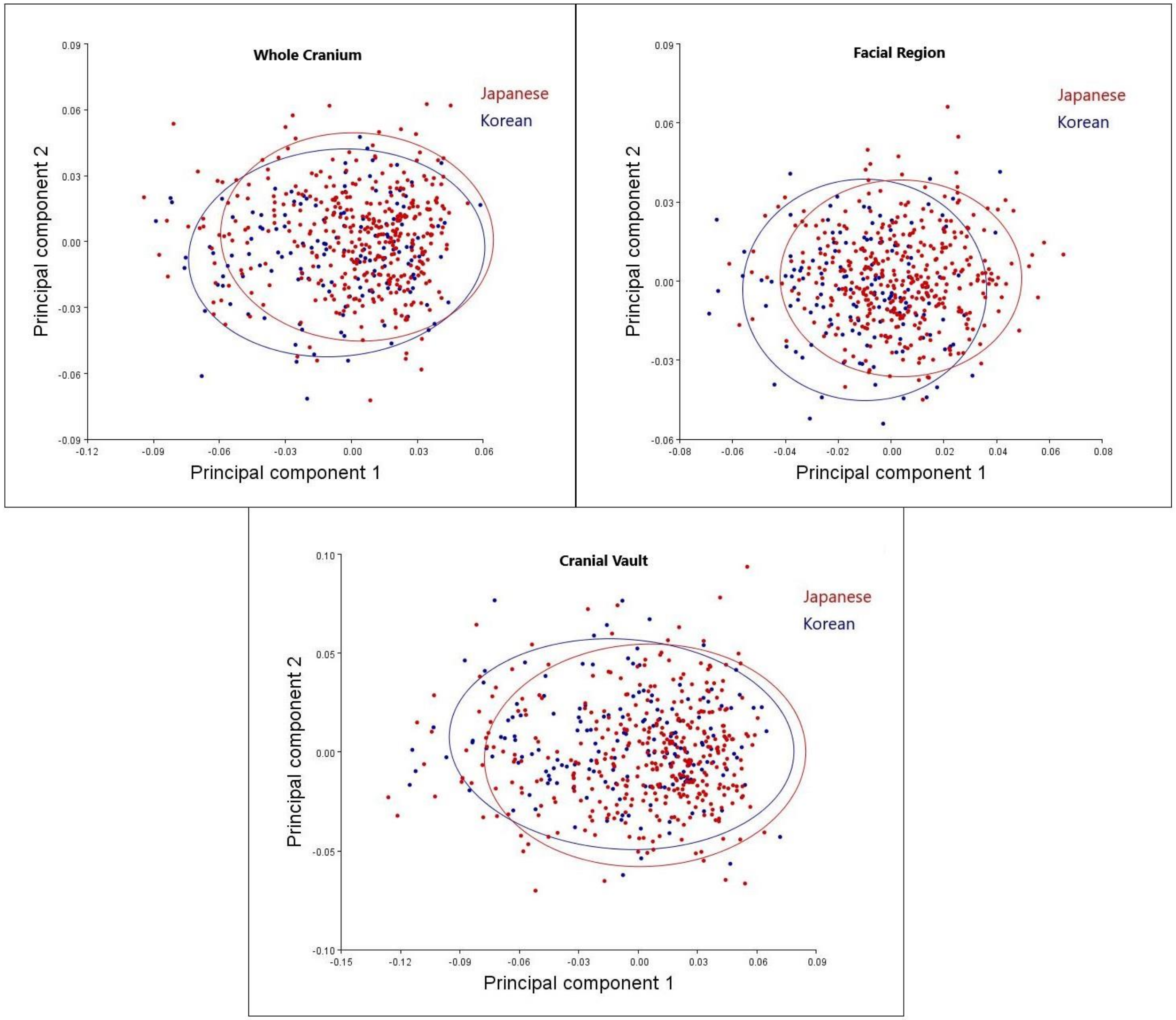

Figure 30: PCA scatterplots showing PC1 and PC2 for the comparison between pooled Korean and pooled Japanese populations.

Table 29: PCA results for the first five PCs for the comparison between the pooled Korean and pooled Japanese populations.

	Whole Cranium		
PC	**Eigenvalue**	**% Variance**	**Cumulative %**
1	0.00087704	20.705	20.705
2	0.00048682	11.493	32.198
3	0.00030917	7.299	39.497
4	0.00024514	5.787	45.285
5	0.00021888	5.167	50.452
	Facial Region		
PC	**Eigenvalue**	**% Variance**	**Cumulative %**
1	0.00045849	14.037	14.307
2	0.00032447	9.934	23.971
3	0.00028854	8.834	32.804
4	0.00023658	7.243	40.047
5	0.00022223	6.804	46.851
	Cranial Vault		
PC	**Eigenvalue**	**% Variance**	**Cumulative %**
1	0.00150001	28.964	28.964
2	0.00066570	12.854	41.819
3	0.00038503	7.435	49.254
4	0.00033823	6.531	55.785
5	0.00027777	5.364	61.148

The results for the comparison between the four populations (Joseon Dynasty, Edo Period, Modern Korean, and Modern Japanese) are similar to those for the two geographic populations reported above. There is a wide variation among individuals and the four populations overlap considerably (Figure 31; only the scatterplots showing PC1-PC2 are provided here since the remaining PCs show similar results). The first five PCs account for approximately half or more of the total variation in each of the three analyses (50.5% for the whole cranium, 46.8% for the facial region, and 61.1% for the cranial vault) (Table 30). The number of PCs the data was reduced to is the same as for the pooled populations. Again, the results show that the variation is spread among the landmarks and that the cranial vault has greater variance accounted for while the facial region accounted for the least (see Table 30). This is largely confirmed by the PC coefficients which show that most landmarks have similar absolute values. The PC coefficients

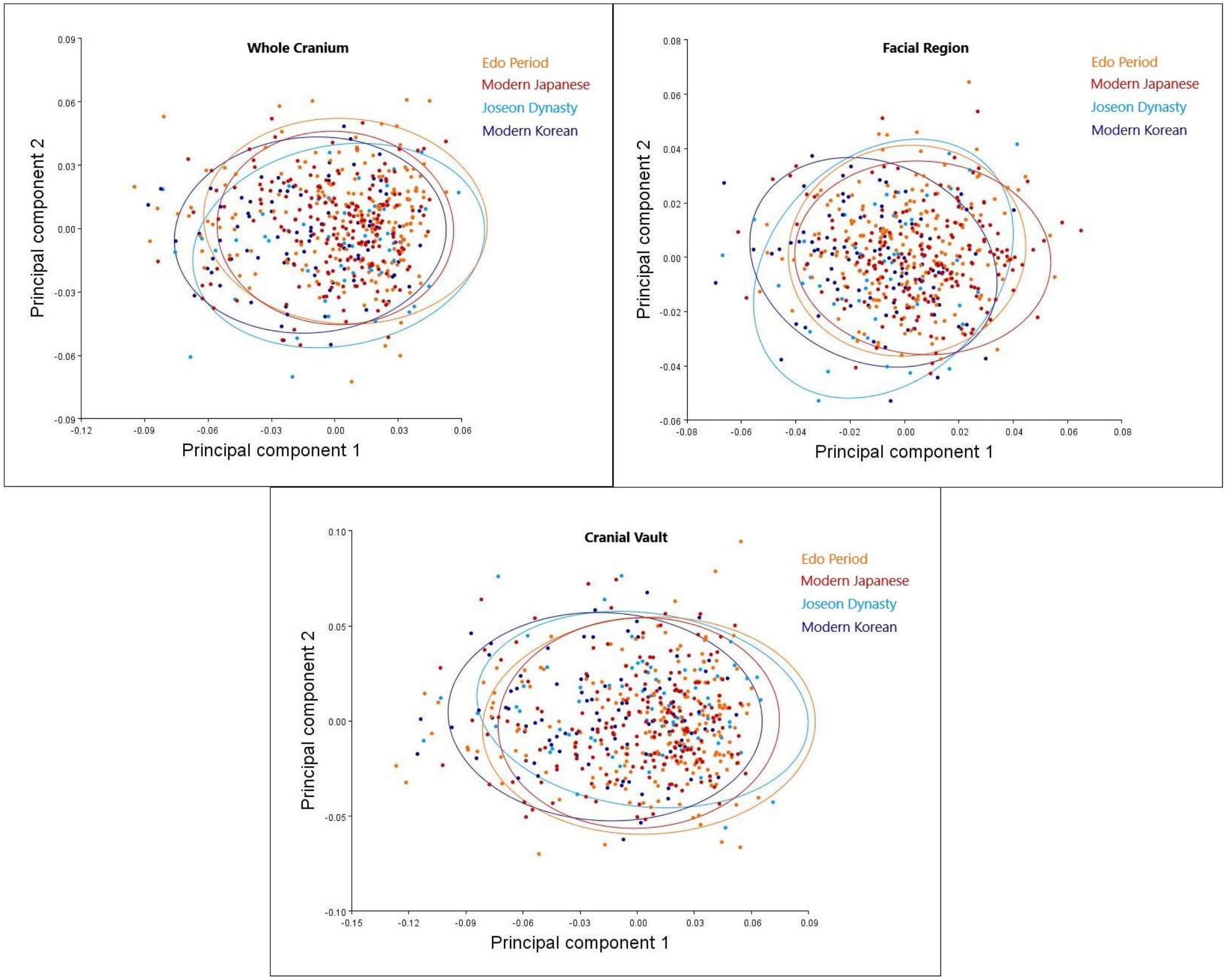

Figure 31: PCA scatterplots showing PC1 and PC2 for the comparison between the Edo Period, Modern Japanese, Joseon Dynasty, and Modern Korean populations.

Table 30: PCA Results for the first five PCs for the comparison between the four populations.

	Whole Cranium		
PC	**Eigenvalue**	**% Variance**	**Cumulative %**
1	0.00086378	20.775	20.775
2	0.00048456	11.654	32.430
3	0.00028997	6.974	39.404
4	0.00024570	5.909	45.313
5	0.00021366	5.139	50.452
	Facial Region		
PC	**Eigenvalue**	**% Variance**	**Cumulative %**
1	0.00045232	14.066	14.066
2	0.00032368	10.065	24.131
3	0.00027850	8.660	32.791
4	0.00023374	7.269	40.060
5	0.00021798	6.778	46.838
	Cranial Vault		
PC	**Eigenvalue**	**% Variance**	**Cumulative %**
1	0.00146961	28.939	28.936
2	0.00066664	13.126	42.061
3	0.00037368	7.357	49.419
4	0.00033138	6.525	55.943
5	0.00026004	5.120	61.064

are provided in the Appendix. For the whole cranium, the landmarks that did have loadings larger than |0.3| were eurion for PC1, stephanion for PC2, cheek height landmarks for PC4, and eurion and lambda for PC5; PC3 did not have any significant landmarks. In the facial cranium, the significant landmarks were frontotemporale for PC1, zygoorbitale for PC2, jugale for PC3, and zygomaxilare for PC5; PC4 did not have any significant landmarks. For the cranial vault, the contributing landmarks were eurion for PC1, stephanion for PC2, eurion and lambda for PC3, lambda for PC4, and bregma, glabella, and lambda for PC5.When the PCA was conducted with the sexes separated, the results show little difference from when the sexes were pooled. Tables and graphs are not presented here due to the similarity with results already reported.

Canonical Variance Analysis

The results of the CVA from MorphoJ provide a clearer indication of the variation between the groups. In the CVA on the pooled Korean and pooled Japanese populations, the three analyses produced one CV, which means that it accounted for 100% of the variation (Table 31). The eigenvalues between the three analyses differ, with the whole cranium having the largest value and the cranial vault the smallest. There is overlap between the pooled Korean and pooled Japanese populations in the histograms, but they are still clearly distinguishable (Figure 32). Since the Mahalanobis distance is dependent on the number of variables and each analysis has a different set of variables, the distances had to be corrected for this in order to compare the three subsets of data. This was done by dividing the distances by the number of variables. Both the original and corrected Mahalanobis distances are included in (Table 32). The corrected distance between the two geographic populations is largest for the cranial vault while the whole cranium has the smallest value. This suggests that the cranial vault performs best at distinguishing the two groups while the whole cranium is worst, but the differences between the three corrected distances are rather small. This combined with the histograms clearly showing more separation between the populations in the whole cranium indicates that the graphs better illustrate that the whole cranium performs better than the two separated components.

Table 31: CVA results for the comparison between the pooled Korean and pooled Japanese populations.

	Whole Cranium		**Facial Region**		**Cranial Vault**	
CV	**Eigenvalue**	**% Variance**	**Eigenvalue**	**% Variance**	**Eigenvalue**	**% Variance**
1	2.61008398	100	1.57387491	100	1.09358918	100

Table 32: CVA results: Mahalanobis distances and corrected Mahalanobis distances for the comparison between the pooled Korean and pooled Japanese populations.

	Whole Cranium	**Facial Region**	**Cranial Vault**
	Mahalanobis distance	**Mahalanobis distance**	**Mahalanobis distance**
	Pooled Japanese	Pooled Japanese	Pooled Japanese
Pooled Koreans	3.5964	2.8099	2.2668
	Corrected Mahalanobis distance	**Corrected Mahalanobis distance**	**Corrected Mahalanobis distance**
	Pooled Japanese	Pooled Japanese	Pooled Japanese
Pooled Koreans	0.09464	0.10807	0.11931

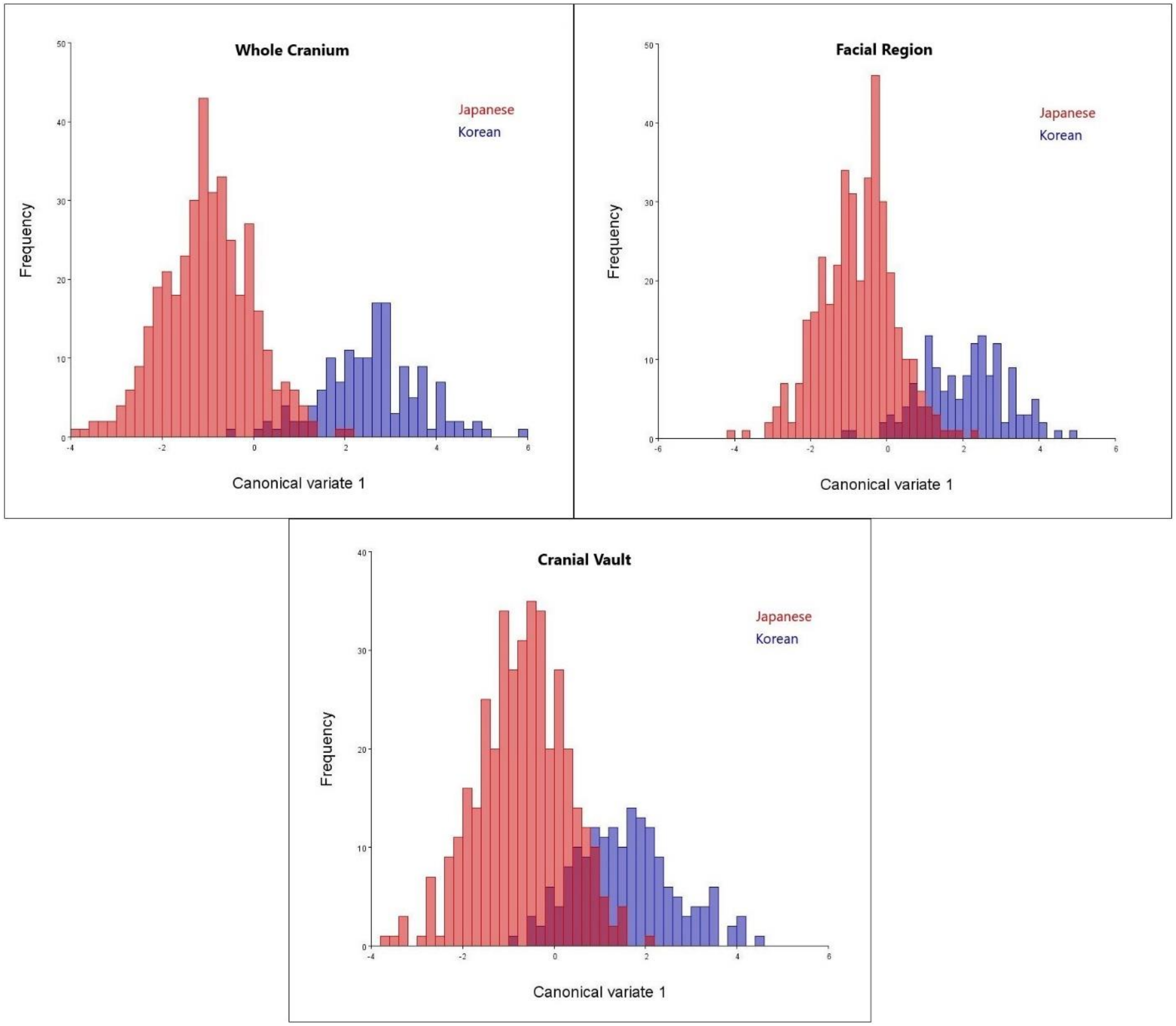

Figure 32: CVA histograms for the comparison of the pooled Korean and pooled Japanese populations.

MorphoJ does not provide canonical standards, and thus only the canonical coefficients are discussed. The coefficients are provided in tables in the Appendix. The majority of the landmarks that contribute most to the differences between two populations are in the facial region. For the whole cranium, the facial landmarks of alare, nasion, nasal inferior border, inferior orbital height landmark, zygoorbitale, cheek height, frontomalare anterior, and frontomalare temporale, and the cranial vault landmark of porion were found to have the highest values, indicating their contributions to differentiating the populations. When the facial region was separated out, the landmarks of alare, frontomalare anterior, frontomalare temporale, jugale, inferior orbital height landmark, cheek height, and zygoorbitale performed the best. For the cranial vault, only two landmarks were found to contribute significantly, the roots of the zygomatic arches and porion.

In the CVA for the pooled geographic population with the sexes segregated, the individuals whose sex was unknown and could not be estimated were removed from the analysis. The CVA resulted in three CVs with the first CV accounting for over 50% of the between group variation and the first two CVs for over 90% in all three analyses (Table 33). The geographic populations are differentiated on CV1 with the Japanese toward the positive side and the Koreans on the negative while the sexes are segregated along CV2 with the females toward the negative end and the males on the positive (Figure 33). CV3 accounted for very little of the between group variation, only representing the residual variation that does not distinguish between the groups. There is overlap among the groups with more occurring between the sexes of the same geographic population. The scatter plot for the whole cranium provides the clearest visual distinction between the groups while the cranial vault has the most overlap of the groups. When the results for the first CV from the whole cranium, facial region, and cranial vault are compared, the landmarks of the cranial vault accounted for more of the variation between the groups, but when the first two CVs are compared the facial region encompasses more of the variation while the cranial vault has the least.

The Mahalanobis distances between each pair of the groups were significant with a p-value of less than 0.01 for each analysis (Table 34). The Mahalanobis distances for all three analyses show that paired sexes within each geographic population were closest to one another (i.e. the Japanese females and males and the Korean females and males had the smallest distance

Table 33: CVA results for the comparison between the pooled geographic populations with the sexes segregated.

	Whole Cranium			**Facial Region**			**Cranial Vault**		
CV	**Eigenvalue**	**% Variance**	**Cumulative %**	**Eigenvalue**	**% Variance**	**Cumulative %**	**Eigenvalue**	**% Variance**	**Cumulative %**
1	2.61943613	54.948	54.948	1.65909812	53.272	53.272	1.15498080	60.407	60.407
2	1.85956773	39.008	93.957	1.31832793	42.330	95.602	0.62484739	32.681	93.088
3	0.28808464	6.043	100	0.13696188	4.398	100	0.13216003	6.912	100

Table 34: CVA results: Mahalanobis distances and corrected Mahalanobis distances for the comparison between the pooled geographic populations with the sexes segregated.

	Whole Cranium			**Facial Region**			**Cranial Vault**		
	Mahalanobis distance			**Mahalanobis distance**			**Mahalanobis distance**		
	JF	JM	KF	JF	JM	KF	JF	JM	KF
JM	2.9930			2.5663			1.8060		
KF	3.6069	4.4481		2.7152	3.5111		2.3329	2.5608	
KM	4.5909	3.9200	3.2582	3.8041	3.0561	2.6966	3.0567	2.4506	2.0313
	Corrected Mahalanobis distnace			**Corrected Mahalanobis distnace**			**Corrected Mahalanobis distnace**		
	JF	JM	KF	JF	JM	KF	JF	JM	KF
JM	0.07876			0.09870			0.09505		
KF	0.09492	0.11706		0.10443	0.13504		0.12278	0.13478	
KM	0.12081	0.10316	0.08574	0.14631	0.11754	0.10372	0.16088	0.12898	0.10691

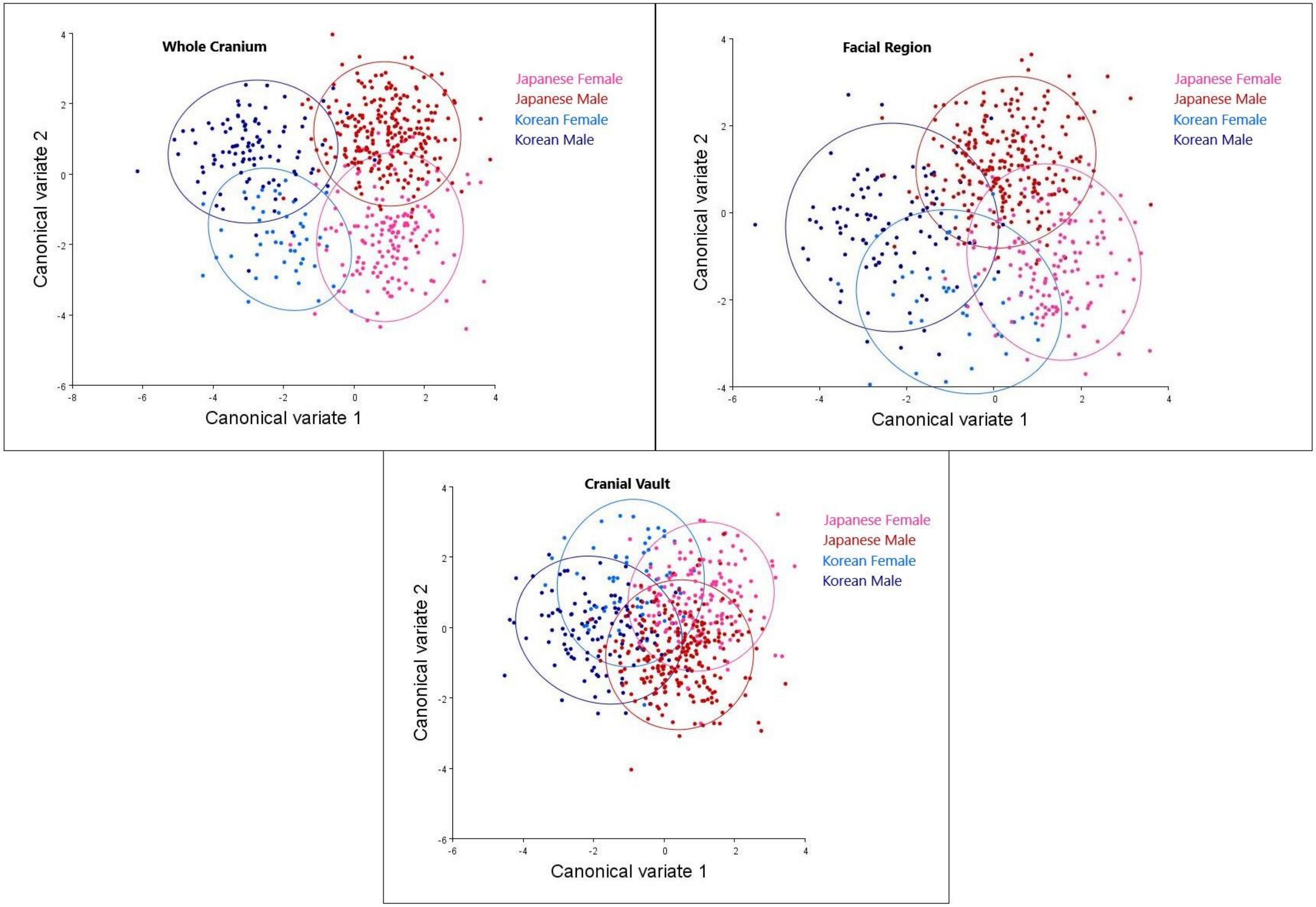

Figure 33: CVA scatterplots for the comparison of the pooled Korean and pooled Japanese populations with the sexes segregated.

measures). The two groups who were most distant were the Korean males and Japanese females in each analysis. When comparing the corrected Mahalanobis distances for each of the three analyses, the cranial vault has the largest distances between the groups, but the three sets of corrected distances are similar with only small differences between them.

The canonical coefficients provided an indication of which landmarks differentiated the four groups and are provided in the Appendix. For the whole cranium analysis, the facial landmarks contributed the most to the differences between the groups for the three CVs, with only a few cranial vault landmarks having high values. For CV1, which separates the two geographic populations, the alare, inferior nasal border, inferior orbital height landmark, cheek height, zygoorbitale, frontomalare anterior, frontomalare temporale, and porion were best at distinguishing between the Korean and Japanese populations. For CV3, which differentiated the two sexes, dacryon, ectoconchion, glabella, frontomalare anterior, frontotemporale, and maximum frontal points had the highest coefficients. The results of the facial region analysis showed that primarily two landmarks, alare and ectoconchion, differentiated between the populations, and glabella and cheek height segregated the two sexes. The cranial vault results showed that the roots of the zygomatic processes and porion in CV1 and stephanion and maximum frontal points in CV2 best contributed to the between group variation.

The CVA for the comparison of the four populations (Joseon Dynasty, Edo Period, Modern Korean, and Modern Japanese) produced three CVs. The results in all three analyses (whole cranium, facial region, cranial vault) show that the first CV account for over 50% of the variation between the populations and the first two CVs account for over 85% (Table 35). The Joseon Dynasty and Modern Koreans were clustered together toward the negative end of CV1 with the Edo Period and Modern Japanese toward the positive end, although there was some overlap between the geographical groups (Figure 34). In the results for the whole cranium and facial region, the Modern Koreans were further to the negative side than the Joseon Dynasty while in the cranial vault they nearly completely overlap with the Joseon Dynasty showing wider variation for CV1 (Figure 34). In all three analyses, the Edo Period was slightly more toward the positive end of CV2 than the other three populations which were toward the negative end (Figure 34). For CV3, the Joseon Dynasty was slightly more separated from the other three populations

Table 35: CVA results for the comparison between all four populations.

	Whole Cranium			Facial Region			Cranial Vault		
CV	**Eigenvalue**	**% Variance**	**Cumulative %**	**Eigenvalue**	**% Variance**	**Cumulative %**	**Eigenvalue**	**% Variance**	**Cumulative %**
1	3.02788519	57.329	57.329	1.93359605	62.311	62.311	1.31256090	56.127	56.127
2	1.46509189	27.740	85.069	0.74110176	23.882	86.193	0.75400272	32.242	88.370
3	0.78860246	14.931	100.000	0.42844738	13.807	100.000	0.27197482	11.630	100.000

Table 36: CVA results: Mahalanobis distances and corrected Mahalanobis distances for the comparison between all four populations.

	Whole Cranium			Facial Region			Cranial Vault		
	Mahalanobis distance			**Mahalanobis distance**			**Mahalanobis distance**		
	EP	JD	MPJ	EP	JD	MPJ	EP	JD	MPJ
JD	3.8376			2.8500			2.3865		
MPJ	3.0219	4.4820		2.1198	3.0728		2.2954	3.0417	
MPK	4.1408	3.5879	4.7855	3.3752	3.0116	3.9139	2.5481	1.9374	2.9768
	Corrected Mahalanobis distance			**Corrected Mahalanobis distance**			**Corrected Mahalanobis distance**		
	EP	JD	MPJ	EP	JD	MPJ	EP	JD	MPJ
JD	0.10099			0.10962			0.12561		
MPJ	0.07952	0.11795		0.08153	0.11818		0.12081	0.16009	
MPK	0.10897	0.09442	0.12593	0.12982	0.11583	0.15053	0.13411	0.10197	0.15667

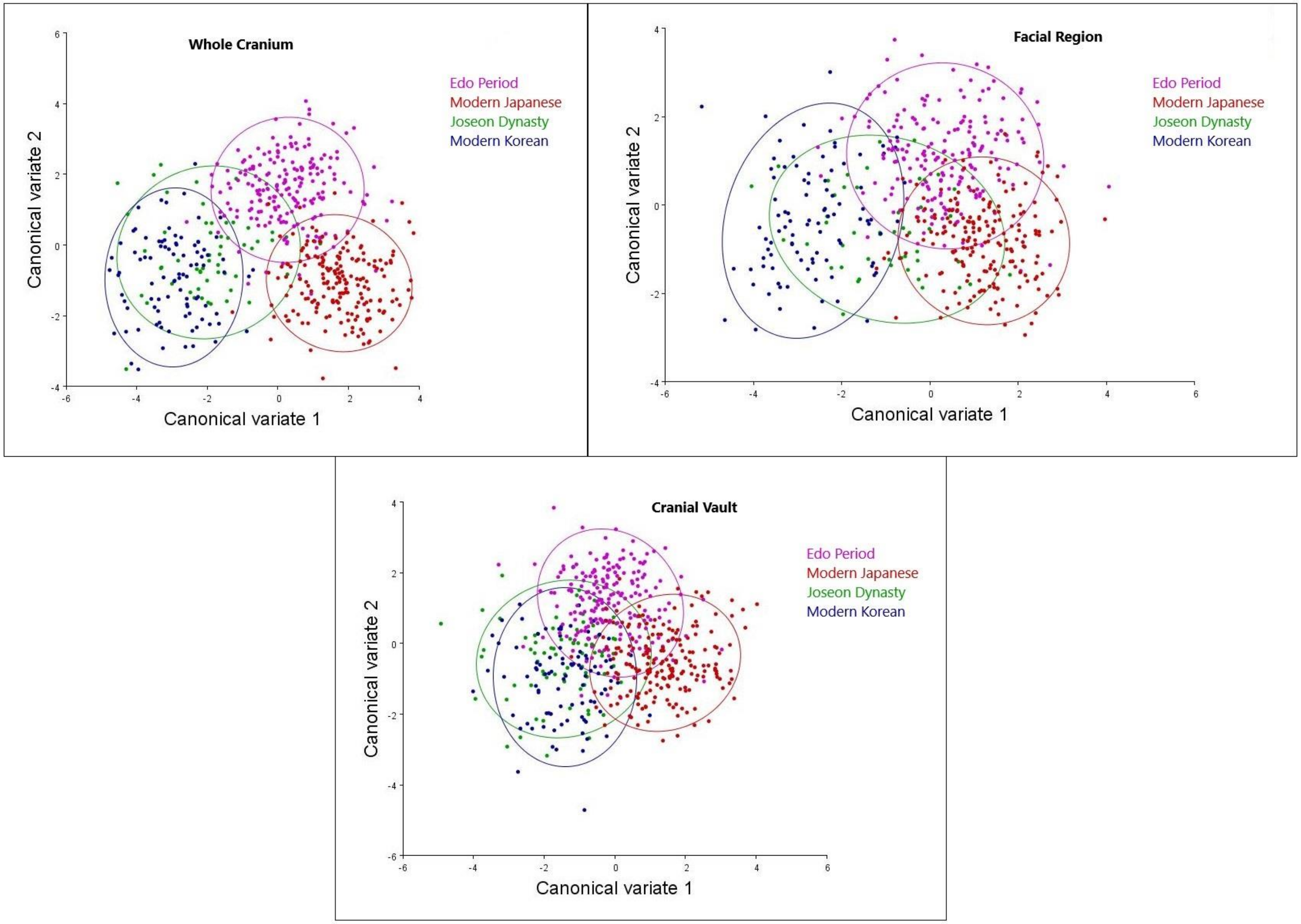

Figure 34: CVA scatterplots for the comparison of the four populations showing CV1 and CV2.

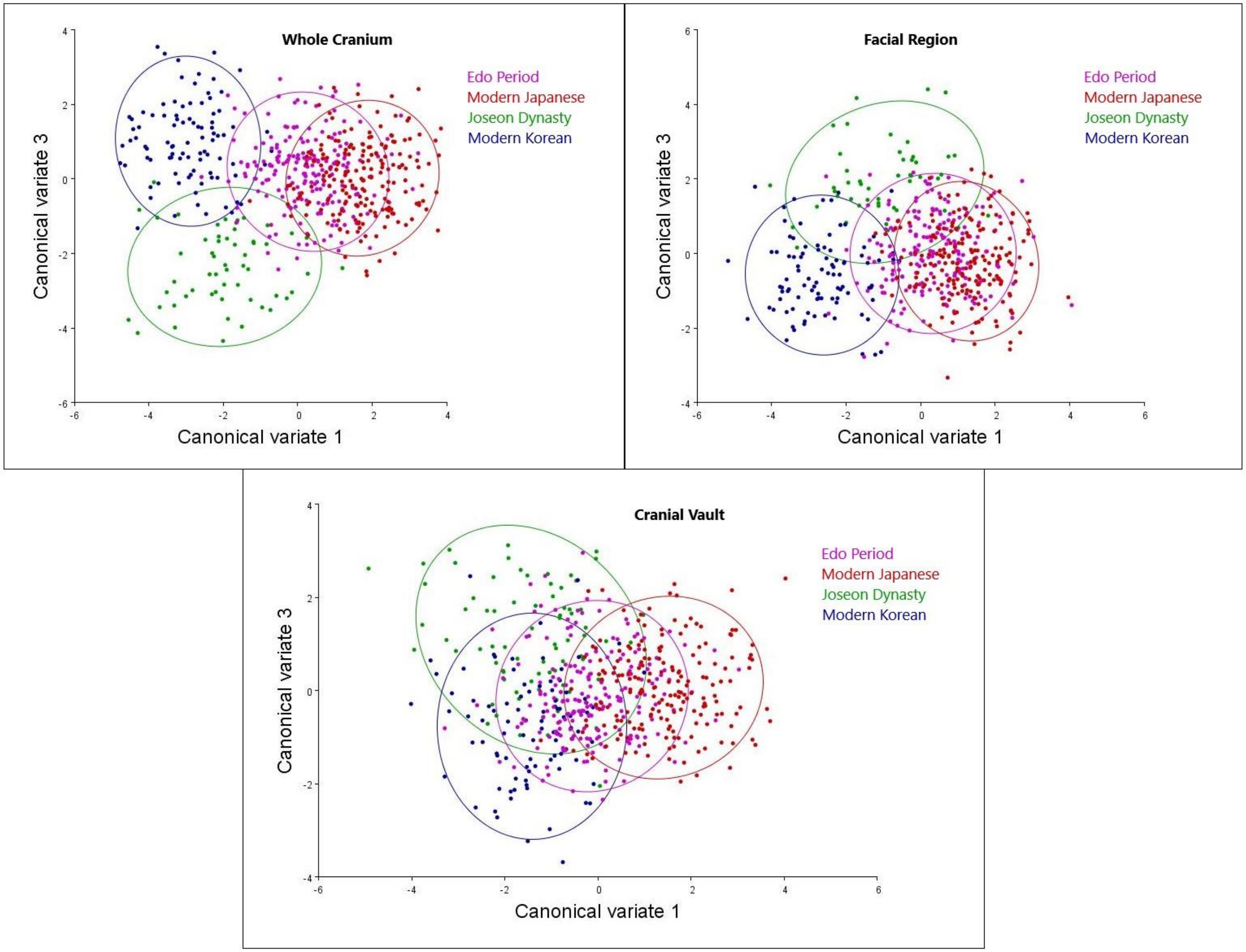

Figure 35: CVA scatterplots for the comparison of the four populations showing CV1 and CV3.

(toward the negative side for the whole cranium and the positive side for the facial region and cranial vault), but still overlapping with them (Figure 35).

The Mahalanobis distances between each pair of the populations were significant with a p-value of less than 0.01 for each analysis (Table 36). The Mahalanobis distances for the whole cranium and facial region show that the Edo Period and Modern Japanese were closest to one another (i.e. had the smallest distance measure) while the cranial vault showed the Joseon Dynasty and Modern Koreans as closest. For the whole cranium and facial region, the two most distant populations were the Modern Koreans and Modern Japanese. However, for the cranial vault, the Joseon Dynasty and Modern Japanese had the largest Mahalanobis distance. The cranial vault had the largest corrected Mahalanobis distances, but the differences between the three sets of distances are small.

The canonical coefficients provided an indication of which landmarks differentiated the four populations and are provided in the Appendix. The coefficients for the whole cranium analysis show that the facial landmarks of alare, nasal inferior border, nasion, zygoorbitale, frontomalare anterior, frontomalare temporale, and cheek height, and the vault landmarks of the roots of the zygomatic processes and porion best separated the geographic populations in CV1. For CV2, dacryon, inferior orbital height landmark, zygoorbitale, and frontomalare anterior best segregated the Edo Period population. The landmarks of alare, nasal inferior border, dacryon, ectoconchion, both orbital height landmarks, zygoorbitale, frontomalare temporale, the roots of the zygomatic processes, and porion best differentiated the Joseon Dynasty in CV3. The facial region analysis showed that the landmarks of alare, nasal inferior border, and cheek height had the highest values for CV1, dacryon, ectoconchion, inferior orbital height landmark, zygoorbitale, and cheek height in CV2, and dacryon, ectoconchion, inferior orbital height landmark, zygoorbitale, and frontomalare temporale in CV3. In the cranial vault analysis, the roots of the zygomatic processes, foramen magnum breadth, and porion performed best in CV1, basion and opisthion in CV2, and basion in CV3.

The CVA for the comparison of the four populations (Joseon Dynasty, Edo Period, Modern Korean, and Modern Japanese) with the sexes segregated produced three CVs for each sex. The results in all three analyses (whole cranium, facial region, cranial vault) show that the first CVs account for over 50% of the variation between the groups for each sex and the first two for over

80% (Table 37 and Table 38). For both sexes, CV1 in all three analyses separates the geographical populations (Figure 36 and Figure 37). For females, CV2 separates out the Edo Period in the whole cranium and cranial vault analyses, while in the facial region it distinguishes between the early modern and modern groups (Figure 36). In the males, CV 2 separates the early modern from the modern populations in the whole cranium analysis, although the Joseon Dynasty overlaps with the modern populations (Figure 37). CV2 in the facial region and cranial vault analyses distinguishes the Edo Period from the other three groups for the males (see Figure 37). In the females, CV3 for the whole cranium distinguishes the temporal Korean populations, but for the facial region and cranial vault it only separates out the Joseon Dynasty from the other three groups (Figure 38). For the males, CV3 segregates out the Joseon Dynasty from the other populations in all three analyses (Figure 39).

The Mahalanobis distances between each pair of the populations for both sexes were significant with a p-value of less than 0.01 for each analysis. The Mahalanobis distances are presented in Table 39 and Table 40. For the whole cranium and facial region in both sexes, the groups that were closest were the Modern Japanese and Edo Period. In the cranial vault, the results were slightly different with the closest groups being the Modern Koreans and Joseon Dynasty for both sexes. The groups that had the largest Mahalanobis distances were slightly different between the sexes. For the whole cranium, the Modern Japanese and Modern Koreans were most distant for both sexes. In the facial region, the Modern Japanese and Joseon Dynasty were furthest from one another in the females, but in the males it was the Modern Japanese and Modern Koreans. The cranial vault results had the Modern Japanese and Modern Korean most distant in the females, and the Modern Japanese and Joseon Dynasty in the males. For both sexes, the cranial vault had slightly larger corrected Mahalanobis distances than the whole cranium or facial region, but these differences are small.

The canonical coefficients provided an indication of which landmarks differentiated the four groups for each sex and are provided in the Appendix. For females in the analysis for the whole cranium, the landmarks of alare, nasal inferior border, ectoconchion, inferior orbital height landmark, zygoorbitale, frontomalare anterior, frontomalare temporale, frontotemporale, and cheek height performed best in distinguishing between the Korean and Japanese populations in

Table 37: CVA results for the comparison between all four populations with only females.

	Whole Cranium			**Facial Region**			**Cranial Vault**		
CV	**Eigenvalue**	**% Variance**	**Cumulative %**	**Eigenvalue**	**% Variance**	**Cumulative %**	**Eigenvalue**	**% Variance**	**Cumulative %**
1	6.14190725	54.723	54.723	2.50006416	50.932	50.932	1.99124768	54.025	54.025
2	2.93120642	26.116	80.839	1.41132234	28.752	79.684	1.13610822	30.824	84.849
3	2.15053997	19.161	100	0.99726153	20.316	100	0.55844339	15.151	100

Table 38: CVA results for the comparison between all four populations with only males.

	Whole Cranium			**Facial Region**			**Cranial Vault**		
CV	**Eigenvalue**	**% Variance**	**Cumulative %**	**Eigenvalue**	**% Variance**	**Cumulative %**	**Eigenvalue**	**% Variance**	**Cumulative %**
1	4.02216159	53.424	53.424	2.50907032	60.743	60.743	1.51120544	52.804	52.804
2	2.19866382	29.204	82.628	0.94235956	22.814	83.557	0.98006560	34.245	87.049
3	1.30791831	17.372	100	0.67919759	16.443	100	0.37064691	12.951	100

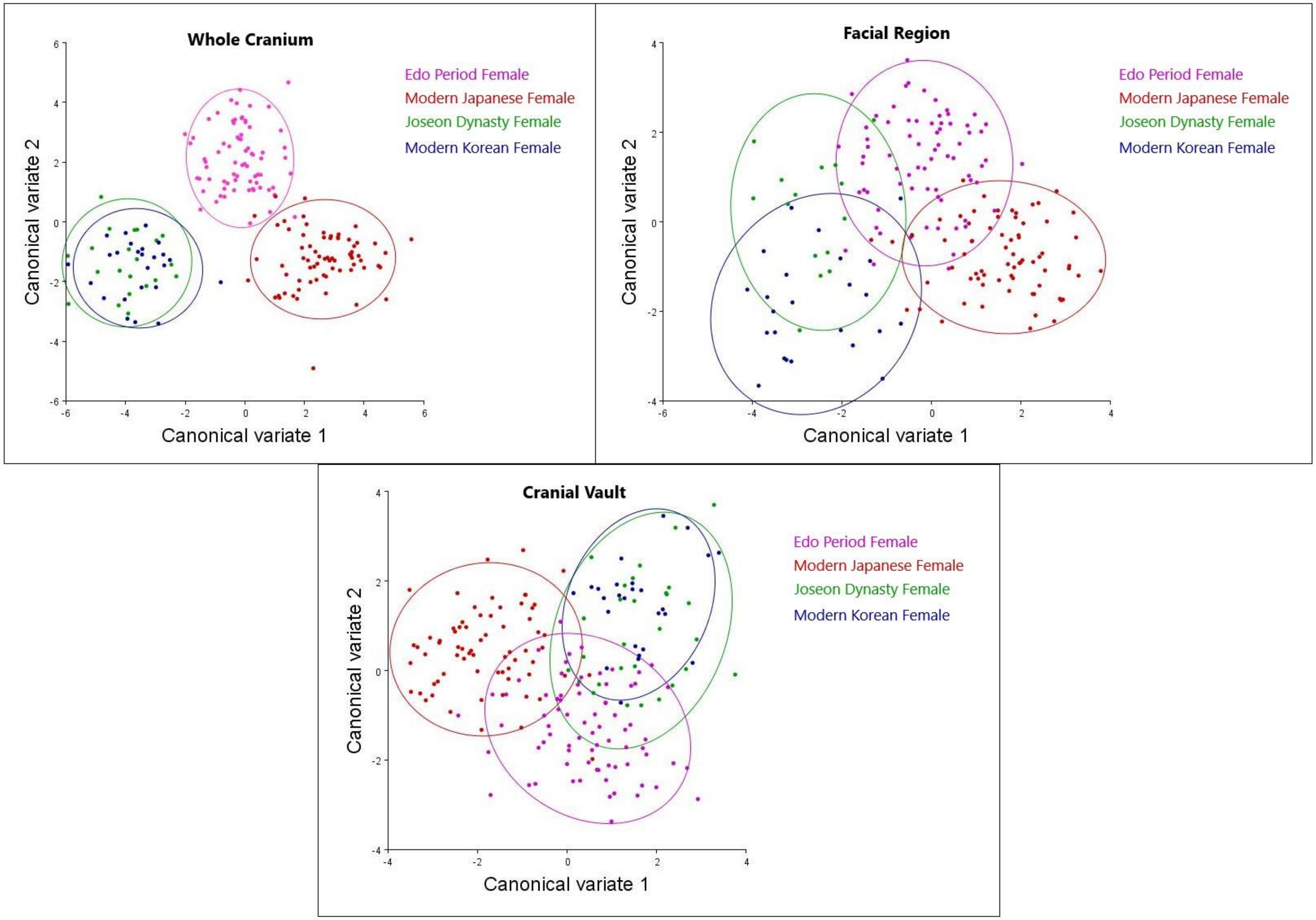

Figure 36: CVA scatterplots for the comparison of the four populations in the females showing CV1 and CV2.

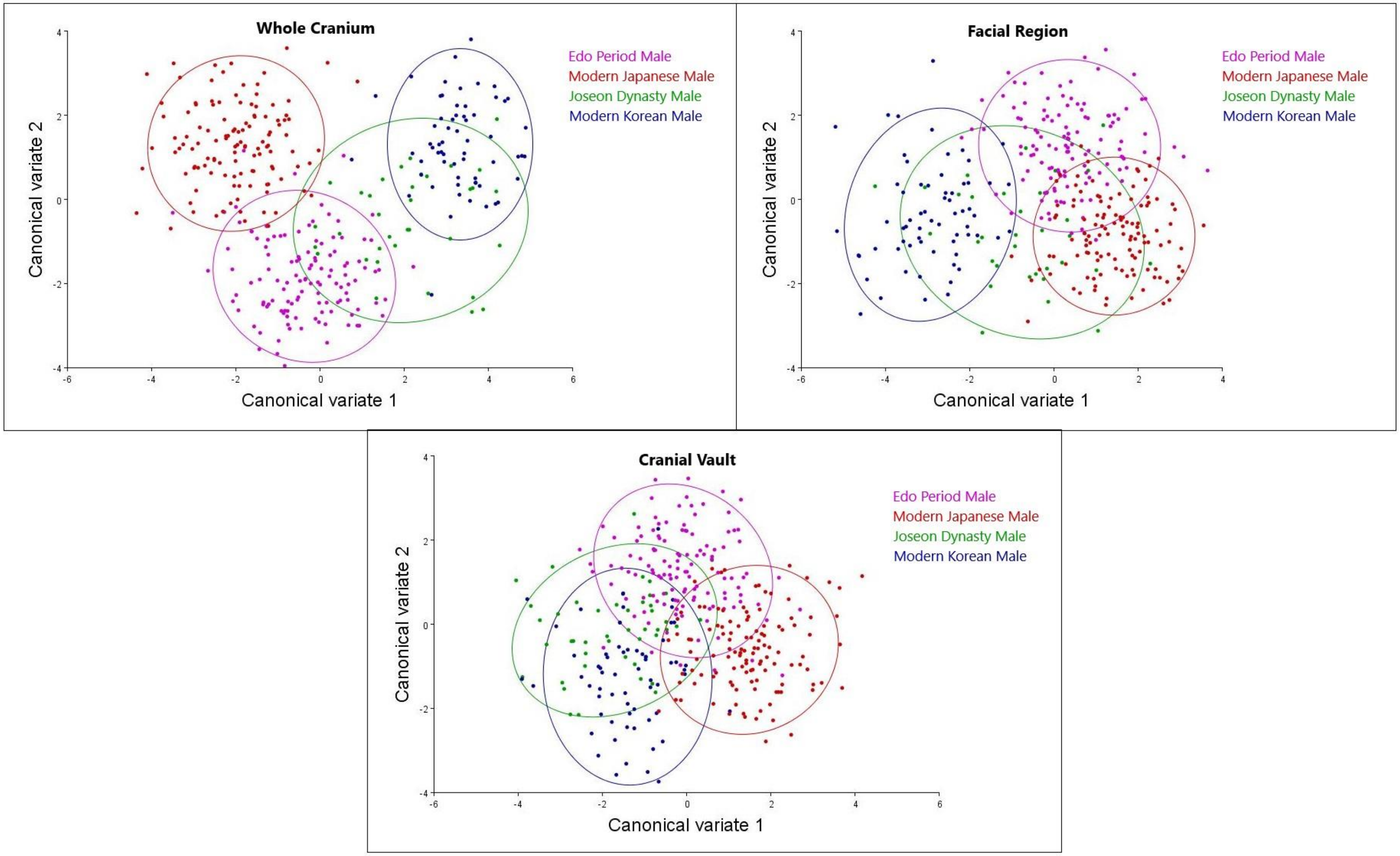

Figure 37: CVA scatterplots for the comparison of the four populations in the males showing CV1 and CV2.

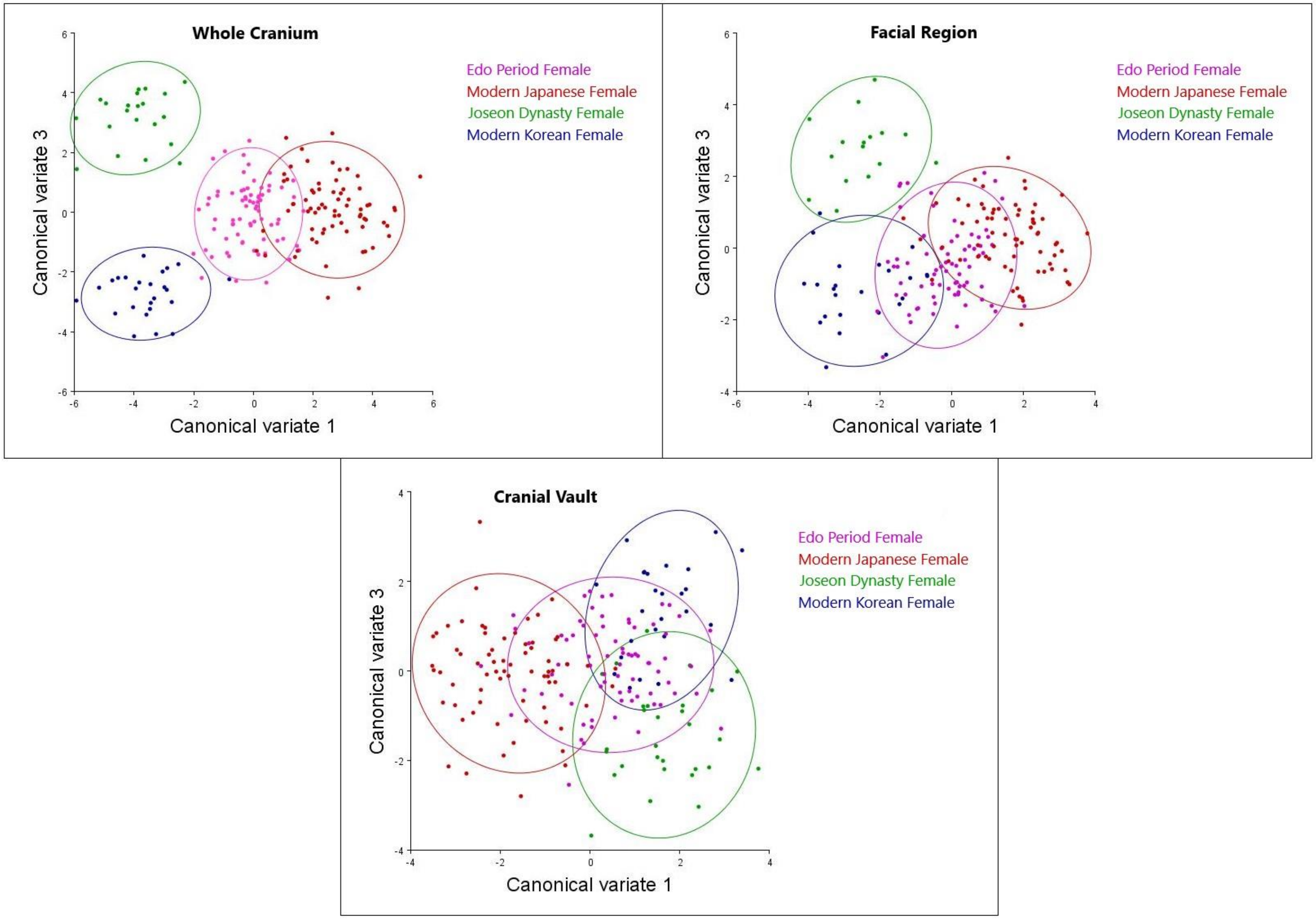

Figure 38: CVA scatterplots for the comparison of the four populations in the females showing CV1 and CV3.

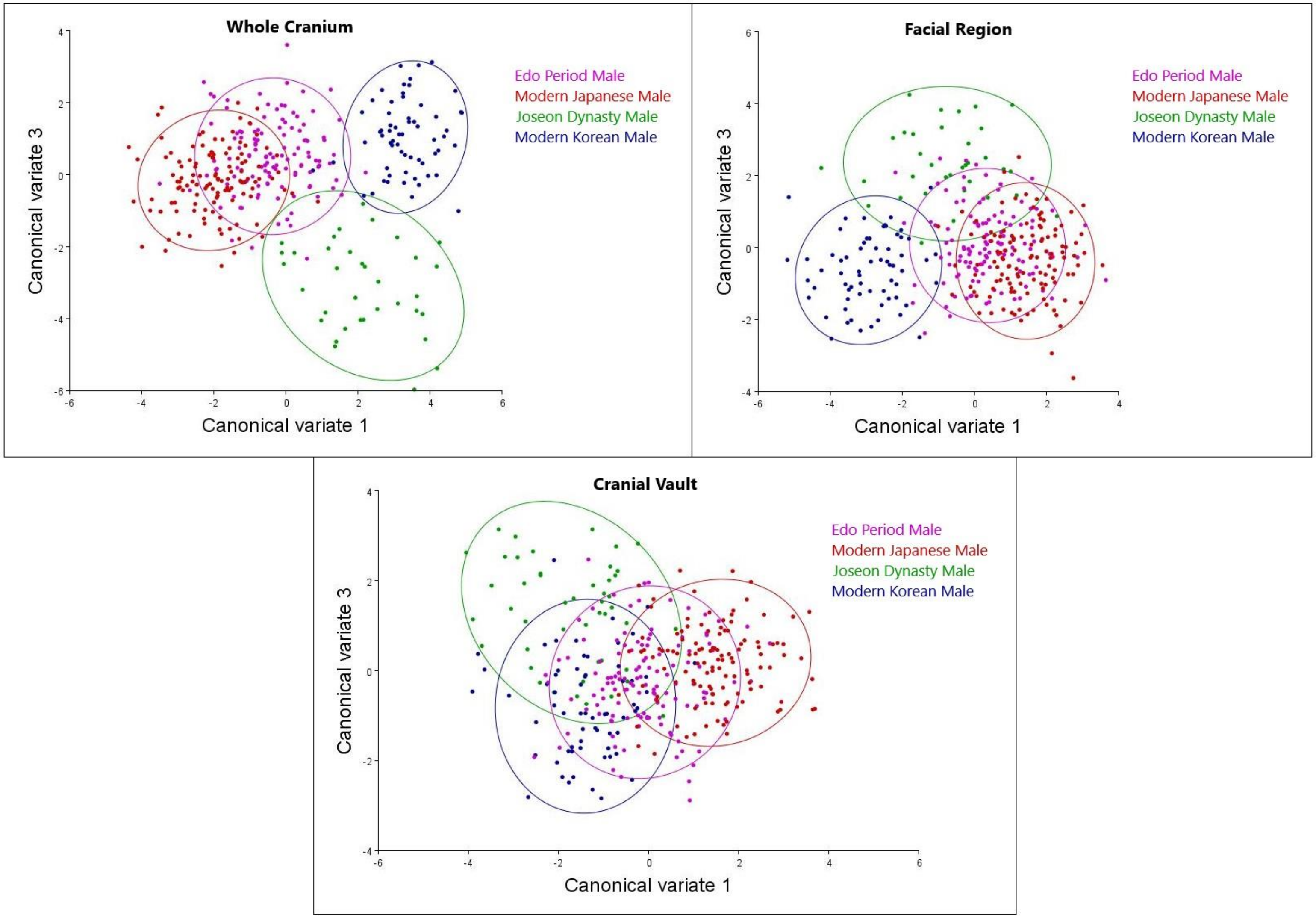

Figure 39: CVA scatterplots for the comparison of the four populations in the males showing CV1 and CV3.

Table 39: CVA results: Mahalanobis distances and corrected Mahalanobis distances for the comparison between all four populations with only females.

	Whole Cranium			**Facial Region**			**Cranial Vault**		
	Mahalanobis distance			**Mahalanobis distance**			**Mahalanobis distance**		
	EP	JD	MPJ	EP	JD	MPJ	EP	JD	MPJ
JD	6.0845			4.1626			2.9430		
MPJ	4.3843	7.2641		2.8647	4.9347		2.8884	3.7497	
MPK	5.7174	5.9120	6.8402	4.0403	4.4541	4.5726	3.2393	2.8499	3.8285
	Corrected Mahalanobis distance			**Corrected Mahalanobis distance**			**Corrected Mahalanobis distance**		
	EP	JD	MPJ	EP	JD	MPJ	EP	JD	MPJ
JD	0.16012			0.16010			0.15489		
MPJ	0.11538	0.19116		0.11018	0.18980		0.15202	0.19735	
MPK	0.15046	0.15558	0.18001	0.15540	0.17131	0.17587	0.17049	0.14999	0.20150

Table 40: CVA results: Mahalanobis distances and corrected Mahalanobis distances for the comparison between all four populations with only males.

	Whole Cranium			**Facial Region**			**Cranial Vault**		
	Mahalanobis distance			**Mahalanobis distance**			**Mahalanobis distance**		
	EP	JD	MPJ	EP	JD	MPJ	EP	JD	MPJ
JD	4.5881			3.2683			2.6511		
MPJ	3.6182	5.3923		2.4261	3.4759		2.4891	3.4235	
MPK	4.8847	4.6626	5.4599	3.7597	3.7042	4.4039	2.8871	2.3739	3.1171
	Corrected Mahalanobis distance			**Corrected Mahalanobis distance**			**Corrected Mahalanobis distance**		
	EP	JD	MPJ	EP	JD	MPJ	EP	JD	MPJ
JD	0.12074			0.12570			0.13953		
MPJ	0.09522	0.14190		0.09331	0.13369		0.13101	0.18018	
MPK	0.12854	0.12270	0.14368	0.14460	0.14247	0.16938	0.15195	0.12494	0.16406

CV1. For CV2, alare, ectoconchion, frontomalare anterior, frontomalare temporale, cheek height, and the maximum frontal points best separated the Edo Period from the other groups. In CV3 the Joseon Dynasty was separated by alare, dacryon, ectoconchion, zygoorbitale, frontomalare temporale, and maximum frontal points. For females in the facial region analysis, the alare, nasal inferior border, dacryon, ectoconchion, inferior orbital height landmark, zygoorbitale, frontomalare temporale, and cheek height had the highest values for CV1. In CV2, it was dacryon, ectoconchion, inferior orbital height landmark, zygoorbitale, and frontomalare temporale. For CV3, dacryon, ectoconchion, inferior orbital height landmark, and frontomalare temporale had the highest values. In females for the cranial vault analysis, the landmarks that performed the best were the roots of the zygomatic arches, porion, and maximum frontal points in CV1, roots of the zygomatic arches, basion, and porion in CV2, roots of the zygomatic arches, eurion, porion, and maximum frontal points in CV3.

For the males in the analysis for the whole cranium, the landmarks of alare, nasion, dacryon, ectoconchion, zygoorbitale, frontomalare anterior, frontomalare temporale, frontotemporale, cheek height, roots of the zygomatic arches, porion, and opisthion perfomed best in distinguishing between the Korean and Japanese populations in CV1. For CV2, alare, nasion, dacryon, ectoconchion, inferior orbital height landmark, frontomalare anterior, frontomalare temporale, cheek height, roots of the zygomatic arches, and porion best separated the Edo Period from the other groups. In CV3 the Joseon Dynasty was separated by alare, nasal inferior border, dacryon, ectoconchion, zygoorbitale, both orbital height landmarks, frontomalare anterior, frontomalare temporale, roots of the zygomatic arches, basion, glabella, stephanion, and porion. For males in the facial region analysis, the inferior orbital height landmark, cheek height, and frontomalare anterior had the highest values for CV1. In CV2, it was alare, nasal inferior border, dacryon, inferior orbital height landmark, zygoorbitale, cheek height, and glabella. For CV3, ectoconchion, both orbital height landmarks, zygoorbitale, and frontomalare temporale had the highest values. In males for the cranial vault analysis, the landmarks that performed the best were the roots of the zygomatic arches and porion in CV1, basion and maximum frontal points in CV2, and basion in CV3.

In summary, the results of the CVA for all four divisions of the data (pooled Korean and pooled Japanese; pooled Korean and pooled Japanese with the sexes segregated; four populations of Joseon Dynasty, Modern Korean, Edo Period, Modern Japanese; and four populations with sexes segregated) indicate that the whole cranium performs better than when the facial region and cranial vault are separated out individually. While the corrected Mahalanobis distances show slightly higher separation between groups for the cranial vault, the differences between the three sets of distances are small. The graphs provide clearer evidence for the better performance of the whole cranium, which reflects the 2D CVA results in which the indices contribute more to the population differences. When the sexes are segregated in separate groups for both the pooled geographic and the four individual subpopulations, the results show that geography plays a larger role in the between-group variation than sex or time period does. This can be seen by the fact that geography (CV1 in both cases) accounts for the largest portion of the variation across the CVs. However, sex does play a role as it is second in the amount of variation accounted for in the data in the analyses of the pooled Korean and pooled Japanese with the sexes separated. In the analyses of the four subpopulations with the sexes separated, the temporal affect was seen in CV2 and CV3 when the Edo Period and Joseon Dynasty, respectively, were distinguished from the other populations. But, for both sexes, the Edo Period accounted for more variance in CV2 than did the Joseon Dynasty in CV3. Thus, the CVA indicates geography (Korea versus Japan) has the strongest influence on the variation observed in the dataset.

In addition to these results, the CVs across the four divisions of the data also show similarity in the landmarks with the highest loadings. The majority of the contributing landmarks are from the facial region, particularly those associated with the nasal aperture, eye orbit, upper facial breadth, and cheek height. The distinguishing cranial vault landmarks are primarily the roots of the zygomatic arches, porion, basion, and maximum frontal points. This indicates that the facial region is more important differentiating the populations than the cranial vault, but that the vault still plays a role in the observed variation. However, while the face contributes more, the whole cranium still performed better at distinguishing the populations, likely a result of the contributing cranial vault landmarks.

Discriminant Function Analysis

The results of the DFA for each pair of populations with the sexes pooled and for all three analyses (whole cranium, facial region, and cranial vault) are presented below in Table 41 through Table 46. The DFA first discriminated the groups with the a-priori groups, and then conducted a cross-validation to determine how many individuals classified correctly. The results of the initial discriminated groups showed that the Modern Koreans and Modern Japanese pair had the highest correct identification rates of all the paired groups. The whole cranium and facial region performed best with a 100% correct classification of individuals for both populations in the case of the former, and 99.5% for Modern Koreans and 100% for Modern Japanese in the case of the latter. The cranial vault was only slightly lower with 96.3% and 96.8% for the Modern Korean and Modern Japanese respectively. The paired groups that had the worst discriminate grouping rates overall were the Edo Period and Modern Japanese. The whole cranium provided results in the mid-90% for both populations while the facial region and cranial vault ranged in the high 80%. The remaining paired populations had results that overall ranged between the highest and lowest pairs. However, one exception to this was the single lowest discriminated group correct classification rate that was 80.3% in the cranial vault for the Joseon Dynasty when paired with the Modern Koreans, indicating close similarities between the two groups for this cranial region. Overall, these initial discriminate group results indicate that four populations have sufficient between-group variation to be able to distinguish them even though there is some overlap in variation among them.

The results of the cross-validation showed that over 1,000 iterations the correct classification rates are lower than the original discriminate group rates for all population pairs. Again, the Modern Korean and Modern Japanese pair had the highest percent classification rates. The whole cranium and facial performed the best in correctly identifying individuals as being from their original population with rates above 95% for both analyses. The cranial vault did not perform as well as the other two analyses, but was still high at 88.3% for the Modern Koreans and 89.4% for the Modern Japanese. The paired group with the worst cross-validation results was the Joseon Dynasty and Modern Korean pair. For this grouping, the facial region performed the best with 78% correct classification for the Joseon Dynasty and 81.9% for the Modern Koreans. The whole

Table 41: DFA results for the comparison of Edo Period and Joseon Dynasty.

Analysis	True Group	Discriminate Group		Cross Validated Group	
		EP	JD	EP	JD
Entire Cranium	EP	99.5%	0.5%	85%	15%
	JD	0%	100%	25%	75%
Facial Region	EP	93.3%	6.7%	82.5%	17.5%
	JD	0%	100%	32%	68%
Cranial Vault	EP	91%	9%	84.9%	15.1%
	JD	11.8%	88.2%	22.4%	77.6%

Table 42: DFA results for the comparison of Modern Japanese and Modern Koreans.

Analysis	True Group	Discriminate Group		Cross Validated Group	
		MJ	MK	MJ	MK
Entire Cranium	MJ	100%	0%	97.9%	2.1%
	MK	0%	100%	5.4%	94.6%
Facial Region	MJ	99.5%	0.5%	97.4%	2.6%
	MK	0%	100%	4.3%	95.7%
Cranial Vault	MJ	96.3%	3.7%	88.3%	11.7%
	MK	3.2%	96.8%	10.6%	89.4%

Table 43: DFA results for the comparison of Joseon Dynasty and Modern Koreans.

Analysis	True Group	Discriminate Group		Cross Validated Group	
		JD	MK	JD	MK
Entire Cranium	JD	100%	0%	62.5%	37.5%
	MK	1.1%	98.9%	29.3%	70.7%
Facial Region	JD	96%	4%	78%	22%
	MK	3.2%	96.8%	18.1%	81.9%
Cranial Vault	JD	80.3%	19.7%	56.6%	43.4%
	MK	11.7%	88.3%	33%	67%

Table 44: DFA results for the comparison of Edo Period and Modern Japanese.

Analysis	True Group	Discriminate Group		Cross Validated Group	
		EP	MJ	EP	MJ
Entire Cranium	EP	94.8%	5.2%	87.1%	12.9%
	MJ	4.8%	95.2%	12.2%	87.8%
Facial Region	EP	88.7%	11.3%	78.9%	21.1%
	MJ	11.1%	88.9%	21.7%	78.3%
Cranial Vault	EP	87.9%	12.1%	80.4%	19.6%
	MJ	10.1%	89.9%	14.9%	85.1%

Table 45: DFA results for the comparison of Joseon Dynasty and Modern Japanese.

Analysis	**True Group**	**Discriminate Group**		**Cross Validated Group**	
		JD	MJ	JD	MJ
Entire Cranium	JD	100%	0%	78.6%	21.4%
	MJ	0.5%	99.5%	8.5%	91.5%
Facial Region	JD	94%	6%	74%	26%
	MJ	4.2%	95.8%	12.2%	87.8%
Cranial Vault	JD	94.7%	5.3%	85.5%	14.5%
	MJ	4.8%	95.2%	9.6%	90.4%

Table 46: DFA results for the comparison of Edo Period and Modern Koreans.

Analysis	**True Group**	**Discriminate Group**		**Cross Validated Group**	
		EP	MK	EP	MK
Entire Cranium	EP	97.9%	2.1%	92.3%	7.7%
	MK	1.1%	98.9%	9.8%	90.2%
Facial Region	EP	98.5%	1.5%	88.1%	11.9%
	MK	8.5%	91.5%	14.9%	85.1%
Cranial Vault	EP	94.7%	5.3%	85.5%	14.5%
	MK	4.8%	95.2%	9.6%	90.4%

cranium results were lower at 62.5% and 70.7% for the Joseon Dynasty and Modern Koreans respectively. The cranial vault performed the worst for this grouping with the Joseon Dynasty classifying correctly 56.6% of the individuals, which is little better than chance. The Modern Koreans had a correct classification rate of 67% for the cranial vault.

While the majority of the remaining cross-validation results were in the 80% to mid-90% range, there were two instances where the rates were below 80%. In both cases, the early modern periods were being compared with the Modern Japanese: the Joseon Dynasty had a correct classification rate of 78.6% and 74% for the whole cranium and facial region respectively, and the Edo Period had a rate of 78.9% for the facial region. In addition, the Modern Japanese were correctly classified only 78.3% for the facial region when paired with the Edo Period. However, they classified correctly above 80% when paired with the Joseon Dynasty. In other words, the early modern populations in both locations were miss-classifying as Modern Japanese more often than the other way around with the exception of the Modern Japanese miss-classifying into the Edo Period just as much as the other way around.

The results of the DFA for each pair of populations with the sexes separated and for all three analyses (whole cranium, facial region, and cranial vault) are presented below in Table 47 through Table 58. In the females, the results of the initial discriminated groups showed that the Modern Koreans and Modern Japanese pair had the highest correct identification rates of all the paired groups. For this pair, all three analyses correctly classified individuals into their original group at a rate of 100%. The paired populations that had the worst discriminate grouping rates overall were the Edo Period and Modern Japanese. The whole cranium provided the best results at 100% for both populations while the facial region was in the mid-90% range and the cranial vault in the high 80% to mid-90% range. The remaining paired populations had results that overall ranged between the highest and lowest pairs. A similar pattern was found in the results for the males. The Modern Koreans and Modern Japanese pair had the highest classification rate overall, with the whole cranium and facial region at a rate of 100% and the cranial vault in the mid-90% range. Again, the Edo Period and Modern Japanese pair performed the worst with correct classification rates in the high 80% to high 90% range. The remaining paired populations had results that were between the highest and lowest pairs. Overall, these initial discriminate group results indicate that in both sexes the four populations have sufficient between-group variation to be able to distinguish them even though there is some overlap in variation among them.

The results of the cross-validation showed that over 1,000 iterations of the analysis that the correct classification rates are much lower than the original discriminate group rates for all population pairs in both sexes. Compared to the pooled sexes above, different pairs of groups performed best and worst when the sexes were separated, and overall the pairs were inconsistent across the three cranial divisions (whole cranium, facial region, and cranial vault). For both sexes, the Modern Korean and Modern Japanese pair had the highest correct classification rate for the whole cranium and facial region, although this rate was much lower in females than in males. In this case, the Modern Japanese had higher rates than Modern Koreans, likely a reflection of the smaller sample size for the latter. In addition to this, in the females the Modern Japanese rates were in the upper-70% while the Modern Koreans were in the mid-50%. The fact that the Modern Korean females were classified correctly only slightly better than chance is

Table 47: DFA results for the comparison of Edo Period and Joseon Dynasty females.

		Discriminate Group		Cross Validated Group	
Analysis	**True Group**	EPF	JDF	EPF	JDF
Entire Cranium	EPF	100%	0%	67.1%	32.9%
	JDF	0%	100%	42.9%	57.1%
Facial Region	EPF	100%	0%	78.1%	21.9%
	JDF	0%	100%	50%	50%
Cranial Vault	EPF	93.3%	6.7%	80%	20%
	JDF	6.9%	93.1%	44.8%	55.2%

Table 48: DFA results for the comparison of Modern Japanese and Modern Korean females.

		Discriminate Group		Cross Validated Group	
Analysis	**True Group**	MJF	MKF	MJF	MKF
Entire Cranium	MJF	100%	0%	77.1%	22.9%
	MKF	0%	100%	44%	56%
Facial Region	MJF	100%	0%	78.6%	21.4%
	MKF	0%	100%	33.3%	66.7%
Cranial Vault	MJF	100%	0%	82.6%	17.4%
	MKF	0%	100%	23.1%	76.9%

Table 49: DFA results for the comparison of Joseon Dynasty and Modern Korean females.

		Discriminate Group		Cross Validated Group	
Analysis	**True Group**	JDF	MKF	JDF	MKF
Entire Cranium	JDF	90.5%	9.5%	76.2%	23.8%
	MKF	0%	100%	32%	68%
Facial Region	JDF	100%	0%	62.5%	37.5%
	MKF	0%	100%	41.7%	58.3%
Cranial Vault	JDF	100%	0%	51.7%	48.3%
	MKF	0%	100%	50%	50%

Table 50: DFA results for the comparison of Edo Period and Modern Japanese females.

		Discriminate Group		Cross Validated Group	
Analysis	**True Group**	EPF	MJF	EPF	MJF
Entire Cranium	EPF	100%	0%	71.2%	28.8%
	MJF	0%	100%	31.4%	68.6%
Facial Region	EPF	95.9%	4.1%	70%	30%
	MJF	4.3%	95.7%	27.1%	72.9%
Cranial Vault	EPF	89.3%	10.7%	76%	24%
	MJF	4.3%	95.7%	15.9%	84.1%

Table 51: DFA results for the comparison of Joseon Dynasty and Modern Japanese females.

		Discriminate Group		Cross Validated Group	
Analysis	True Group	JDF	MJF	JDF	MJF
Entire Cranium	JDF	100%	0%	66.7%	33.3%
	MJF	0%	100%	25.7%	74.3%
Facial Region	JDF	100%	0%	50%	50%
	MJF	0%	100%	31.4%	68.6%
Cranial Vault	JDF	100%	0%	79.3%	20.7%
	MJF	1.5%	98.5%	15.9%	84.1%

Table 52: DFA results for the comparison of Edo Period and Modern Korean females.

		Discriminate Group		Cross Validated Group	
Analysis	True Group	EPF	MKF	EPF	MKF
Entire Cranium	EPF	100%	0%	67.1%	32.9%
	MKF	0%	100%	48%	52%
Facial Region	EPF	100%	0%	79.5%	20.5%
	MKF	0%	100%	41.7%	58.3%
Cranial Vault	EPF	98.7%	1.3%	85.3%	14.7%
	MKF	3.8%	96.2%	34.6%	65.4%

Table 53: DFA results for the comparison of Edo Period and Joseon Dynasty males.

		Discriminate Group		Cross Validated Group	
Analysis	True Group	EPM	JDM	EPM	JDM
Entire Cranium	EPM	100%	0%	81.8%	18.2%
	JDM	0%	100%	34.3%	65.7%
Facial Region	EPM	99.2%	0.8%	83.5%	16.5%
	JDM	2.9%	97.1%	35.3%	64.7%
Cranial Vault	EPM	94.4%	5.6%	86.3%	13.7%
	JDM	6.4%	93.6%	29.8%	70.2%

Table 54: DFA results for the comparison of Modern Japanese and Modern Korean males.

		Discriminate Group		Cross Validated Group	
Analysis	True Group	MJM	MKM	MJM	MKM
Entire Cranium	MJM	100%	0%	95%	5%
	MKM	0%	100%	16.1%	83.9%
Facial Region	MJM	100%	0%	96.6%	3.4%
	MKM	0%	100%	3.1%	96.9%
Cranial Vault	MJM	96.6%	3.4%	89.9%	10.1%
	MKM	3.2%	96.8%	19%	81%

Table 55: DFA results for the comparison of Joseon Dynasty and Modern Korean males.

Analysis	True Group	Discriminate Group		Cross Validated Group	
		JDM	MKM	JDM	MKM
Entire Cranium	JDM	100%	0%	48.6%	51.4%
	MKM	0%	100%	37.1%	62.9%
Facial Region	JDM	100%	0%	61.8%	38.2%
	MKM	0%	100%	27.7%	72.3%
Cranial Vault	JDM	89.4%	10.6%	63.8%	36.2%
	MKM	6.3%	93.7%	38.1%	61.9%

Table 56: DFA results for the comparison of Edo Period and Modern Japanese males.

Analysis	True Group	Discriminate Group		Cross Validated Group	
		EPM	MJM	EPM	MJM
Entire Cranium	EPM	98.3%	1.7%	87.6%	12.4%
	MJM	0%	100%	14.3%	85.7%
Facial Region	EPM	90.1%	9.9%	78.5%	21.5%
	MJM	5%	95%	12.6%	87.4%
Cranial Vault	EPM	88.7%	11.3%	81.5%	18.5%
	MJM	8.4%	91.6%	17.6%	82.4%

Table 57: DFA results for the comparison of Joseon Dynasty and Modern Japanese males.

Analysis	True Group	Discriminate Group		Cross Validated Group	
		JDM	MJM	JDM	MJM
Entire Cranium	JDM	100%	0%	65.7%	34.3%
	MJM	0%	100%	16.8%	83.2%
Facial Region	JDM	97.1%	2.9%	73.5%	26.5%
	MJM	0%	100%	14.3%	85.7%
Cranial Vault	JDM	97.9%	2.1%	87.2%	12.8%
	MJM	3.4%	96.6%	10.1%	89.9%

Table 58: DFA results for the comparison of Edo Period and Modern Korean males.

Analysis	True Group	Discriminate Group		Cross Validated Group	
		EPM	MKM	EPM	MKM
Entire Cranium	EPM	100%	0%	90.9%	9.1%
	MKM	0%	100%	16.1%	83.9%
Facial Region	EPM	99.2%	0.8%	87.6%	12.4%
	MKM	3.1%	96.9%	16.9%	83.1%
Cranial Vault	EPM	97.6%	2.4%	89.5%	10.5%
	MKM	1.6%	98.4%	17.5%	82.5%

likely a reflection of the small sample size for females across the board as well as the smaller sample size of Koreans compared to Japanese. For the cranial vault, the Edo Period and Modern Japanese pair had the highest rates at low 80% in the females. In the males, the Joseon Dynasty and Modern Japanese pair were highest with correct classification rates in the upper 80%. The pair that performed the worst overall for the males was the Joseon Dynasty and Modern Korean pair with rates between 48% (Joseon Dynasty for the whole cranium) and 72% (Modern Korean in the facial region). In the females, the Edo Period and Modern Korean pair was lowest for the cranial vault while the Joseon Dynasty and Modern Korean pair was worst for the facial region and cranial vault with scores in the low 50% to upper 60% in all three analyses. The remaining pairs were between the lowest and highest correct classification rates.

FORDISC Results for Unknown Individuals

The 21 unknown individuals and one known Korean from Jikei University were run through the FORDISC 3.1 software to estimate their ancestry. As discussed in Chapter3, FORDISC 3.1 uses reference data bases with which it compares the unknown individual and forces it into a classification. When the 22 individuals were compared with the Forensic Database and Howells database, the majority were classified as belonging to one of the Asian populations, a few as Hispanic or Native American, and three as Black American (results not shown). However, only a couple of individuals had high posterior probabilities (pp) and the range of pp was between 0.18 and 0.97. With both of the reference databases lacking any Korean samples and having small Japanese and Asian samples, these results are not surprising. This highlights the need for proper reference samples when attempting to estimate ancestry or population affiliation of unknown individuals, especially when the context indicates or excludes certain groups, as is the case here.

When my database of Modern Koreans and Modern Japanese[6] was used as the reference database in FORDISC, the results were clearer. The pp ranged between 0.548 and 1.0 (Table 59). As we saw in the 3D and 2D analyses results, there is considerable overlap in the variation between Korean and Japanese populations. When an unknown individual plots in the

[6] Only the modern samples collected for this dissertation were used as it was known that the unknown individuals were of the modern period rather than the early modern period.

Table 59: FORDISC 3.1 results for the known Korean individual (JU190) and unknown individuals from Jikei University.

Sample ID	**Estimated Population and Sex**	**Posterior Probability**
JU190	Korean Male	0.793
JU191	Korean Male	0.957
JU192	Japanese Male	0.997
JU193	Korean Female	0.925
JU194	Japanese Female	0.599
JU195	Korean Male	0.619
JU196	Japanese Male	0.944
JU197	Japanese Female	1.000
JU198	Japanese Female	0.638
JU199	Japanese Female	0.632
JU200	Japanese Male	0.943
JU201	Korean Male	0.548
JU202	Korean Male	0.988
JU203	Korean Male	0.940
JU204	Japanese Female	1.000
JU205	Japanese Male	0.727
JU206	Japanese Male	0.981
JU207	Japanese Male	0.942
JU208	Japanese Female	0.999
JU209	Japanese Female	0.883
JU210	Japanese Male	0.974
JU211	Japanese Female	0.833

overlapping regions, the pp is lower in the estimation of ancestry as there is an increased chance of the individual being from either group. On the other hand, when an individual plots in an area of variation where the populations do not overlap, the pp is much higher due to the reduced probability of them originating from the other population. As examples, JU201 with the lowest pp (0.548), JU190 with a middle level pp (0.793), and JU197 with the highest pp (1.000) are depicted on scatter plots with the reference database from this dissertation research (Figure 40). As can be seen on these three plots, JU201 is located in the overlap between the Korean Males and Japanese Males, JU190 is in the Korean Male ellipsis but not outside of the full range of Japanese Males, and JU197 is within the Japanese Female ellipsis and outside of the range of the other groups.

Intra-observer Error and Inter-method Error Analysis

The results of the intra-observer error analysis shows that there was no error (p-value = <0.00) between the three measurement events for each crania. In fact, with only a few instances where the 3Skull calculated ILDs were 1mm different, the majority of ILDs were exactly the same among the measurement events for each sample. These results indicate two important aspects about data collection. First, it demonstrates that I as an observer can consistently identify landmarks and take measurements across events. Second, it also suggests that the microscribe used to take the landmark coordinates and 3Skull software were consistent in capturing the landmarks and calculating the ILDs.

As with the intra-observer error, the results of the inter-method error analysis shows that there is virtually no difference between the 3D calculated ILDs and the caliper measured ILDs (p-value = <0.00). There were very few cases in which measurements from each method differed, and when they did it was by 1mm. This suggests that the 3Skull algorithms that calculate the ILDs from the landmark coordinates are consistent and reliable when compared with caliper measurements. It also indicates that I am consistent in identifying the landmarks when measuring with calipers and with using the digitizer’s stylus.

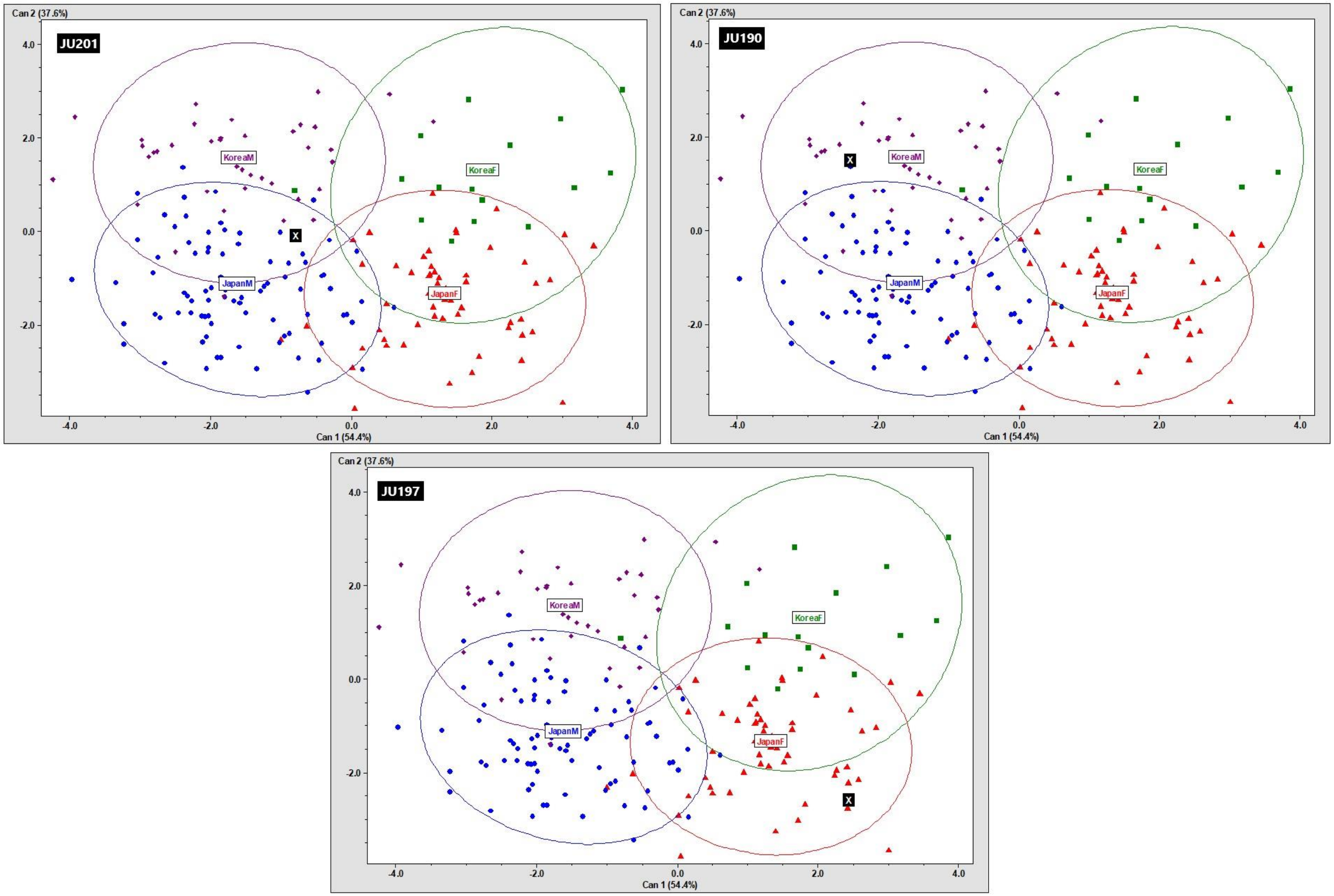

Figure 40: FORDISC 3.1 scatter plot results for JU201 (pp = 0.548), JU190 (pp = 0.793), and JU197 (pp = 1.000).

CHAPTER 5: DISCUSSION

The three primary questions that were posed at the beginning of this research are: 1) Can two closely related populations be differentiated using cranial morphometric methods, and what components of it best accomplish this, 2) Which morphometric methodology performs best in addressing the first question, and 3) Can gene flow be detected in the cranium. This chapter also includes a discussion of methodologies and applications for population estimation for the Korean and Japanese. The results of the various analyses presented in Chapter 4 help to answer these questions. They are discussed here in the context of the population histories of the groups and using interpretations under the framework of microevolution and the Neutral Theory.

Differentiating Two Closely Related Populations

One of the primary goals of this research was to determine whether cranial morphometric methods could be utilized to differentiate two closely related populations. What the results demonstrate is that there is enough between group variation to distinguish the Korean and Japanese populations on a statistical level, especially in the modern period where the two groups are most different as seen by the CVA results and the DFA cross-validation classification rates. Both the 2D craniometric and 3D GM analyses were able to differentiate between the two geographical populations. For the craniometrics results, the canonical coefficients demonstrated size differences in the nasal aperture, orbits, and in several of the indices, including the cranial index, length-height index, breadth-height index, mean basion-height index and the fronto-parietal index. The canonical structures, on the other hand, indicated that the cranial length (maximum and nasio-occipital), bregma angle, cranial index, length-height index, mean basion-height index and the fronto-parietal index best differentiate the two populations. As expected from their close relationship, there was quite a bit of overlap between the Koreans and Japanese on the CV histogram. The 3D GM analyses was able to more clearly distinguish the populations visually. The majority of the differences found in the CV coefficients are in the facial region, although the cranial vault also contributed. Due to the fact that the Koreans and Japanese are closely related, it was expected that the facial region would have more differences between them as it has been demonstrated that this area of the cranium is less congruent with genetic data (e.g.: Harvati and Weaver, 2006; Hubbe et al., 2009; Roseman and Harpending, 2004; Relethford, 2010; Smith, 2009). Conversely, the CV coefficients indicate that the cranial vault landmarks that contribute to the variation between them are on the temporal bone (porion and the roots of the zygomatic arch) which has generally been demonstrated to be highly correlated with neutral genetic data (Harvati and Weaver, 2006; Smith, 2009; von Cramon-Taubadel, 2009a, 2014).

One point to consider is that these interpretations for the 3D GM analyses are based on the canonical coefficients and not the canonical structures that are a preferred measure of the correlation between the canonical variables and the original variables (Pituch and Stevens, 2016). Therefore, it is possible that the canonical structures could present different results as was seen with the 2D craniometric analysis, and thus change the interpretation of which cranial components are contributing to the between-population variation. When comparing the 2D canonical structures and the PC coefficients, the measurements contributing to the observed variation are consistent with only a few measurements being different between the two statistical methods. It is therefore possible that the PC coefficients from the 3D GM analyses are suggestive of what the canonical structures might indicate for the landmarks contributing to the between-population variation. If this is the case, then the PC coefficients results indicate that the landmarks of stephanion, cheek height, frontotemporale, zygoorbitale, and zygomaxilare on the facial region, and jugale, glabella, eurion, and lambda on the cranial vault could be significant for the canonical structures. This would mean that in terms of the facial region versus the cranial vault, the former again has more landmarks that contribute to population variation, but that the latter also contributes to it. Again, we would also have a temporal bone landmark, jugale in this instance, that is significant.

Despite the lack of canonical structures, the PC and CV coefficients both lead to three possible explanations for the results in relation to the previously published cranial studies and the Neutral Theory: one, the temporal bone is less neutral than previous studies have concluded; two, that the Koreans and Japanese are less related to one another than is generally presumed given the multiple lines of evidence for their shared population histories; or three, that the results are an indication of the differential admixture that likely occurred between these two populations and others in East Asia during the time periods included in this research. Which of these is correct is difficult, if not impossible, to determine from this study alone. However, given the preponderance of evidence from previous studies for the neutrality of the temporal bone and the close relation of the Koreans and Japanese, I posit that the third option of differential admixture from other populations is the more likely scenario. This would not only account for the demonstrated genetic influence on the temporal bone but would also allow for genetic reasoning behind why this bone showed significant differences between two related populations. In addition to this, as Lieberman (2011) discusses, the cranium is an integrated series of modules that influence each other. Thus, the temporal bone, being connected to the face via the zygomatic arch, is likely both influencing and being influenced by the facial regions, especially in terms of the width at the roots of the zygomatic arches. This is supported by the results in which the whole cranium better differentiates the two geographic populations than when the two components are separated and analyzed separately. The historical circumstances and potential populations providing this outside admixture are discussed in more detail below in the next section.

In terms of the general morphological differences between the two groups identified in the 2D craniometric and 3D GM results, the Japanese have a tendency to be more dolichocephalic and have shorter (height) crania with slightly smaller facial features, especially cheek height, nasal length, and facial width, whereas the Koreans have more brachycephalic and taller crania with larger facial features. It is important to note that the cranial index changes are primarily due to the length of the crania as the width is similar in both groups. Similar results were seen between the populations when the sexes were separated. The facial features also exhibit some shape differences, particularly in the nose and cheeks. In addition to this some of the results indicated that the bregma angle and fronto-parietal index were larger in the Japanese crania while the mean basion-height index was greater for the Koreans. This means that the Japanese exhibit a larger angle between the cranial vault and facial region at bregma and have a larger ratio of the minimum frontal width to the maximum cranial breadth, whereas the Koreans have a larger ratio of cranial height to cranial length and breadth.

While the results for the four temporal-geographic populations did not demonstrate many significant differences between the time periods, there were some morphological differences that separated out the Joseon Dynasty or Edo Period. In particular, the Joseon Dynasty was shown to have a shorter posterior occipital length (occipital chord) in the craniometric analyses, and shape differences in the nose, eyes, facial width landmarks, and temporal bone width landmarks in the 3D GM results. The Edo Period also showed differences in the shape of the eye orbit in the 3D GM analyses, but no significant differences in the craniometrics. Additionally, while the results do not show a statistically significant difference between the temporal periods within each geographic location, they do show some overall secular trends in the size and shape of the cranium. In particular, the means of the cranial index and length-height index which were significant in differentiating the two geographic populations indicate that in both locations the groups are undergoing brachycephalization. This means that from the early modern to modern periods in both Koreans and Japanese the cranium is becoming wider and taller compared to the length. However, while brachycephalization is occurring in both, the Japanese remain statistically significantly more dolicocephalic and the Koreans more brachycephalic.

Methodological Approaches

Both the 2D craniometric and 3D GM methods attempt to analyze morphological variation between groups, but they use different approaches. Despite the differences, both methods were able to differentiate the two geographical populations, as discussed above, as well as between the four temporal-geographical populations. The results from the two methods provided us with different types of information. For the craniometric results, many of the measurements that consistently contributed to the cranial variation were indices, angles, and subtenses, with only a few facial dimensions, especially for the separation of the geographic populations. This indicates that the overall size of the cranium in multiple directions and the shape components are what best distinguishes the two groups. This corroborates the 3D GM results where the whole cranium performed better than either the facial region or cranial vault alone. The craniometric results also demonstrate the importance of the subtenses, angles, and indices when conducting the types of analyses used in this study as they provide information that standard caliper measurements do not capture. This highlights the advantages of using a digitizer and software to capture landmark coordinates and convert them into these types of measurements.

In this study, the results of the methodologies suggest that the 3D GM method performs better at distinguishing closely related populations. The CV scatterplots from the 3D method more visibly separates the groups and the DFA cross-validation more accurately reclassifies individuals into their original group. In addition to this, the versatility of the 3D landmark data to be segmented into smaller datasets allows for them to then be compared to test any number of hypotheses. Due to many of the craniometric measurements encompassing many parts of the cranium, it is not possible to dissect the data based on anatomical sections as can be done with the 3D data. For this dissertation, the landmark data was used to test whether certain components of the cranium segregated the populations better than others and what this implies about the microevolutionary processes that may have caused the observed variation. From the results of the various analyses, we learned that the whole cranium performs best when attempting to distinguish populations, probably due to the integrated modularity of the cranium. For the Korean and Japanese samples used here, we also learned that there are both genetic and non-genetic influences that contributed to the differences and similarities between them. These types of conclusions could not have been deduced from the 2D method with as much confidence as was done with the 3D GM method. Nonetheless, when the two methods are combined, as was done here, more can be learned about the nature of the variation between groups. While the 2D results do not perfectly align with the 3D results, and even contradict them in some cases, it does add a layer of complexity to the interpretations discussed. What the craniometric results add is that the 3D method does not capture all of the variation in size. This is in part due to the way in which Procrustes reduces the differences in size by scaling all samples to the same centroid size (Slice, 2007; Richtsmeier et al., 2002). Therefore, while the 3D GM method may perform better overall than the 2D method, the latter should not be discarded as it does provide valuable information, especially when combined with 3D methods.

When combined, the two methodologies indicate several interesting points about the between population variation in this dataset. First, the Joseon Dynasty and Edo Period are more similar in cranial shape than they are in size. Second, even though the Joseon Dynasty and Modern Koreans are more similar in shape than the Edo Period and Modern Japanese, both pairs have comparable level of size differences. And lastly, the two modern populations are distinguished from one another in both shape and size. Why the discrepancies and parallels exist between the two sets of results may be caused by the ways in which genetic and non-genetic factors interact in cranial form.

Results in the Context of Population History

The relationship between the four populations are partially revealed in the results of the various analyses conducted. Overall, we can see that all four groups are related. Within each geography the early modern and modern populations show continuity, but that this is stronger in the Koreans. The Joseon Dynasty and Edo period also appear to be more closely related to one another than the Modern Korean and Modern Japanese. The gene flow that occurred during the early modern period appears in the modern period through the Joseon Dynasty having similarities with the Modern Japanese. And finally, there is evidence of more outside gene flow coming into Japan during both temporal periods than in Korea. The summation of the relationships between the populations are illustrated in Figure 41. The historical evidence that supports these results are discussed in this section.

Given the close genetic ties and intertwined population histories, it is no surprise that the results show overlap in the cranial variation of the Korean and Japanese samples. The PCA results for both the 2D craniometric and the 3D GM methods show that the populations overlap to the point of being indistinguishable. However, the CVA results demonstrate that there is enough between group variation to distinguish them. This is in part due to the CVA method maximizing the between group differences, whereas PCA does not. So, while they are very similar in cranial form, these results suggest that there is enough variation to differentiate the two populations. As discussed above, the facial region and the temporal bone showed the most differences between the two groups in the 3D GM results. Of the possible reasons behind this, the hypothesis of differential admixture from other populations is the most likely scenario that explains the patterns observed from the sectioning of the cranium as well as from the overall combination of 2D and 3D results. When looking at the historical evidence, it becomes clear that there are many instances of greater admixture from other populations in Japan, including from other East Asian populations and Westerners (primarily the Dutch) (Baba, 2019; Caprio, 2009; Kerr, 2000; Leupp, 2003; Lewallen, 2016). The Koreans, on the other hand, has less evidence for instances of admixture due to their more seclusionary policies when dealing with interactions with foreigners. This is not to say that there was not gene flow between Koreans and other populations, but rather to say that it was at a much-reduced rate relative to Japan. This provides

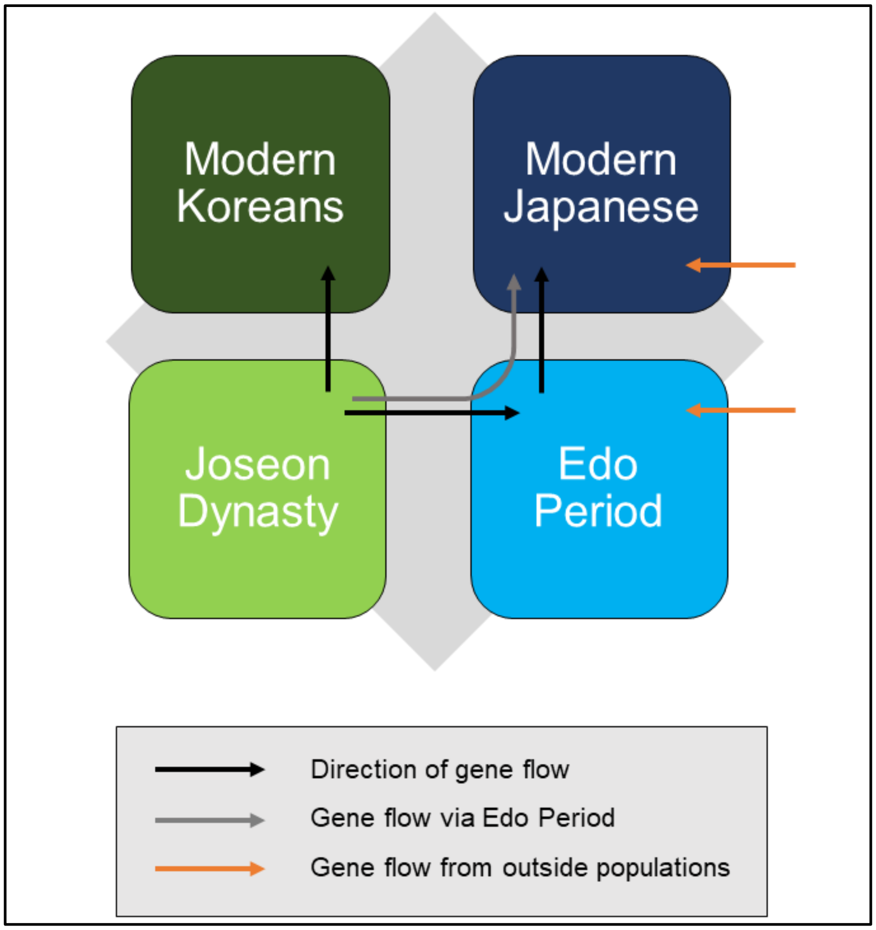

Figure 41: Diagram showing the continuity of the geographical populations and the gene flow between groups.

some explanation for the differentiation we see between the two geographical populations, especially in the early modern period.

It is clear from the analyses that the Joseon Dynasty and Modern Koreans have a strong ancestor-descendant relationship (continuity), more so than the Edo Period and Modern Japanese who show some divergence in the GM results (the craniometric results display similar levels of variation between the two pairs). This is especially seen in the 3D GM CVA scatterplots where we saw that the Joseon Dynasty and Modern Koreans overlapped in variation to the point of being indistinguishable from one another. Their continuity as a population through time is also seen in the DFA results where they have the highest miss-classification cross-validation rates of all the pairs of populations for the 3D GM analyses, and second highest rate in the 2D craniometric analyses. When considering the different regions of the cranium under the Neutral Theory, the cranial vault, which is generally more neutral and thus more reflective of genetic relationships, was only slightly better than chance at correctly classifying the Joseon Dynasty individuals. It was a little more accurate with the Modern Koreans, but overall such results are indicative of the continuity of the Korean populations from the early modern to modern periods, and thus of either similar patterns of outside gene flow in both periods or a general lack of a large amount of incoming gene flow from outside groups. However, this does not preclude genetic drift from having occurred, which it likely did given that there were some differences seen between the two groups and since historically speaking they were not entirely cut off from other populations as they had diplomatic and trade relations with several nations. The facial region performed much better at re-classifying the Korean individuals into their temporal groups than the whole cranium or cranial vault region. Since the facial region is thought to be an indicator of non-neutral factors more so than genetic factors, this indicates that there was some change in the population that occurred between the two time periods that had in some way to do with non-genetic influences.

As noted, the Japanese temporal populations showed more divergence than the Korean populations did in the 3D analyses, while the 2D analyses demonstrated that they were slightly more similar to one another than the two Korean groups. The difference in the results for the two methodologies suggests that cranial size does not change as much as cranial shape between the temporal Japanese groups. It is unclear why this might be in terms of genetic and non-genetic factors, but it does highlight that the Procrustes method is removing some of the size variation by scaling all samples to the same centroid while the craniometric method retains size.

For the 3D results, in the CVA scatterplots we saw that they were more separated from one another for the most part, especially when the sexes were separated, and the DFA cross-validation showed a higher percentage of correctly classified individuals than the Korean groups did. In addition to this, the facial region had the most overlap between the two Japanese groups in general for the CVA scatter plots and the lowest correct classification rates for the DFA results. Under the Neutral Theory and previous research on different factors influencing the different regions of the cranium, these results suggest that the primary change in cranial form for the Japanese temporal populations is the product of genetics more so than environmental factors. This means that the environmental circumstances in the Edo Period and Modern Japan are similar enough to cause a 21% misclassification rate in the facial cranium for both temporal populations. Conversely, this moderately low rate also signifies that there were enough changes in these types of factors to cause facial variation large enough to correctly classify individuals into their a-priori groups nearly 30% greater than chance alone, a similar rate to the Joseon Dynasty and Modern Koreans. This is likely due in part to the modernization that occurred in both localities as it has been illustrated that environmental changes as a result of industrialization and modernization are correlated with secular trends in cranial morphology (e.g.: Weisensee and Jantz, 2016).

The major difference between the Korean and Japanese temporal populations rests in the considerable difference of the cranial vault results. Whereas the two Korean groups were correctly classified only slightly better than chance, the Japanese populations saw much higher rates. The potential genetic factors involved in the higher variation in the cranial vault between the two Japanese groups include both genetic drift and incoming gene flow from outside populations. In terms of gene flow, there is the question of if there was more admixture occurring in one or the other temporal population, and/or if there was a change in the outside populations from which this was coming. While the former question is nearly impossible to determine with the cranial results, the latter is more feasible to answer with historical information. Just prior to and during the Edo Period, there are a couple of key pieces of evidence for outside gene flow into the Japanese population. First, as discussed in Chapter 2, during the Imjin War at the end of the Azuchi-Momoyama Period, between 60,000 and 100,000 Koreans were captured and brought to Japan to either be sold into the slave trade or be forced into labor in Japan (Hawley, 2005; Kang, 1997; Turnbull, 2002). Of the latter, many were of the artisan trades or were scribes (Hawley, 2005; Seth, 2016a; Turnbull, 2002). While 3,000 to 7,500 were repatriated at the beginning of the Edo Period, a good number remained in Japan (Hawley, 2005; Kang, 1997; Turnbull, 2002). It is generally believed that these Koreans were already absorbed into Japanese society (Hawley, 2005). These Koreans and their descendants would have contributed to the gene pool of the Japanese population, and thus could have affected the cranial variation observed to some small degree. The second piece of evidence comes from the Japanese relations with the foreign traders and missionaries that were coming to Japan during the Edo Period, including the Chinese and Dutch. There were often intermarriages of foreigners and Japanese, especially Japanese women to foreign men, on both temporary and more permanent basis (Leupp, 2003). This included both registered marriages and common law marriages to visitors living temporarily or permanently in Japan. In addition to this, there was also prostitution, which was rampant in ports, and government provided women caretakers for visiting high-ranking individuals (Hoare, 1994; Leupp, 2003). This was in part an effort to make foreigners feel welcome and to promote foreign trade. Toward the end of the Edo Period and after the Meiji Restoration, other Western nations also called to port in Japan and traded with them, such as Britain and the U.S. As with the Chinese and Dutch, these newcomers also sought out prostitutes and, for those that lived in the foreign districts, local wives (Hoare, 1994).

After the Meiji Restoration the Japanese government became more concerned with expanding its borders in an effort to put itself on level with Western powers as well as to provide a protective buffer to its core (van Dijk, 2015; Duus, 1995). Two of the first groups to be occupied or controlled formally by Japan were Ezo (1855; Ezo was renamed as Hokkaido in 1869) and the Ryukyu Kingdom (1872)[7], followed shortly after by the incorporation of Taiwan as a result of the Sino-Japanese War (1895) (Baba, 2019; Caprio, 2009; Kerr, 2000; Lewallen, 2016; Paine, 2003). It is well known that in the case of Hokkaido, Japan promoted the intermarriage of Japanese men to Ainu women as part of their assimilation program (Lewallen, 2016). The Ryukyuans, on the other hand, had low rates of intermarriage with Japanese, in part due to the segregation and discrimination they faced in main-island Japan (Kerr, 2000). Intermarriage between Taiwanese and Japanese during the colonial period was not discouraged, and in some cases was promoted by the government (Baba, 2019). The same was true for intermarriages between Koreans and Japanese (Baba, 2019). As discussed in Chapter 2, there were several documented instances of Japanese-Korean marriages both in Japan and Korea. By the early 1920s, family registry laws for foreign marriages (including those with Koreans, Taiwanese, and others) were established (Baba, 2019), signifying that there were enough cases of

[7] Both Ezo and the Ryukyu Kingdom had either been strongly influenced by Japan or held Japanese interest long prior to them being formally recognized as under Japanese control by other powers (e.g., Kerr, 2000; Turnbull, 2009; Walker, 2006).

this to warrant a systematic way of dealing with registries. Thus, while intermarriage with foreigners occurred during the Edo Period, the colonization in the modern period allowed for more instances of admixture with more populations. It is therefore hypothesized that this is likely one of the main reasons for the differences between the Edo Period and Modern Japanese in cranial form that are documented by the results.

When looking at the results for the contemporary populations, it is clear that the Modern Koreans and Modern Japanese are more distinct from one another than the Edo Period and Joseon Dynasty are in cranial form. Interestingly, they have about the same level of size variation between the contemporary pairs in the craniometric results. The differences in cranial shape indicates that there was more gene flow between the two early modern period populations than there was in the modern period. This seems counter-intuitive since during the Joseon Dynasty the Korean government restricted the ability for foreigners to enter their kingdom and over time reduced the number of open ports to the Japanese (Kang, 1997; Lewis, 2003; Seth, 2016a), whereas in the modern period there was significant movement of people between the Korean peninsula and the Japanese archipelago due to the Japanese annexing and occupying Korea (Kawashima, 2009; Morris-Suzuki, 2006; Seth, 2016b; Uchida, 2011; Weiner, 1994). There are several possible explanations for the results in light of the historical evidence. One, the immigrants in each nation during the modern period contributed little to the population of the host nation due their making up a relatively small percentage of the total national population, and thus being undetectable in the cranium (i.e., their numbers, while seemingly large, was not large enough to influence the genetic and phenotypic makeup of the local population). Alternatively, the immigrants did not intermarry or interbreed with the native population on a large enough scale to impact the genotype and phenotype of the host nation, despite there being recorded cases of this occurring. A third possibility is that such evidence of interactions did not make it into my population samples due to the localized nature of the dataset (i.e., my samples are from four regions of the two nations and may not contain a representative sample of the variation of the entire national population). The fourth possible explanation is that there was more admixture between Koreans and Japanese during the early modern period despite the Joseon Dynasty's efforts in curtailing the contact between foreigners and their own populace. And finally, it is also possible that the early modern populations are more similar due to them being temporally closer to the previous periods in which more admixture occurred while that the modern populations are less similar due to their being more temporally removed from those instances (i.e., there is increased divergence between the Koreans and Japanese through time as they admixed less). This last hypothesis is related to the differences observed between the Edo Period and Modern Japanese and the lack thereof between the Joseon Dynasty and Modern Koreans as discussed above. All of these hypotheses present different aspects of the historical record and/or microevolutionary theory that could explain the results of this study, and it is probably some combination of them that contributes to the patterns of cranial variation described here.

Despite the divergence of the modern populations, the gene flow that occurred between the Edo Period and Joseon Dynasty populations does show up in the results. In the CVA graphs for the 2D craniometric analysis, the Joseon Dynasty's variation is spread widely among the other three populations and is somewhat in the middle between the Modern Koreans and the Japanese groups on CV1. When analyzing the 3D GM CVA scatterplots, it is interesting to note that for the facial region the Joseon Dynasty overlaps with and is situated in the middle of the other three groups, while the two modern populations have practically no overlap in variation. Conversely, for the cranial vault it is the Edo Period that overlaps with and is in the middle of the other populations. The DFA results show that the Joseon Dynasty misclassify as Edo Period at a higher rate than the other way around. In addition to this, the DFA results also show that both the Joseon Dynasty and Edo Period misclassify as Modern Japanese, although the Edo Period generally have higher rates of misclassification. Together, these statistics illustrate a few important points about these populations. One, given that the facial region is more correlated with environmental factors, the results suggest that the Joseon Dynasty environment was similar to the other three populations since they have facial variation in common with all the groups. On the other hand, the two modern populations have a less similar environment as they overlap very little. During the annexed period, while Japan was attempting to modernize Korea, there was not a lot of change in the economy of the local people as many remained farmers while the Japanese settlers held primarily non-agrarian positions (Duus, 1995; Seth, 2016b; Uchida, 2011; Weiner, 1994). Thus, while some aspects of the environment, such as electricity, rail lines, and schools changed, Korea continued to be primarily agricultural, which is not surprising as Japan sought to use the Peninsula as their rice fields (Duus, 1995; Seth, 2016b; Uchida, 2011). The Joseon

Dynasty would have had a lot of environmental similarities with the first 35 years of the modern period in Korea, as well as some commonalities with the Edo Period due to the time period and level of modernization in the two nations. It is perhaps due to the Annexation Period that the Modern Koreans and Modern Japanese are more dissimilar in this study as the majority of both the modern samples date to this earlier part of the period. However, differential gene flow and genetic drift cannot be ruled out as explanations for these results since they do affect facial variation even if the environmental factors are more correlated. Therefore, it also entirely possible that these results are a reflection of the shared genetics between the Joseon Dynasty and the other three populations as well as the divergence of the two modern groups.

The second point is that there was gene flow from the Joseon Dynasty into the Edo Period, but very little the other way around. This is seen by the DFA cross-validation results where more Joseon Dynasty misclassifying as Edo Period and as Modern Japanese than the Edo Period does into the Joseon Dynasty or Modern Koreans. This is seen for both the 2D and 3D analyses. This was a somewhat unexpected result given the historical evidence for gene flow from the Edo Period into the Joseon Dynasty via the *waegwan* and little evidence for it the other way with the exception of the Koreans who stayed in Japan after the Imjin War. It is unclear as to why there would be more gene flow from Korea into Japan during the early modern period. It is possible that the admixture from the *waegwan* was not captured in my sample as the *waegwan* were located in southeastern ports, whereas only a small portion of my sample Joseon Dynasty sample originates from this region of Korea. These results, however, do indicate that gene flow from the *waegwan* did not extend much into the larger population as a result of the constrained geographical nature.

The final set of results to discuss here is the fact that both of the early modern populations contributed to the Modern Japanese at similar rates; the Edo Period show only slightly higher rates of misclassification into the Modern Japanese in some of the DFA results. This contrasts with the Modern Koreans where the Joseon Dynasty was the primary contributor. The reason for these results is likely due to the gene flow from the Joseon Dynasty into the Edo Period, which is then showing up as similarities between them and the Modern Japanese. Interestingly though, Modern Koreans, who are very similar to the Joseon Dynasty through descendancy, are significantly dissimilar to the Modern Japanese. While I cannot fully explain why this is the case, there are two primary reasons for this. First, as discussed above, both the Edo Period and the Modern Japanese appear to have received more gene flow from outside populations than their Korean contemporaries. This would have the effect of the Modern Japanese being more distinct from both of the Korean groups. Second, it is possible that the samples included in this study do not capture the full range of variation in either population, and thus the variation that was collected happens to be dissimilar in the modern period samples.

When the sexes were separated for the analyses, the results were overall similar to when they were pooled. As was seen above, the Joseon Dynasty and Modern Koreans show strong continuity, there was gene flow from the Joseon Dynasty into the Edo Period, the continuity between the Edo Period and Modern Japanese was moderate, and the gene flow between the two early modern periods shows up in the Modern Japanese. There were two main differences between the sexes in the results. First, the CVA scatterplots indicate that it was the males that were moving and/or contributing to the admixture more than the females. This is illustrated in the 3D GM results by the two temporal groups for Korean females being nearly identical while the males show greater variation between the two periods. In particular, the Joseon Dynasty males overlap with both the Modern Korean males and the Edo Period males. Interestingly, the Edo Period and Modern Japanese females overlap very little in comparison to their Korean counterparts. This combined with the results for the males (again the Japanese groups overlap to a lesser extent than do the Korean groups) supports there being more outside gene flow into the Japanese populations. The craniometric results show that the temporal groups for both populations have similar size variation in both females and males. The main differences are between the geographical populations. Second, in both methodologies, the DFA correct classification rates for the females were much lower than for the males in all pairings. This is likely primarily due to the sample size for females being much smaller than for the males. This sex bias means that there is less variation captured for the females, hence a higher uncertainty when cross-validating. While it might be expected that there would be better results for the sexes separated due to sexual dimorphism in cranial morphology, this is not the case here. The males also had lower correct classification rates than when the sexes were pooled. This is also probably due to the inherently smaller sample sizes for the four groups in each sex. The sex bias in the samples potentially affects the interpretation of the results for the sex-pooled analyses. However, how large this affect is cannot be determined from the results of this study due to the fact that female and male analyses overall showed the same patterns of variation and population relationships as was observed for when the sexes were pooled.

One final confounding variable to note is that the Joseon Dynasty and Edo Period encompassed a much longer time span, 518 years and 271 year respectively, than the modern period does at around 120 years. In this study, the individuals from the Joseon Dynasty and Edo Period date to later than the 1600s, with the majority post-1700, according to the collections' information (see Chapter 3). In addition to this, the modern period samples primarily date to the Japanese colonial period as most of the birth years date to that time or shortly before or after, and thus only a small proportion of the modern individuals have birth years that date to post-1945 for the Japanese collection and post-1950 for the Korean collection. While this shortens the time depth for the early-modern periods, it is still more than double the time span of the modern period. As Lieberman (2011) explains, the differences observed in the between population variation arose mostly within the last 10,000 years in the evolution of humans; meaning that compared to the millions of years of hominin evolution, the differences observed in modern groups developed relatively quickly. Secular change studies on modern populations are demonstrating this with results that show cranial morphological changes occurring over the past 150 years in other populations (e.g.: Weisensee and Jantz, 2016). With the early-modern periods being longer than the modern period, this then suggests that there would be differences in the variation captured in the data based on this concept of fast microevolution and time depth. This could in part explain some of the results, including the greater overlap between the early modern populations and divergence in the modern period.

Ancestry Estimation of Unknown Individuals

In order to test the ability to estimate the ancestry of unknown individuals presumed to be Japanese, FORDISC 3.1 was utilized with the reference databased collected in this study. The recorded Korean individual form the Jikei University collection was tested first, and he was estimated to be Korean. As the life history of this individual is unknown, it is difficult to say how he ended up in Japan and in the Jikei University's anatomy collection. There are various scenarios for this, some of which are: 1) he grew up in Korea and moved to Japan after growth and development had completed, 2) he was born in Korea but brought to Japan as a child, 3) he was born in Japan to Korean parents. Knowing which of these is the correct version has important implications for how the results can be interpreted. Each of these would have impacted his cranial form through environmental factors differently in relation to other Koreans, assuming that he is of Korean descent and thus having the same genetic variation as that population. If scenario one occurred, then it would be no surprise that his cranium was most similar to other Koreans having grown up in the same environment. In scenario two, two somewhat different environments might have impacted his phenotype depending on where he grew up in the two nations and how old he was when he moved. In the third option, he would have grown and developed solely in Japan, which could have caused him to have some phenotypic differences from his Korean parents. The results show that his cranial morphology is situated in the Korean ellipsis, but within close proximity to some of the Japanese, hence the 0.79 pp. With these results, it is practically impossible to determine which of the three scenarios presented above is likely correct.

For the remaining 21 unknown individuals, there is no documentation indicating their ancestry, although they are presumed to be Japanese by the collection. Of these, fifteen were estimated as Japanese and six as Korean. Of the fifteen identified as Japanese by FORDISC 3.1, eleven have pps over 0.80 and thus strongly indicating that they are Japanese. One individual had a pp of 0.72, suggesting that they are most likely Japanese. The remaining three had pps of between 0.59 and 0.63. All three of them were estimated as being female by FORDISC 3.1, but one of them was estimated to be male by myself and was estimated as male in the collection records. Based on the low pps for these three individuals, it is just as possible for them to not be Japanese as it is for them to be Japanese. For the six that were identified as Korean, four have high pps of greater than 0.9, strongly indicating that they are either Korean or of recent Korean ancestry. The other two were situated in the middle of the Koreans and Japanese with pps between 0.5 and 0.6, thus they could be of either population. And so, while the Jikei University anatomy collection assumes that the unknown individuals are Japanese, it cannot be conclusively supported by the FORDISC 3.1 results for all of the unknown individuals included in this study. However, it must be considered that the composition of the reference database is not adequate enough to capture the range of variation in each population, thus skewing the results presented here. Nonetheless, the results from the CVA, DFA, and FORDISC 3.1 do illustrate that the Korean and Japanese populations can be differentiated using cranial morphological methods and that their ancestry can be estimated using FORDISC 3.1 software.

CHAPTER 6: CONCLUSION

This dissertation research set out to explore whether two closely related populations could be differentiated using cranial morphometrics and if gene flow could be detected. To answer these questions two different methodological approaches and cranial data from Korean and Japanese skeletal collections were used. The cranium was selected as the focus of this study due to its form being the result of primarily neutral factors, but also to some extent environmental and developmental factors (e.g.: Boas, 1912; Lewontin, 1972; Lieberman, 2011; Relethford, 1994; Roseman and Weaver, 2004; von Cramon-Taubadel, 2014). Previous research has demonstrated that cranial variation co-varies with genetic data as well as geographic distance between populations (e.g.: Relethford, 1994, 2010; Smith, 2009; von Cramon-Taubadel, 2014). Therefore, two closely related populations who are in close proximity should theoretically be very similar in their cranial variation. To test this hypothesis, the Korean and Japanese populations were chosen as the subjects for this research due to their demonstrated close relationship by multiple lines of evidence, including genetics, archaeology, and history (e.g.: Barnes, 2000, 2015; Hammer et al., 2006; Horai et al., 1996; Hudson, 1999; Kim et al., 2000; Lewis, 2003; Morris-Suzuki, 2006; Nakagome et al., 2015; Uchida, 2011). Based on a review of the historical events during the early modern and modern period, it was expected that 1) the two geographical populations would be similar to one another during both time periods, 2) during the early modern period there would be evidence for more gene flow from Japan into Korea, and 3) that the two modern groups would be closer together than those of the early modern period.

The two morphometric methods utilized were the traditional 2D craniometric and 3D GM Procrustes methods, both of which have been well-established in biological anthropology studies. Craniometric and 3D cranial landmark data was collected from Korean and Japanese crania dating to the early modern (Joseon Dynasty and Edo Period respectively) and modern periods. These samples were housed at several skeletal collections in Korea and Japan (Catholic University of Korea, Yonsei University School of Dentistry, Seoul National University, Hanyang University Museum, Dong-A University, Jikei University, and the National Museum of Nature and Science). For the 3D GM method, the cranial analysis was conducted for three partitions of the cranium: the whole cranium, the facial region, and the cranial vault. The goal was to compare how each component performed in distinguishing the populations in order to test hypotheses about the Neutral Theory. Specifically, this was a validation test for the previous research that has indicated that the facial region is more correlated with non-genetic factors while the cranial vault minus the occipital bone is more correlated with genetic data (e.g.: Harvati and Weaver, 2006; Hubbe et al., 2009; Relethford, 2010; Smith, 2009; von Cramon-Taubadel, 2009).

Overall, the results of the analyses demonstrated that yes, two closely related populations can be differentiated using cranial morphometrics and that evidence of gene flow is detectable in the morphology of the cranium. In terms of methodological approaches, it appears that the 3D GM method better distinguished the two groups than did the craniometric analyses. This suggests that while size does contribute to the differences between the Koreans and Japanese, there is more shape variation between them. Nonetheless, when the unknown individuals were analyzed through FORDISC 3.1 using the dataset collected in this study, the ancestry estimation for 15 of the 21 crania had high pp values. Since FORDISC 3.1 uses craniometric data for its analysis, it is clear that the size differences are enough to be able to use it for ancestry estimation.

For the cranial variation between the populations, we saw that the Japanese have more dolichocephalic and shorter crania with smaller facial features where the Koreans have more brachycephalic and taller crania with larger facial features. In the 3D GM results, the facial region contributed most to the variation between the two populations, but that the temporal bone also contributed. The latter was unexpected due to researchers having found this bone to be most congruent with genetic data (e.g.: Harvati and Weaver, 2006; Hubbe et al., 2009; Smith, 2009; von Cramon-Taubadel, 2009, 2014). Given this and the historical evidence, it is hypothesized that this means there was differential admixture with other populations not included in this study.

This outside gene flow was also indicated when the four temporal-geographic populations were compared. The results of this comparison provided evidence for a more structured hypothesis. With the Joseon Dynasty and Modern Koreans showing more continuity in cranial variation than the Edo Period and Modern Japanese and with the two modern groups showing divergence, it is likely that the majority of this outside gene flow was going into the Japanese populations. From the historical evidence, it is hypothesized here that the probable contributing populations to the admixture in the Japanese are the Chinese and Dutch during the Edo Period and the Ainu, Ryukyuans, Taiwanese, and Westerners during the modern period (Baba, 2019; Caprio, 2009; Hoare, 1994; Kerr, 2000; Leupp, 2003; Lewallen, 2016; Paine, 2003).

In terms of gene flow between the Koreans and Japanese, the results show that the Joseon Dynasty and Edo Period are closer in variation than the two modern populations, indicating that there was more admixture during the early modern than the modern period. The DFA classification rates misclassify the Joseon Dynasty individuals into the Edo Period more often than vice versa. In addition to this, the Joseon Dynasty also misclassify as Modern Japanese at a much higher rate than the Edo Period does as Modern Korean. Such results clearly demonstrate that the gene flow was more unidirectional during the early modern period, and that the direction was from Korea to Japan. This is the opposite of what was expected from the historical literature. It is possible that the expected gene flow was not captured in the dataset used in this study. Beyond this, it is unclear why this direction of admixture is the case here.

The disparity between the results and the expectation that the two modern populations would show more similarities than the early modern groups is probably accounted for by some combination of possible explanations. First, the immigrants during the modern period did not contribute to the local population as much as expected, either because the percentage of admixed groups was relatively small compared to the total national population size or due to low levels of intermarriage. It is also possible that the full breadth of variation for each group was not captured in the dataset collected for this dissertation research, and thus missed evidence for the admixture. Another explanation is that there was more gene flow between the early modern populations than expected despite the Joseon Dynasty's attempts to curtail contact with foreigners. Lastly, it could also be that these two geographical populations were diverging through time. If that is the case, then the seeming greater degree of admixture between the early modern groups is actually due to shared common ancestry, while the more recent groups were more separate How much each of these contributed to the variation documented in this dissertation is difficult to determine, but it is likely that some combination of these factors explain the results.

The results for when the sexes were separated demonstrated that while the observed variation in the pooled sex analyses were the same, the men showed greater variation and more similarities with the other male groups than the females did. This suggests that the men were moving and/or providing more gene flow into the other population more than the females.

However, with the female sample size being smaller than the male's, it is possible that the sample size discrepancy between the sexes is contributing to the patterns seen in the results.

As with any research such as this that is inherently retrospective, there are confounding variables that cannot be controlled. These include the sex bias in the dataset due to differential inclusion of males over females in the skeletal collections. In the case of the archaeological assemblages, this is primarily due to chance differential preservation of skeletal remains. For the anatomy collections, the imbalance in the sex ratio likely represents a trend of males donating their bodies more often than females. Another sample composition factor is whether or not the individuals in the South Korean collections are from North Korea. As far as I know, there are no North Koreans in the collections, although this is a potential likelihood given the historical movement of people across the peninsula after WWII and during the Korean War. An additional confounding variable is the difference in length of time for each of the temporal periods. This could affect the amount of variation in each period as well as the differences between them, and thus the results in this study. Finally, the gene flow from other populations not included in this research is another confounding variable that cannot be fully accounted for in a narrow project such as this one.

In conclusion, this dissertation research answered the primary questions it aimed to address, but also brought up some interesting issues that need to be further researched. The Koreans and Japanese can be distinguished with cranial morphometric methods and there is evidence for gene flow in the crania, albeit not exactly as we thought it would occur. In order to address the potential problems with the sample composition and its representation of the population variation, more data collection will need to be conducted. This is especially the case for the sex bias observed in which more females need to be included. To test the hypothesis that the admixture in the *waegwan* was a localized occurrence, Joseon Dynasty samples from the geographical areas in which they were located will need to be collected. In relation to the two populations used in this project, questions about outside gene flow into these groups was raised when the results of the analyses were not what was expected given the known population history between the two. For example, which other populations contributed to the Korean and Japanese early modern and modern groups? How different was the rate of admixture between the time periods in a single population and between contemporary populations? Future research that adds data from other Asian groups, including the Chinese, Taiwanese, Ainu, and Ryukyuans who have historical evidence to indicate admixture with the Koreans and/or Japanese will help to address these questions.

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APPENDIX: PCA AND CVA TABLES

2D Craniometric PCA Tables

Table 60: PCA coefficients for the analysis comparing the pooled Korean and pooled Japanese populations (measurements with the highest loadings [≥ |0.3|]are bolded; only the first five PCs are presented).

Landmark	PC1 Coefficients	PC2 Coefficients	PC3 Coefficients	PC4 Coefficients	PC5 Coefficients
GOL	0.222603	-.188857	-.008983	0.108597	-.149179
NOL	0.220436	-.199289	-.010428	0.079778	-.158357
BNL	0.229430	-.036728	0.168449	0.022488	-.096525
BBH	0.176857	0.233567	0.237352	0.084402	-.084975
XCB	0.127872	0.279214	-.261512	-.037805	-.032956
XFB	0.162316	0.186546	-.162171	-.034563	0.095148
WFB	0.204209	-.003581	-.033410	-.051539	0.209915
AUB	0.200702	0.199002	-.141178	0.027755	-.049326
ASB	0.154693	0.070750	-.124283	0.076798	-.134353
NLH	0.179076	0.102354	0.000992	-.190026	-.162605
JUB	0.249925	0.074233	-.059912	0.106513	0.042714
NLB	0.125554	-.031092	-.061915	0.194774	0.272450
OBH	0.056045	0.112439	-.045090	**-.302727**	0.057026
OBB	0.213477	-.008522	-.007876	-.128777	-.000148
DKB	0.148827	-.019057	-.003192	0.080505	**0.344339**
FMB	0.261376	-.004371	-.018642	-.008704	0.154864
NAS	0.159304	-.132819	0.155331	-.260283	0.039749
EKB	0.248572	-.014378	-.029744	0.038293	0.196662
DKS	0.117662	-.048236	0.079293	**-.419962**	0.045350
IML	0.153985	0.017358	-.018883	0.122919	-.151137
XML	0.189874	0.025597	-.012696	0.125590	-.242965
WMH	0.148130	0.058133	-.013058	0.093250	-.181074
STB	0.100962	0.185659	-.147554	-.058345	0.150313
FRC	0.169925	0.090867	-.048345	0.002560	-.196968
PAC	0.144084	-.066351	0.102440	0.162694	0.029646
OCC	0.098202	0.045201	0.018412	0.061168	-.138262
FOL	0.132047	0.027568	0.023348	0.008019	-.125433
FOB	0.104643	0.164903	0.055129	-.012918	-.080601
MOW	0.092627	-.006712	-.021419	-.044207	**0.330229**
UFBR	0.264519	0.018889	-.036306	0.018281	0.145519
NBA	-.057156	0.286598	0.269040	0.106640	0.113366
BBA	-.009610	-.111170	**-.322309**	-.081172	-.135098
BRA	0.092367	-.269542	0.004943	-.044375	-.008380
NFA	-.089691	0.145942	-.183229	0.291153	0.012717

Landmark	PC1 Coefficients	PC2 Coefficients	PC3 Coefficients	PC4 Coefficients	PC5 Coefficients
DKA	-.074284	0.050796	-.091178	**0.429438**	-.050910
CI	-.080889	**0.346009**	-.181156	-.111674	0.093915
LHI	-.045798	**0.370282**	0.209704	-.024756	0.061098
BHI	0.052924	-.030271	**0.468041**	0.113981	-.052959
MBHI	-.006905	0.252857	**0.395842**	0.041132	0.016796
FPI	0.098173	-.210965	0.163861	-.023357	0.222420
NI	-.024165	-.098716	-.055246	**0.302333**	**0.346784**
OI	-.116473	0.110822	-.033525	-.178754	0.055055

Table 61: PCA coefficients for the analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese (measurements with the highest loadings [≥ |0.3|] are bolded; only the first five PCs are presented).

Landmark	PC1 Coefficients	PC2 Coefficients	PC3 Coefficients	PC4 Coefficients	PC5 Coefficients
GOL	0.223323	-.188276	-.010232	0.106946	-.153122
NOL	0.220614	-.199654	-.010665	0.078297	-.162736
BNL	0.230300	-.036150	0.169645	0.021508	-.093450
BBH	0.177415	0.235592	0.233341	0.085687	-.088863
XCB	0.128804	0.277324	-.262650	-.042309	-.034027
XFB	0.161580	0.186395	-.164452	-.034465	0.094166
WFB	0.203750	-.002391	-.032893	-.050675	0.213107
AUB	0.201783	0.197758	-.142461	0.023311	-.046646
ASB	0.154548	0.070698	-.128590	0.072594	-.136260
NLH	0.178777	0.100709	0.005157	-.191285	-.160184
JUB	0.250473	0.073965	-.061597	0.104700	0.045308
NLB	0.124705	-.035380	-.061461	0.196985	0.267049
OBH	0.054674	0.111232	-.045304	**-.301696**	0.057888
OBB	0.213423	-.009160	-.008579	-.131709	0.004675
DKB	0.148559	-.019953	-.004340	0.080964	**0.342354**
FMB	0.261681	-.004615	-.018854	-.010004	0.157872
NAS	0.157411	-.132338	0.163395	-.258586	0.041693
EKB	0.248857	-.015829	-.031569	0.036637	0.199229
DKS	0.114805	-.048072	0.082514	**-.421432**	0.046941
IML	0.153681	0.015829	-.019294	0.120387	-.149328
XML	0.191001	0.025113	-.011119	0.120776	-.237980
WMH	0.148904	0.058060	-.012023	0.090576	-.179796
STB	0.101219	0.183879	-.147458	-.059223	0.149101
FRC	0.169301	0.089453	-.050110	0.001537	-.208011
PAC	0.144156	-.061485	0.098953	0.166565	0.025901
OCC	0.102306	0.040177	0.013440	0.054848	-.142851
FOL	0.130438	0.027494	0.026853	0.012833	-.125405
FOB	0.105625	0.164498	0.057146	-.011918	-.076494

Landmark	PC1 Coefficients	PC2 Coefficients	PC3 Coefficients	PC4 Coefficients	PC5 Coefficients
MOW	0.090667	-.007690	-.025131	-.041575	**0.325517**
UFBR	0.264834	0.018012	-.037151	0.017074	0.148237
NBA	-.056318	0.290028	0.262955	0.109988	0.114798
BBA	-.011242	-.115012	**-.320198**	-.083643	-.144227
BRA	0.093515	-.270016	0.010509	-.046623	0.000595
NFA	-.086866	0.144919	-.191888	0.288060	0.011903
DKA	-.070657	0.050438	-.094616	**0.429842**	-.051215
CI	-.081118	**0.345011**	-.181217	-.114041	0.096715
LHI	-.045738	**0.371353**	0.207466	-.022115	0.061218
BHI	0.053256	-.026149	**0.466822**	0.119764	-.056081
MBHI	-.006876	0.256114	**0.392566**	0.045801	0.015386
FPI	0.097138	-.208303	0.165106	-.019159	0.226274
NI	-.024678	-.100457	-.057637	**0.303434**	**0.338527**
OI	-.117339	0.110216	-.033080	-.175551	0.052116

2D Craniometric CVA Tables

Table 62: CVA coefficients for the analysis comparing the pooled Korean and pooled Japanese populations (measurements with the highest loadings are bolded).

Landmark	CV1 Coefficients
GOL	0.287542383
NOL	-0.178893712
BNL	-0.303317789
BBH	-0.351815487
XCB	0.172587346
XFB	-0.053691999
WFB	0.244593526
AUB	0.025480420
ASB	0.025384175
NLH	0.342619830
JUB	0.033276385
NLB	**-0.416187733**
OBH	**1.012580287**
OBB	**-0.983034342**
DKB	0.103480144
FMB	-0.085556089
NAS	**0.570010140**
EKB	-0.022767426
DKS	0.090907864
IML	0.020403741
XML	0.040790494
WMH	0.057323489
STB	0.034769765

Landmark	CV1 Coefficients
FRC	-0.270458765
PAC	0.112626621
OCC	0.099905243
FOL	0.031530745
FOB	0.070395600
MOW	0.052820012
UFBR	-0.039632150
NBA	**-0.569665021**
BBA	0.235320902
BRA	0.209294582
NFA	0.267952319
DKA	-0.002013851
CI	**-1.092348735**
LHI	**3.357871387**
BHI	**0.580276341**
MBHI	**-9.239200014**
FPI	**-0.429439867**
NI	0.221591773
OI	-0.396351895

Table 63: CVA structure for the analysis comparing the pooled Korean and pooled Japanese populations (measurements with the highest loadings [≥ |0.4|] are bolded).

Landmark	CV1 Structure
GOL	**-0.473148**
NOL	**-0.482593**
BNL	-0.168467
BBH	0.303103
XCB	0.353813
XFB	0.098775
WFB	-0.213944
AUB	0.324046
ASB	0.087915
NLH	0.242349
JUB	0.113638
NLB	0.084017
OBH	0.187432
OBB	-0.108323
DKB	0.107180
FMB	-0.082675
NAS	-0.166612
EKB	-0.055062
DKS	0.022603
IML	0.095918
XML	0.003882

Landmark	CV1 Structure
WMH	0.220018
STB	0.157071
FRC	0.209245
PAC	-0.152990
OCC	-0.019126
FOL	-0.061541
FOB	0.296845
MOW	0.175747
UFBR	-0.031255
NBA	0.370642
BBA	-0.009818
BRA	**-0.506752**
NFA	0.163009
DKA	-0.056833
CI	**0.629851**
LHI	**0.695719**
BHI	-0.029494
MBHI	**0.484174**
FPI	**-0.462510**
NI	-0.097711
OI	0.254284

Table 64: CVA coefficients for the analysis comparing the pooled Korean and pooled Japanese populations with the sexes separated (measurements with the highest loadings are bolded).

Landmark	CV1 Coefficients	CV2 Coefficients	CV3 Coefficients
GOL	0.22922703	0.04239184	**2.47236154**
NOL	-0.08221007	-0.15673837	0.01524768
BNL	-0.02221580	-0.28921533	0.02148331
BBH	-0.50211029	-0.19143469	-0.94728063
XCB	0.00466425	0.32109553	**-2.08263247**
XFB	0.10697378	-0.06053936	-0.07580566
WFB	0.43468268	0.11458008	0.29905246
AUB	-0.01361074	0.03140949	-0.04625087
ASB	0.01890273	0.02174554	0.02932563
NLH	0.30922106	0.40019659	-0.73342424
JUB	0.11994734	0.02869230	-0.09532951
NLB	-0.41777689	-0.56175988	**1.48693616**
OBH	0.04725925	**1.11893128**	**-1.16715488**
OBB	-0.28947663	**-1.05287104**	**1.16460129**
DKB	-0.08016307	0.10546847	-0.13313604
FMB	0.18630230	-0.10423426	-0.09279543
NAS	0.09409292	0.31824446	**1.44797195**
EKB	-0.12445532	0.01436686	-0.00078382
DKS	-0.06915624	0.12193178	**-1.25753465**

Landmark	CV1 Coefficients	CV2 Coefficients	CV3 Coefficients
IML	-0.02276820	0.02736348	0.00252061
XML	0.07685723	0.01800740	0.07662245
WMH	-0.01266321	0.06557221	-0.01716959
STB	-0.01574272	0.03258166	0.01565869
FRC	0.07411979	-0.21798650	-0.34965622
PAC	-0.00558863	0.10525150	0.06943251
OCC	-0.02673633	0.09879738	-0.00800088
FOL	0.06616965	0.01494679	0.08748245
FOB	0.05264401	0.07878081	-0.10772481
MOW	0.03790667	0.04294155	0.06027090
UFBR	-0.04833278	-0.02846047	0.00534143
NBA	0.16635285	-0.53116477	-0.66009670
BBA	0.03602529	0.16752438	-0.00580669
BRA	0.22152587	0.15866710	-0.41096466
NFA	0.02082247	0.15059464	0.67763772
DKA	-0.03098234	-0.00008467	-0.38744918
CI	-0.30336900	**-1.58929229**	**5.71356073**
LHI	0.95183697	**3.93375145**	**-6.94286489**
BHI	0.49180360	0.63101845	**-2.58661224**
MBHI	**-2.23395669**	**-13.02623783**	**44.57458627**
FPI	-0.74105642	-0.22249131	-0.39075891
NI	0.20416046	0.30246625	-0.76761249
OI	-0.07444923	-0.42852014	0.43271367

Table 65: CVA structure for the analysis comparing the pooled Korean and pooled Japanese populations with the sexes separated (measurements with the highest loadings [≥ |0.4|] are bolded).

Landmark	CV1 Structure	CV2 Structure	CV3 Structure
GOL	**0.565900**	**-0.590802**	-0.015861
NOL	**0.520982**	**-0.593712**	-0.011230
BNL	**0.695873**	-0.311855	-0.001231
BBH	**0.733917**	0.163548	-0.012512
XCB	**0.506137**	0.250824	0.149635
XFB	**0.580758**	-0.008958	0.040824
WFB	0.357418	-0.284331	0.081596
AUB	**0.687200**	0.200093	0.005678
ASB	**0.461970**	-0.004803	0.105249
NLH	**0.629776**	0.124328	-0.014870
JUB	**0.765838**	-0.021025	-0.044018
NLB	0.282968	0.019619	0.096738
OBH	0.065382	0.182009	-0.050235
OBB	**0.445200**	-0.194185	0.016147
DKB	0.304434	0.048541	-0.020066
FMB	**0.630789**	-0.208383	0.061723
NAS	0.289662	-0.213422	0.010990

Landmark	CV1 Structure	CV2 Structure	CV3 Structure
EKB	**0.534044**	-0.163334	0.039803
DKS	0.174295	0.014412	-0.079190
IML	**0.484783**	-0.004389	0.111010
XML	**0.637603**	-0.121377	0.025306
WMH	**0.536781**	0.130838	-0.042271
STB	0.288461	0.093303	0.108478
FRC	**0.566310**	0.100970	0.002127
PAC	**0.435469**	-0.236497	0.164893
OCC	0.233017	-0.087524	-0.165692
FOL	**0.510103**	-0.156375	0.052608
FOB	**0.477036**	0.221455	-0.056914
MOW	0.154339	0.148170	0.098787
UFBR	**0.635905**	-0.154851	0.048645
NBA	0.076308	0.365578	-0.030876
BBA	-0.162623	0.020692	0.006690
BRA	0.100138	**-0.539250**	-0.017240
NFA	-0.109218	0.169346	0.026867
DKA	-0.078376	-0.070297	0.086234
CI	-0.077576	**0.647716**	0.148026
LHI	0.130633	**0.678703**	0.024958
BHI	0.245596	-0.069896	-0.151299
MBHI	0.218422	**0.452473**	-0.065891
FPI	-0.039479	**-0.451331**	-0.043214
NI	-0.214457	-0.063800	0.069864
OI	-0.291528	0.316275	-0.050440

Table 66: CVA coefficients for the analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese (measurements with the highest loadings are bolded).

Landmark	CV1 Coefficients	CV2 Coefficients	CV3 Coefficients
GOL	0.24033528	0.03122852	0.32149082
NOL	-0.17308366	0.17207723	-0.12469073
BNL	-0.26014589	-0.28654744	-0.20191637
BBH	-0.20802837	0.29341032	**-1.05744570**
XCB	0.10275364	-0.38970482	0.60708999
XFB	-0.06582744	-0.14764596	0.12473648
WFB	0.24427502	0.04293477	0.01772099
AUB	0.00888725	0.07137666	0.08034165
ASB	0.01318310	-0.00284244	0.08082306
NLH	0.37067714	0.02548414	-0.14066480
JUB	0.01778907	0.00221334	0.10053277
NLB	-0.45006742	-0.25586642	0.25448057
OBH	0.95668287	**1.21587140**	0.02350880
OBB	-0.86177010	**-1.42607396**	-0.34983128
DKB	0.13895619	-0.12129674	-0.16296480

Landmark	CV1 Coefficients	CV2 Coefficients	CV3 Coefficients
FMB	-0.07953260	0.08655102	-0.08156727
NAS	0.58392522	-0.80632879	0.29153166
EKB	-0.05889233	0.31222877	0.10551047
DKS	-0.04265720	-0.45169583	**1.01908376**
IML	0.02016229	-0.00523471	0.00615160
XML	0.02484165	0.04055409	0.08993571
WMH	0.05193762	-0.00770596	0.04413213
STB	0.03385072	0.06460172	-0.01408355
FRC	-0.26061778	0.01713813	-0.10342415
PAC	0.10564761	-0.03281979	0.07080956
OCC	0.10707517	-0.01716446	-0.02539880
FOL	0.04452550	0.02022543	-0.08492587
FOB	0.08994890	-0.03719514	-0.09927041
MOW	0.04438218	-0.01244176	0.06445134
UFBR	-0.02646981	0.01500419	-0.09329470
NBA	-0.51613176	-0.05672879	-0.38832676
BBA	0.25724558	0.09140478	-0.14112956
BRA	0.18590618	0.62359366	-0.06149305
NFA	0.27952672	-0.29310228	0.07308020
DKA	-0.04142373	-0.22271110	0.33067878
CI	**-1.14127711**	**-1.12074106**	0.58688540
LHI	**3.40155257**	**4.46061466**	**-1.51870365**
BHI	0.45010144	0.54818052	0.68438532
MBHI	**-9.89106962**	**-18.56374035**	**9.88346446**
FPI	-0.41859441	-0.07586415	-0.09537204
NI	0.23885371	0.08312697	-0.11058684
OI	-0.38124223	-0.50389560	0.04376670

Table 67: CVA structure for the analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese (measurements with the highest loadings [≥ |0.4|] are bolded).

Landmark	CV1 Structure	CV2 Structure	CV3 Structure
GOL	**-0.467989**	0.124039	-0.122606
NOL	**-0.476901**	0.168222	-0.144449
BNL	-0.147390	0.240510	-0.268987
BBH	0.343037	0.038575	-0.303522
XCB	**0.408213**	-0.352904	-0.261826
XFB	0.125039	**-0.427300**	-0.032854
WFB	-0.196102	-0.070997	-0.127299
AUB	0.319710	0.046398	0.039689
ASB	0.094121	0.043273	-0.058511
NLH	0.265662	-0.091575	-0.128502
JUB	0.094711	0.185577	0.084309

Landmark	CV1 Structure	CV2 Structure	CV3 Structure
NLB	0.071130	0.058809	0.083880
OBH	0.184265	-0.139515	0.092080
OBB	-0.106535	0.099906	-0.060301
DKB	0.102411	0.202965	-0.033082
FMB	-0.083390	0.163519	-0.063408
NAS	-0.161368	0.113202	-0.096602
EKB	-0.069991	0.262730	0.011129
DKS	0.030225	0.124368	-0.105523
IML	0.069100	0.200897	0.138561
XML	-0.013912	0.265796	0.036582
WMH	0.216431	0.109201	0.002063
STB	0.193466	-0.281642	-0.163487
FRC	0.227504	0.087138	-0.160326
PAC	-0.176068	-0.052334	0.188588
OCC	0.035022	0.049699	**-0.442113**
FOL	-0.034726	-0.037088	-0.199030
FOB	0.337587	-0.053087	-0.275007
MOW	0.161377	-0.002112	0.125590
UFBR	-0.029879	0.160357	-0.074695
NBA	0.399050	-0.183995	-0.123198
BBA	-0.030648	0.015241	0.155599
BRA	**-0.521076**	0.270699	-0.029789
NFA	0.156546	-0.076362	0.091656
DKA	-0.065303	-0.117115	0.106835
CI	**0.663793**	-0.333406	-0.089789
LHI	**0.724448**	-0.064950	-0.147645
BHI	-0.041571	0.356593	-0.045315
MBHI	**0.499130**	0.129992	-0.130921
FPI	**-0.486534**	0.197775	0.077023
NI	-0.125866	0.116271	0.167306
OI	0.250239	-0.215426	0.133028

Table 68: CVA coefficients for the analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese with only females (measurements with the highest loadings are bolded).

Landmark	CV1 Coefficients	CV2 Coefficients	CV3 Coefficients
GOL	0.76653919	-0.31998867	-0.23861542
NOL	-0.15193154	0.21095546	0.16627203
BNL	-0.26380779	0.32055089	0.36545823
BBH	0.64914827	-0.34817354	**-1.69091692**
XCB	-0.35062259	-0.45648789	0.66023601
XFB	-0.06319467	-0.08624419	-0.07993572
WFB	**-1.64704279**	**1.50769775**	**1.45286612**

Landmark	**CV1 Coefficients**	**CV2 Coefficients**	**CV3 Coefficients**
AUB	-0.01698716	0.07357436	0.04789263
ASB	0.04220154	-0.03552627	-0.14098519
NLH	-0.51141202	-0.94392977	0.44943676
JUB	-0.04028487	0.16537814	-0.03008992
NLB	**1.08344132**	**1.48025638**	-0.82055996
OBH	0.74564102	**1.62400985**	**-4.38935447**
OBB	-0.73125424	**-1.77080519**	**3.97539121**
DKB	-0.00942388	-0.34674620	0.27130827
FMB	-0.06682538	-0.26713538	0.26504890
NAS	**1.25494428**	0.48456892	-0.11848484
EKB	-0.03332654	0.41940798	-0.23875145
DKS	-0.90715514	-0.74661079	0.56982337
IML	0.00498591	-0.04358634	-0.03041259
XML	0.13622741	-0.00555346	-0.14514021
WMH	0.00090246	-0.03640854	-0.00082152
STB	-0.01302790	0.03953135	0.07610759
FRC	0.03959804	-0.28617526	0.09160686
PAC	0.15536974	-0.02740822	-0.04448574
OCC	0.12243978	0.06512261	0.03798432
FOL	0.17969337	0.03307604	0.08331655
FOB	0.07394370	0.03442567	0.09265922
MOW	0.11583030	-0.01326431	-0.04950492
UFBR	-0.06068251	0.00502384	-0.09002742
NBA	-0.46379883	0.02224651	0.19247596
BBA	-0.10808121	0.54478931	-0.02799193
BRA	0.30218534	-0.23726033	-0.56592321
NFA	0.53753855	0.21951303	0.02861718
DKA	-0.30176233	-0.30317238	0.15609619
CI	-0.02062254	**-1.44613622**	**-2.20238154**
LHI	**2.21578442**	**6.08887078**	**4.86188384**
BHI	**-2.06579270**	**2.76959135**	**2.22323861**
MBHI	-0.83305125	**-31.47693002**	**-19.03185456**
FPI	**2.21077397**	**-2.06452935**	**-1.93478562**
NI	-0.52366255	-0.75383372	0.39398649
OI	-0.28636734	-0.59442706	**1.65598336**

Table 69: CVA structure for the analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese with only females (measurements with the highest loadings [≥ |0.4|] are bolded).

Landmark	**CV1 Structure**	**CV2 Structure**	**CV3 Structure**
GOL	**-0.465635**	0.069863	0.143279
NOL	**-0.461193**	0.137257	0.129417
BNL	-0.182749	0.372380	0.072716
BBH	0.271794	0.238464	0.260921
XCB	**0.426743**	-0.140908	0.386257
XFB	0.120647	-0.190014	0.360365
WFB	-0.105200	0.014765	0.232356
AUB	0.294943	0.097334	0.241010
ASB	0.127893	-0.102851	-0.139547
NLH	0.159707	-0.129759	0.231289
JUB	0.052152	0.351736	0.096298
NLB	0.133923	0.073089	0.019783
OBH	0.104854	0.050826	0.159914
OBB	-0.073614	0.130711	0.152123
DKB	0.068403	0.049984	0.174749
FMB	-0.029967	0.106996	0.161315
NAS	-0.127943	0.065345	-0.051959
EKB	-0.023053	0.251962	0.079519
DKS	-0.014695	0.065266	0.305413
IML	0.137313	0.072307	-0.297276
XML	-0.015550	0.196223	-0.215672
WMH	0.138557	-0.042221	0.089761
STB	0.253954	-0.163111	0.396776
FRC	0.186849	0.132185	0.302884
PAC	0.001802	-0.138853	-0.065669
OCC	-0.162763	0.246295	0.275816
FOL	0.001415	0.027374	0.279428
FOB	0.195798	-0.037944	0.330577
MOW	0.226840	0.028305	0.112763
UFBR	0.008299	0.177444	0.151565
NBA	0.264668	-0.039435	0.037751
BBA	0.009308	-0.105457	0.104812
BRA	**-0.417151**	0.197106	-0.185119
NFA	0.144993	-0.033986	0.095624
DKA	-0.009397	-0.043143	-0.287624
CI	**0.635761**	-0.137142	0.178176
LHI	**0.595744**	0.122420	0.079767
BHI	-0.156354	0.292121	-0.126151
MBHI	0.317623	0.236177	-0.019544
FPI	**-0.405776**	0.112024	-0.085409
NI	-0.011975	0.148626	-0.144469

Landmark	CV1 Structure	CV2 Structure	CV3 Structure
OI	0.168950	-0.057584	0.053662

Table 70: CVA coefficients for the analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese with only males (measurements with the highest loadings are bolded).

Landmark	CV1 Coefficients	CV2 Coefficients	CV3 Coefficients
GOL	-0.11748688	0.10995182	0.18019937
NOL	-0.17414455	0.08459229	-0.12228332
BNL	-0.18877279	-0.32150387	0.00187088
BBH	-0.85582439	0.29434892	**-1.58514483**
XCB	0.65275224	0.02670445	**1.27255898**
XFB	-0.02581428	-0.11143197	0.13560084
WFB	0.73486243	-0.77961334	0.17123841
AUB	0.01843672	0.09761220	0.09375301
ASB	-0.00036208	0.03320246	0.03898456
NLH	0.80480425	0.46902751	-0.19334873
JUB	0.04314276	-0.02957014	0.10668916
NLB	**-1.30697595**	**-1.09084391**	0.22104063
OBH	**1.83628762**	0.53492745	-0.46786869
OBB	**-1.59631677**	-0.74681867	0.09180643
DKB	0.16862934	0.02016183	-0.06143738
FMB	-0.08310004	0.32102704	-0.05124714
NAS	-0.11445244	**-1.39904638**	0.35657939
EKB	0.00557331	0.16954926	0.01448983
DKS	0.22069088	0.02109825	**1.85835634**
IML	0.01287645	-0.00972338	0.00580710
XML	0.00402055	0.05197382	0.01667790
WMH	0.06385899	0.06886282	0.04142059
STB	0.02267626	0.06920894	-0.01000513
FRC	-0.06558091	0.07846576	-0.29443017
PAC	0.07870771	-0.02406431	0.07847298
OCC	0.10654633	-0.05608307	-0.00306436
FOL	0.00579984	-0.02693526	-0.05580693
FOB	0.11909450	-0.04909359	-0.11857620
MOW	0.02401316	0.00129048	0.03569295
UFBR	-0.04312823	-0.09902454	-0.16087787
NBA	-0.32643752	-0.06635257	-0.37396336
BBA	0.05434931	-0.05540051	0.20630602
BRA	0.11371924	0.55397668	-0.32184273
NFA	-0.05026292	-0.54849237	0.10647235
DKA	0.02776998	-0.06749748	0.61913843
CI	**-2.49478704**	**-1.26852673**	0.13104142
LHI	**5.20660566**	**3.61220551**	-0.58900800

Landmark	CV1 Coefficients	CV2 Coefficients	CV3 Coefficients
BHI	**1.47313235**	-0.26719809	**1.86110381**
MBHI	**-18.25220469**	**-12.38717400**	**4.74806747**
FPI	**-1.09639632**	**1.05981365**	-0.28076644
NI	0.70999592	0.52442130	-0.09430670
OI	-0.72541690	-0.24332674	0.27398571

Table 71: CVA structure for the analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese with only males (measurements with the highest loadings [≥ |0.4|] are bolded).

Landmark	CV1 Structure	CV2 Structure	CV3 Structure
GOL	**-0.596850**	0.169488	-0.077657
NOL	**-0.592969**	0.185320	-0.105156
BNL	-0.260143	0.113320	-0.337827
BBH	0.339556	-0.130634	-0.346395
XCB	0.339718	**-0.455823**	-0.162682
XFB	0.076309	**-0.465112**	0.166816
WFB	-0.262532	-0.081509	-0.043182
AUB	0.308817	0.057101	0.094680
ASB	0.026727	0.055366	-0.197973
NLH	0.263917	-0.067406	-0.120743
JUB	0.071883	0.163884	0.124912
NLB	0.006283	0.053091	0.106129
OBH	0.216795	-0.166894	0.227754
OBB	-0.170449	0.090816	-0.012295
DKB	0.071799	0.263464	-0.032237
FMB	-0.191006	0.199637	-0.059494
NAS	-0.185738	0.093487	-0.164732
EKB	-0.150354	0.263171	0.015035
DKS	0.051586	0.179033	-0.056263
IML	-0.003149	0.204801	-0.005353
XML	-0.079807	0.258765	-0.080941
WMH	0.211108	0.180289	-0.052262
STB	0.116564	-0.275608	-0.029237
FRC	0.188144	0.052377	-0.126551
PAC	-0.294223	0.053476	0.196257
OCC	0.037886	-0.134075	-0.349548
FOL	-0.105769	-0.066397	-0.150240
FOB	0.355994	-0.078356	-0.271078
MOW	0.117986	0.025942	0.175363
UFBR	-0.118234	0.153028	-0.073598
NBA	**0.422779**	-0.264708	-0.138171
BBA	-0.032173	0.144202	0.210940
BRA	**-0.551491**	0.231679	-0.076117

Landmark	**CV1 Structure**	**CV2 Structure**	**CV3 Structure**
NFA	0.142022	-0.053698	0.173714
DKA	-0.102151	-0.177846	0.070902
CI	**0.639596**	**-0.403521**	-0.051483
LHI	**0.715319**	-0.214562	-0.185716
BHI	-0.004011	0.288638	-0.143856
MBHI	**0.532953**	-0.025150	-0.212422
FPI	**-0.466627**	0.237031	0.071471
NI	-0.139150	0.089871	0.163143
OI	0.317331	-0.223788	0.217687

3D GM PCA Tables

Table 72: PCA coefficients for the whole cranium analysis comparing the pooled Korean and pooled Japanese populations (landmarks with the highest loadings [≥ |0.3|] are bolded; only the first five PCs are presented).

	PC1 Coefficients			**PC2 Coefficients**			**PC3 Coefficients**			**PC4 Coefficients**			**PC5 Coefficients**		
Landmark	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
alarl	0.00	-0.04	0.00	0.00	0.02	0.08	0.00	-0.14	-0.03	0.05	0.00	-0.01	0.02	0.04	0.02
alarr	0.02	-0.04	0.00	0.02	0.02	0.09	-0.03	-0.14	-0.02	0.05	-0.02	0.00	0.00	0.04	0.01
astl	-0.02	-0.05	0.06	-0.04	0.01	0.02	-0.06	0.16	-0.13	0.07	0.08	-0.04	-0.10	0.12	-0.03
astr	0.02	-0.05	0.10	0.06	-0.01	0.03	0.03	0.17	-0.12	0.00	0.00	-0.03	0.12	0.13	-0.01
aubl	-0.08	-0.02	0.03	-0.01	0.00	-0.01	-0.11	0.17	-0.02	0.05	0.04	-0.01	-0.02	0.11	-0.06
aubr	0.08	-0.03	0.04	0.04	-0.01	0.01	0.08	0.18	-0.05	0.05	-0.02	0.03	0.03	0.12	-0.03
bas	0.00	-0.05	0.05	0.01	-0.04	0.06	-0.02	0.16	-0.01	0.06	0.05	0.02	0.01	0.03	0.01
brg	0.00	0.00	0.00	0.01	-0.02	0.08	0.01	-0.06	0.16	0.00	0.01	-0.01	0.04	0.13	-0.05
dacl	-0.01	-0.01	0.02	-0.01	0.00	0.04	0.01	-0.07	0.03	0.04	-0.02	-0.03	0.02	-0.05	-0.03
dacr	0.02	-0.01	0.03	0.03	0.00	0.05	-0.02	-0.07	0.02	0.05	-0.03	-0.02	-0.01	-0.06	-0.03
ectl	-0.04	-0.01	0.01	-0.03	-0.02	0.04	0.01	-0.04	-0.01	0.02	-0.02	-0.01	0.03	0.02	-0.01
ectr	0.06	-0.02	0.01	0.05	-0.03	0.05	-0.02	-0.04	-0.02	0.06	-0.06	0.02	-0.02	0.00	0.00
eurl	-0.01	**0.34**	**-0.55**	-0.07	-0.03	-0.01	-0.24	0.13	0.07	0.00	0.12	0.06	-0.09	**-0.42**	-0.24
eurr	0.03	**0.35**	**-0.56**	0.08	-0.02	0.03	0.22	0.15	0.09	0.03	0.09	0.16	0.08	**-0.36**	-0.23
fmal	-0.04	0.00	0.04	-0.02	-0.03	0.05	0.00	-0.01	0.01	0.02	-0.02	-0.03	0.03	0.00	-0.01
fmar	0.05	0.00	0.04	0.04	-0.05	0.05	0.00	-0.01	0.00	0.06	-0.07	0.00	-0.03	-0.02	0.00
fmtl	-0.05	0.01	0.03	-0.03	-0.05	0.02	0.00	0.00	0.01	0.02	-0.01	-0.03	0.04	-0.01	0.01
fmtr	0.05	0.00	0.04	0.05	-0.07	0.02	0.00	0.00	-0.02	0.05	-0.06	0.00	-0.04	-0.02	0.00
glb	0.00	0.00	0.04	0.01	-0.03	0.08	0.00	-0.06	0.04	0.04	-0.03	-0.03	-0.01	-0.08	-0.01
lam	-0.02	0.03	0.10	0.00	-0.06	0.12	0.00	0.11	-0.01	-0.01	0.09	-0.13	-0.01	0.18	**0.52**
nas	0.01	0.00	0.04	0.00	-0.02	0.06	0.00	-0.07	0.01	0.04	-0.02	-0.04	0.00	-0.06	-0.05
nlhil	0.01	-0.04	0.00	0.00	0.03	0.10	-0.01	-0.15	-0.03	0.05	-0.01	-0.01	0.01	0.05	0.02
nlhir	0.01	-0.04	-0.01	0.01	0.03	0.10	-0.03	-0.15	-0.03	0.05	-0.02	0.00	0.02	0.05	0.02
obhi	-0.02	-0.02	0.01	-0.02	0.01	0.05	0.04	-0.11	-0.04	0.03	-0.01	0.01	0.02	0.01	0.00
obhs	-0.04	0.00	0.04	-0.03	-0.03	0.05	-0.01	-0.03	0.03	0.04	-0.02	-0.02	0.04	-0.03	-0.01
ops	0.00	-0.08	0.06	0.00	-0.03	0.02	-0.02	0.19	-0.04	0.04	0.09	-0.03	0.00	0.02	-0.02

Landmark	PC1 Coefficients			PC2 Coefficients			PC3 Coefficients			PC4 Coefficients			PC5 Coefficients		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
porl	-0.06	-0.02	0.03	-0.01	-0.01	0.00	-0.10	0.11	-0.05	0.05	0.05	-0.02	-0.04	0.07	-0.07
porr	0.07	-0.03	0.04	0.04	-0.03	0.02	0.06	0.10	-0.07	0.05	0.00	0.02	0.04	0.07	-0.04
stpl	0.01	-0.03	0.05	-0.24	0.21	**-0.51**	-0.26	0.01	0.03	0.03	0.03	0.06	0.04	0.01	-0.02
stpr	0.01	-0.03	0.06	0.19	0.17	**-0.47**	0.25	-0.01	0.03	-0.01	-0.05	0.09	-0.04	-0.02	0.01
wfbl	-0.03	-0.01	0.07	-0.10	-0.08	-0.06	-0.06	0.01	-0.06	0.02	-0.01	-0.05	0.06	-0.01	-0.03
wfbr	0.04	-0.02	0.07	0.11	-0.09	-0.06	0.06	0.02	-0.05	0.03	-0.05	-0.01	-0.07	-0.01	-0.01
whmi	-0.05	-0.03	0.01	-0.07	0.01	0.07	0.12	-0.12	0.01	**-0.65**	-0.03	0.00	-0.12	0.04	0.04
whms	-0.05	-0.02	0.01	-0.09	0.00	0.04	0.11	-0.10	-0.04	**-0.60**	-0.05	0.02	-0.10	0.01	0.01
xfbl	-0.03	0.01	-0.02	-0.06	0.13	-0.21	-0.19	-0.01	0.20	0.00	0.04	-0.02	0.06	-0.05	0.15
xfbr	0.03	0.00	-0.01	0.05	0.13	-0.20	0.21	-0.05	0.21	0.02	-0.04	0.07	-0.05	-0.08	0.15
zygool	-0.02	-0.02	0.01	-0.01	0.01	0.05	0.01	-0.12	-0.05	0.02	-0.01	0.01	0.04	0.01	0.00
zygoor	0.05	-0.03	0.01	0.02	0.01	0.06	-0.02	-0.11	-0.05	0.09	-0.03	0.02	0.01	0.00	0.00

Table 73: PCA coefficients for the facial region analysis comparing the pooled Korean and pooled Japanese populations (landmarks with the highest loadings [≥ |0.3|] are bolded; only the first five PCs are presented).

Landmark	PC1 Coefficients			PC2 Coefficients			PC3 Coefficients			PC4 Coefficients			PC5 Coefficients		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
alarl	-0.01	-0.01	0.24	0.03	0.03	0.00	0.01	0.16	0.12	0.03	0.16	-0.22	0.01	0.09	0.19
alarr	0.04	0.00	0.26	-0.04	0.03	0.00	0.03	0.15	0.11	-0.06	0.17	-0.23	-0.10	0.09	0.18
dacl	-0.07	0.06	0.01	0.02	0.04	0.07	-0.03	0.08	-0.13	0.06	0.17	0.04	0.04	0.05	0.23
dacr	0.09	0.07	0.02	-0.02	0.04	0.08	0.03	0.08	-0.13	-0.05	0.15	0.05	-0.05	0.04	0.23
ectl	-0.07	-0.03	-0.02	0.03	0.02	0.01	0.03	-0.06	-0.01	0.05	-0.08	0.05	0.08	0.02	-0.10
ectr	0.09	-0.05	0.00	-0.04	0.03	-0.02	-0.02	-0.05	-0.01	-0.07	-0.09	0.06	-0.10	-0.01	-0.10
fmal	-0.08	0.00	-0.06	-0.03	-0.01	-0.11	0.05	-0.07	-0.09	0.06	-0.07	0.11	0.05	0.06	0.02
fmar	0.10	-0.02	-0.08	0.02	0.00	-0.10	-0.06	-0.05	-0.08	-0.05	-0.10	0.12	-0.04	0.02	0.01
fmtl	-0.07	-0.02	-0.09	-0.04	-0.03	-0.06	0.08	-0.09	-0.07	0.08	-0.09	0.13	0.05	0.10	0.00
fmtr	0.10	-0.04	-0.13	0.04	-0.02	-0.05	-0.08	-0.07	-0.04	-0.06	-0.10	0.08	-0.05	0.04	-0.03
glb	0.01	0.17	-0.06	0.00	0.14	-0.04	0.00	0.16	-0.22	0.00	0.00	0.20	0.03	0.02	0.15
jugl	-0.01	-0.06	-0.02	-0.07	-0.21	0.03	-0.01	**-0.32**	0.14	0.17	-0.10	0.09	0.06	0.06	-0.16

Landmark	PC1 Coefficients			PC2 Coefficients			PC3 Coefficients			PC4 Coefficients			PC5 Coefficients		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
jugr	0.03	-0.07	-0.02	0.07	-0.21	0.02	0.01	**-0.31**	0.15	-0.16	-0.14	0.12	-0.09	0.01	-0.23
nas	0.01	0.10	0.03	-0.01	0.07	0.03	0.00	0.12	-0.16	0.01	0.11	0.04	0.01	0.03	0.26
nlhil	0.00	0.00	0.22	0.03	0.00	0.00	0.01	0.19	0.07	0.06	0.24	-0.21	-0.05	0.08	0.07
nlhir	0.01	0.00	0.23	-0.03	0.00	0.00	0.02	0.19	0.08	-0.07	0.25	-0.23	-0.08	0.09	0.09
obhi	-0.07	0.00	0.01	-0.01	0.04	0.13	-0.08	0.05	0.02	0.03	0.05	-0.05	0.25	-0.05	0.00
obhs	-0.09	0.08	-0.07	-0.01	0.07	-0.06	0.08	0.03	-0.11	0.02	-0.04	0.13	-0.07	0.01	0.06
wfbl	-0.23	0.10	**-0.41**	-0.10	-0.05	-0.04	0.27	-0.03	0.18	-0.14	-0.02	-0.23	0.04	0.06	0.07
wfbr	0.24	0.09	**-0.41**	0.10	-0.04	-0.05	-0.25	-0.02	0.17	0.11	-0.09	-0.15	-0.03	-0.01	0.09
whmi	0.02	-0.11	0.11	0.02	-0.03	-0.14	-0.07	-0.03	0.00	0.01	-0.12	0.03	0.06	-0.15	-0.16
whms	-0.08	-0.02	-0.01	0.02	0.01	0.09	-0.05	0.02	0.06	0.03	-0.05	-0.03	0.06	-0.10	-0.07
zygoml	0.00	-0.11	0.11	0.01	-0.04	-0.16	-0.15	-0.11	-0.03	0.13	-0.15	0.10	-0.03	-0.21	**-0.32**
zygomr	0.03	-0.11	0.12	-0.02	-0.04	-0.16	0.17	-0.12	-0.03	-0.14	-0.13	0.11	-0.01	-0.21	**-0.33**
zygool	-0.13	0.00	0.00	**0.52**	0.07	0.28	-0.16	0.05	0.00	-0.03	0.04	-0.06	-0.11	-0.07	-0.09
zygoor	0.15	-0.01	0.02	**-0.51**	0.08	0.26	0.16	0.05	0.00	0.00	0.04	-0.05	0.05	-0.07	-0.05

Table 74: PCA coefficients for the cranial vault analysis comparing the pooled Korean and pooled Japanese populations (landmarks with the highest loadings [≥ |0.3|] are bolded; only the first five PCs are presented).

Landmark	PC1 Coefficients			PC2 Coefficients			PC3 Coefficients			PC4 Coefficients			PC5 Coefficients		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
astl	-0.02	0.05	0.07	0.05	-0.01	0.04	-0.09	-0.01	-0.15	-0.07	0.05	0.10	-0.01	0.12	-0.01
astr	0.02	0.08	0.07	-0.06	0.00	0.03	0.10	0.01	-0.16	0.09	0.03	0.07	0.03	0.13	0.01
aubl	-0.08	0.05	0.03	0.03	-0.08	0.01	-0.03	-0.06	-0.12	0.00	0.10	0.00	0.03	0.06	-0.08
aubr	0.08	0.05	0.03	-0.04	-0.07	0.01	0.01	-0.03	-0.13	0.00	0.11	0.02	-0.02	0.07	-0.06
bas	0.00	0.05	0.04	0.01	-0.20	0.00	0.00	0.02	-0.04	0.00	0.08	-0.03	0.00	-0.27	0.02
brg	0.00	0.02	0.05	-0.03	-0.12	-0.23	0.04	-0.05	-0.15	0.00	0.02	-0.06	-0.01	0.00	**0.36**
eurl	-0.01	**-0.49**	**-0.41**	0.10	0.10	-0.04	-0.10	-0.29	**0.38**	0.12	-0.23	0.28	0.07	0.11	-0.05
eurr	0.03	**-0.51**	**-0.43**	-0.12	0.07	-0.03	0.09	-0.27	**0.33**	-0.11	-0.25	**0.31**	-0.09	0.03	-0.11
fobl	-0.01	0.04	0.05	-0.01	-0.15	0.03	-0.01	0.01	-0.03	0.00	0.04	-0.02	-0.04	-0.28	0.06
fobr	0.00	0.05	0.05	0.01	-0.16	0.02	-0.01	0.02	-0.04	0.00	0.04	-0.02	0.05	-0.29	0.05

	PC1 Coefficients			PC2 Coefficients			PC3 Coefficients			PC4 Coefficients			PC5 Coefficients		
Landmark	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
glb	0.00	0.09	0.02	0.00	-0.21	-0.13	0.00	-0.06	0.09	0.00	0.12	-0.20	0.02	**0.34**	0.21
lam	-0.01	0.07	0.02	-0.01	-0.01	-0.16	-0.01	**0.54**	-0.15	-0.02	-0.22	**0.32**	0.01	**0.39**	-0.03
ops	0.00	0.05	0.07	0.01	-0.11	0.05	0.00	0.02	-0.04	0.00	0.00	0.03	0.00	-0.24	0.08
porl	-0.07	0.04	0.03	0.03	-0.08	-0.01	-0.04	-0.07	-0.08	-0.02	0.11	-0.01	0.01	0.05	-0.06
porr	0.07	0.05	0.04	-0.04	-0.07	-0.02	0.02	-0.05	-0.07	0.02	0.12	-0.02	0.00	0.05	-0.05
stpl	0.02	0.12	0.10	**0.31**	**0.46**	0.19	0.01	-0.02	0.03	0.23	0.09	-0.15	0.10	-0.10	-0.07
stpr	-0.01	0.11	0.09	-0.26	**0.44**	0.15	-0.01	0.00	0.05	-0.22	0.08	-0.16	-0.13	-0.06	-0.02
xfbl	-0.03	0.04	0.04	0.10	0.09	0.05	0.04	0.15	0.12	0.16	-0.15	-0.22	0.16	-0.03	-0.14
xfbr	0.02	0.04	0.04	-0.10	0.10	0.04	-0.02	0.14	0.15	-0.18	-0.14	-0.25	-0.17	-0.08	-0.12

Table 75: PCA coefficients for the whole cranium analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese (landmarks with the highest loadings [≥ |0.3|] are bolded; only the first five PCs are presented).

	PC1 Coefficients			PC2 Coefficients			PC3 Coefficients			PC4 Coefficients			PC5 Coefficients		
Landmark	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
alarl	0.00	-0.04	0.00	0.00	0.01	0.09	0.00	-0.13	-0.05	0.05	-0.01	-0.02	0.02	0.03	0.00
alarr	0.02	-0.04	0.00	0.02	0.01	0.09	-0.03	-0.14	-0.04	0.05	-0.02	-0.01	0.00	0.03	0.00
astl	-0.03	-0.04	0.06	-0.04	0.01	0.01	-0.06	0.13	-0.12	0.07	0.08	-0.05	-0.11	0.13	-0.04
astr	0.02	-0.04	0.10	0.06	-0.01	0.02	0.02	0.15	-0.12	-0.01	0.01	-0.04	0.13	0.14	-0.03
aubl	-0.08	-0.02	0.02	-0.02	0.01	-0.01	-0.11	0.16	-0.03	0.04	0.05	-0.01	-0.04	0.14	-0.07
aubr	0.08	-0.03	0.04	0.04	-0.01	0.01	0.08	0.17	-0.05	0.05	-0.01	0.03	0.05	0.15	-0.04
bas	0.00	-0.04	0.04	0.01	-0.03	0.06	-0.03	0.15	-0.02	0.06	0.05	0.01	0.00	0.04	-0.01
brg	0.00	0.00	0.00	0.01	-0.01	0.08	0.00	-0.08	0.16	0.00	-0.01	-0.01	0.04	0.13	-0.03
dacl	-0.01	-0.01	0.03	-0.01	-0.01	0.04	0.00	-0.06	0.03	0.04	-0.03	-0.03	0.02	-0.06	-0.04
dacr	0.02	-0.01	0.03	0.03	0.00	0.04	-0.02	-0.06	0.02	0.04	-0.03	-0.02	-0.01	-0.06	-0.04
ectl	-0.04	-0.01	0.01	-0.03	-0.02	0.04	0.00	-0.05	-0.01	0.02	-0.02	-0.01	0.01	0.00	-0.01
ectr	0.06	-0.02	0.01	0.04	-0.03	0.05	-0.01	-0.04	-0.02	0.07	-0.06	0.02	-0.01	-0.01	0.00
eurl	-0.02	**0.34**	**-0.55**	-0.08	-0.04	-0.02	-0.22	0.21	0.14	0.00	0.15	0.09	-0.11	**-0.35**	-0.17
eurr	0.04	**0.35**	**-0.56**	0.09	-0.02	0.03	0.19	0.18	0.11	0.04	0.11	0.17	0.10	**-0.34**	-0.20
fmal	-0.04	0.01	0.04	-0.02	-0.03	0.05	-0.01	-0.03	0.01	0.02	-0.02	-0.03	0.02	-0.03	-0.01

Landmark	PC1 Coefficients			PC2 Coefficients			PC3 Coefficients			PC4 Coefficients			PC5 Coefficients		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
fmar	0.05	0.00	0.04	0.04	-0.04	0.05	0.00	-0.02	0.00	0.06	-0.07	0.00	-0.02	-0.03	0.01
fmtl	-0.05	0.01	0.03	-0.03	-0.05	0.02	-0.02	-0.02	0.01	0.02	-0.01	-0.03	0.03	-0.03	0.00
fmtr	0.05	0.00	0.04	0.05	-0.07	0.02	0.01	-0.01	-0.01	0.05	-0.07	0.00	-0.03	-0.04	0.01
glb	0.00	0.00	0.05	0.01	-0.03	0.08	0.00	-0.07	0.03	0.04	-0.03	-0.03	-0.01	-0.11	-0.01
lam	-0.02	0.03	0.11	0.00	-0.06	0.12	0.00	0.10	-0.05	-0.01	0.09	-0.14	-0.01	0.21	**0.53**
nas	0.01	-0.01	0.05	0.00	-0.02	0.06	0.00	-0.07	0.01	0.04	-0.03	-0.04	0.01	-0.08	-0.06
nlhil	0.01	-0.04	0.00	0.01	0.02	0.10	-0.02	-0.15	-0.04	0.05	-0.02	-0.01	0.01	0.04	0.01
nlhir	0.01	-0.04	-0.01	0.01	0.02	0.10	-0.03	-0.15	-0.04	0.05	-0.03	-0.01	0.02	0.04	0.01
obhi	-0.02	-0.02	0.01	-0.02	0.01	0.05	0.02	-0.10	-0.04	0.03	-0.01	0.01	0.00	0.01	-0.01
obhs	-0.04	0.00	0.04	-0.03	-0.03	0.05	-0.02	-0.04	0.04	0.03	-0.02	-0.02	0.04	-0.05	0.00
ops	0.00	-0.08	0.06	0.00	-0.02	0.03	-0.02	0.18	-0.05	0.04	0.10	-0.04	0.00	0.04	-0.05
porl	-0.07	-0.02	0.03	-0.01	-0.01	0.00	-0.10	0.12	-0.05	0.04	0.05	-0.02	-0.05	0.10	-0.08
porr	0.07	-0.03	0.04	0.04	-0.03	0.01	0.06	0.12	-0.07	0.05	0.00	0.02	0.05	0.11	-0.05
stpl	0.00	-0.03	0.05	-0.25	0.21	**-0.51**	-0.24	0.00	0.04	0.02	0.03	0.06	0.02	0.01	-0.02
stpr	0.01	-0.03	0.06	0.20	0.17	**-0.47**	0.23	-0.01	0.04	0.00	-0.04	0.10	-0.03	-0.01	0.02
wfbl	-0.03	-0.01	0.07	-0.10	-0.07	-0.07	-0.07	0.00	-0.01	0.02	-0.01	-0.04	0.06	-0.04	0.00
wfbr	0.04	-0.02	0.07	0.12	-0.09	-0.07	0.05	0.01	0.00	0.03	-0.05	0.00	-0.06	-0.04	0.02
whmi	-0.05	-0.03	0.01	-0.07	0.00	0.08	0.17	-0.10	-0.02	**-0.63**	-0.03	-0.01	-0.12	0.05	0.02
whms	-0.05	-0.02	0.01	-0.09	0.00	0.04	0.16	-0.09	-0.05	**-0.59**	-0.05	0.02	-0.10	0.01	0.00
xfbl	-0.03	0.01	-0.02	-0.07	0.13	-0.20	-0.18	-0.02	0.20	-0.01	0.04	-0.01	0.05	-0.05	0.18
xfbr	0.03	0.00	0.00	0.06	0.12	-0.19	0.19	-0.03	0.17	0.02	-0.04	0.07	-0.05	-0.07	0.16
zygool	-0.02	-0.02	0.01	-0.01	0.01	0.05	0.01	-0.11	-0.05	0.02	-0.01	0.01	0.04	0.01	-0.01
zygoor	0.05	-0.03	0.01	0.02	0.00	0.06	-0.03	-0.10	-0.05	0.08	-0.04	0.02	0.01	0.00	-0.01

Table 76: PCA coefficients for the facial region analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese (landmarks with the highest loadings [≥ |0.3|] are bolded; only the first five PCs are presented).

	PC1 Coefficients			**PC2 Coefficients**			**PC3 Coefficients**			**PC4 Coefficients**			**PC5 Coefficients**		
Landmark	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
alarl	-0.01	-0.01	0.25	0.03	0.02	-0.02	0.01	0.19	0.10	0.03	0.13	-0.24	0.01	0.07	0.17
alarr	0.04	0.00	0.26	-0.05	0.02	-0.02	0.01	0.19	0.09	-0.06	0.14	-0.25	-0.10	0.07	0.17
dacl	-0.07	0.07	0.01	0.03	0.03	0.08	-0.01	0.08	-0.09	0.05	0.17	0.03	0.04	0.10	0.24
dacr	0.10	0.08	0.02	-0.02	0.03	0.09	0.01	0.07	-0.09	-0.04	0.16	0.04	-0.05	0.09	0.24
ectl	-0.07	-0.04	-0.02	0.04	0.02	0.01	0.06	-0.05	0.00	0.04	-0.08	0.04	0.06	0.00	-0.10
ectr	0.09	-0.05	-0.01	-0.04	0.03	-0.01	-0.05	-0.05	-0.01	-0.04	-0.09	0.06	-0.08	-0.02	-0.11
fmal	-0.08	-0.01	-0.07	-0.03	0.00	-0.09	0.07	-0.06	-0.09	0.05	-0.07	0.12	0.03	0.05	0.04
fmar	0.10	-0.02	-0.08	0.02	0.00	-0.09	-0.07	-0.05	-0.07	-0.04	-0.10	0.13	-0.02	0.01	0.03
fmtl	-0.07	-0.03	-0.10	-0.04	-0.02	-0.04	0.09	-0.07	-0.05	0.06	-0.10	0.13	0.03	0.10	-0.02
fmtr	0.10	-0.05	-0.13	0.04	-0.01	-0.04	-0.09	-0.06	-0.03	-0.05	-0.11	0.08	-0.03	0.02	-0.04
glb	0.01	0.18	-0.08	0.00	0.11	-0.01	0.00	0.15	-0.17	0.00	-0.01	0.19	0.03	0.04	0.17
jugl	-0.01	-0.08	-0.01	-0.07	-0.18	0.02	0.00	**-0.33**	0.14	0.18	-0.07	0.08	0.09	0.07	-0.18
jugr	0.03	-0.08	-0.01	0.07	-0.18	0.00	0.00	**-0.34**	0.14	-0.17	-0.10	0.12	-0.12	0.03	-0.25
nas	0.01	0.11	0.02	-0.01	0.06	0.05	0.00	0.11	-0.12	0.01	0.11	0.03	0.01	0.06	0.27
nlhil	0.00	0.00	0.23	0.03	0.00	-0.03	0.02	0.24	0.04	0.05	0.20	-0.21	-0.05	0.05	0.06
nlhir	0.01	0.00	0.24	-0.04	-0.01	-0.03	0.00	0.24	0.04	-0.06	0.21	-0.22	-0.08	0.06	0.08
obhi	-0.08	0.01	0.02	0.00	0.04	0.12	-0.03	0.04	0.03	0.01	0.06	-0.05	0.23	-0.03	-0.02
obhs	-0.09	0.09	-0.08	-0.01	0.06	-0.04	0.08	0.04	-0.10	0.01	-0.05	0.13	-0.09	0.00	0.08
wfbl	-0.22	0.09	**-0.39**	-0.12	-0.05	-0.05	0.26	-0.01	0.15	-0.17	-0.03	-0.24	0.00	0.03	0.09
wfbr	0.23	0.09	**-0.40**	0.12	-0.04	-0.07	-0.25	-0.01	0.16	0.14	-0.10	-0.16	0.02	-0.05	0.11
whmi	0.02	-0.10	0.10	0.03	-0.03	-0.15	-0.08	-0.06	-0.04	0.03	-0.09	0.06	0.10	-0.15	-0.13
whms	-0.08	-0.01	-0.01	0.03	0.00	0.08	-0.04	-0.01	0.07	0.03	-0.03	-0.04	0.07	-0.09	-0.11
zygoml	-0.01	-0.11	0.10	0.03	-0.03	-0.16	-0.15	-0.14	-0.07	0.16	-0.13	0.14	0.05	-0.20	-0.29
zygomr	0.04	-0.12	0.11	-0.04	-0.03	-0.15	0.17	-0.15	-0.07	-0.17	-0.10	0.14	-0.10	-0.19	**-0.30**
zygool	-0.12	0.01	0.01	**0.54**	0.07	0.27	-0.11	0.04	0.02	-0.04	0.05	-0.07	-0.12	-0.05	-0.11
zygoor	0.14	0.00	0.03	**-0.52**	0.07	0.26	0.10	0.04	0.02	0.01	0.06	-0.05	0.05	-0.06	-0.07

Table 77: PCA coefficients for the cranial vault analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese (landmarks with the highest loadings [≥ |0.3|] are bolded; only the first five PCs are presented).

	PC1 Coefficients			**PC2 Coefficients**			**PC3 Coefficients**			**PC4 Coefficients**			**PC5 Coefficients**		
Landmark	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
astl	-0.02	0.05	0.06	0.05	0.00	0.04	-0.11	0.00	-0.11	-0.05	0.05	0.12	0.00	0.14	-0.01
astr	0.02	0.08	0.06	-0.06	0.00	0.03	0.12	0.01	-0.13	0.06	0.03	0.10	0.03	0.12	0.02
aubl	-0.08	0.05	0.03	0.03	-0.08	0.01	-0.02	-0.04	-0.12	0.00	0.12	0.04	0.04	0.09	-0.09
aubr	0.08	0.05	0.03	-0.04	-0.07	0.01	0.02	0.00	-0.13	0.00	0.10	0.05	-0.03	0.08	-0.05
bas	0.00	0.05	0.04	0.01	-0.21	0.00	0.00	0.04	-0.04	0.00	0.08	-0.03	-0.01	-0.26	0.02
brg	0.00	0.02	0.05	-0.03	-0.12	-0.23	0.04	-0.04	-0.16	0.00	0.03	-0.04	-0.01	0.00	**0.34**
eurl	-0.02	**-0.50**	**-0.40**	0.11	0.10	-0.04	-0.07	**-0.31**	**0.41**	0.13	-0.21	0.22	0.08	0.06	0.00
eurr	0.03	**-0.51**	**-0.43**	-0.13	0.07	-0.03	0.05	**-0.32**	**0.41**	-0.11	-0.18	0.21	-0.08	0.06	-0.11
fobl	-0.01	0.04	0.05	-0.01	-0.15	0.03	0.00	0.02	-0.03	0.00	0.06	-0.01	-0.05	-0.29	0.06
fobr	0.00	0.05	0.05	0.01	-0.16	0.02	-0.01	0.03	-0.04	0.00	0.05	-0.01	0.05	-0.29	0.06
glb	0.00	0.09	0.02	0.00	-0.21	-0.13	0.00	-0.04	0.04	0.00	0.11	-0.22	0.01	**0.36**	0.22
lam	-0.01	0.09	0.02	-0.01	0.00	-0.15	-0.01	**0.49**	-0.07	-0.02	**-0.37**	**0.33**	0.02	**0.35**	-0.02
ops	0.00	0.05	0.07	0.01	-0.11	0.05	0.00	0.01	-0.03	0.00	0.02	0.03	0.00	-0.25	0.08
porl	-0.07	0.04	0.03	0.03	-0.08	-0.01	-0.04	-0.05	-0.09	-0.02	0.13	0.02	0.01	0.07	-0.04
porr	0.07	0.05	0.04	-0.04	-0.07	-0.02	0.03	-0.01	-0.09	0.01	0.12	0.02	-0.01	0.05	-0.03
stpl	0.02	0.12	0.10	**0.31**	**0.45**	0.19	0.07	-0.01	0.00	0.22	0.11	-0.15	0.10	-0.07	-0.09
stpr	0.00	0.11	0.09	-0.26	0.44	0.15	-0.07	0.01	0.02	-0.19	0.09	-0.16	-0.13	-0.06	-0.03
xfbl	-0.03	0.04	0.03	0.10	0.09	0.05	0.07	0.12	0.08	0.14	-0.19	-0.25	0.15	-0.06	-0.19
xfbr	0.02	0.04	0.04	-0.10	0.10	0.04	-0.07	0.10	0.09	-0.15	-0.15	-0.26	-0.17	-0.08	-0.13

3D GM CVA Tables

Table 78: CVA coefficients for the whole cranium analysis comparing the pooled Korean and pooled Japanese populations (landmarks with the highest loadings are bolded).

Landmark	CV1 Coefficients		
	X	Y	Z
alarl	47.3865	-77.8557	**114.1481**
alarr	**166.9353**	**149.3297**	**-151.1572**
astl	26.1079	14.1284	-32.7330
astr	42.5119	-23.7768	15.9641
aubl	-88.5939	18.3548	-82.2847
aubr	37.8885	-58.5005	34.3414
bas	21.7663	-21.6297	24.1246
brg	16.1625	1.1581	39.5624
dacl	-55.7408	-28.0385	54.0748
dacr	-3.9953	16.4732	8.0426
ectl	22.0688	-76.3840	30.4708
ectr	-22.6625	89.3640	-35.5949
eurl	7.0308	-12.3746	15.4855
eurr	-5.9560	3.3952	-10.5160
fmal	**-167.3142**	17.9182	67.1753
fmar	**-93.1503**	11.2204	-39.4504
fmtl	34.0940	12.6232	-16.3167
fmtr	28.1405	**-104.3915**	20.3584
glb	-78.8793	-86.3905	-22.1361
lam	-8.6057	45.9398	-18.4977
nas	60.5586	43.1389	-21.9934
nlhil	-46.3487	-58.3785	-15.8613
nlhir	**-179.2196**	-52.7724	20.4899
obhi	75.1343	**125.6485**	**-105.9323**
obhs	3.5962	-34.7123	2.2541
ops	-75.8131	-0.8561	-44.5241
porl	**98.4082**	30.1728	72.8841
porr	8.9552	47.6662	-8.2992
stpl	-20.7921	-12.8668	-13.8293
stpr	11.9238	0.6931	25.4998
wfbl	35.5420	29.5925	-3.2508
wfbr	55.6404	53.0486	-1.2760
whmi	-75.7152	-36.2600	2.5132
whms	**90.3656**	**126.1596**	**-119.1959**
xfbl	20.1473	4.6765	5.6572
xfbr	-51.9900	-1.9455	-10.2202
zygool	3.0097	-76.2121	**106.3170**
zygoor	61.4025	-77.3562	**93.7058**

Table 79: CVA coefficients for the facial region analysis comparing the pooled Korean and pooled Japanese populations (landmarks with the highest loadings are bolded).

Landmark	**CV1 Coefficients**		
	X	**Y**	**Z**
alarl	21.7399	-54.5276	22.6375
alarr	46.4748	**98.6009**	-35.5907
dacl	-21.8101	-8.9901	20.2893
dacr	29.9875	-7.9602	18.1357
ectl	-13.0711	-53.4235	-14.9920
ectr	-45.2686	31.8662	-7.3472
fmal	**-82.0939**	12.3034	18.5113
fmar	-53.5821	15.3252	-43.0935
fmtl	-23.9381	-7.0328	14.5291
fmtr	-23.0884	**-61.1303**	12.0078
glb	-49.0779	-35.0033	-11.4135
jugl	6.1053	25.1100	10.7984
jugr	**60.2628**	10.3535	34.7987
nas	48.5617	38.9612	-9.4125
nlhil	-40.1020	-17.5202	-1.6145
nlhir	-81.4646	-32.3615	-5.3994
obhi	41.9281	**64.7844**	-46.0257
obhs	36.2835	-25.3137	19.4701
wfbl	37.0957	6.9215	-8.1778
wfbr	20.3853	25.2039	-0.3987
whmi	-29.7555	18.8474	-0.9847
whms	57.5781	**80.4733**	**-75.8560**
zygoml	19.8660	-15.6719	-4.4590
zygomr	-1.5178	-8.9486	-22.5345
zygool	-3.0220	**-63.9860**	**63.7397**
zygoor	41.5236	-36.8811	52.3821

Table 80: CVA coefficients for the cranial vault analysis comparing the pooled Korean and pooled Japanese populations (landmarks with the highest loadings are bolded).

Landmark	**CV1 Coefficients**		
	X	**Y**	**Z**
astl	15.4852	-6.0305	-5.0933
astr	17.1157	-4.4069	6.7710
aubl	**-133.4371**	**-84.0474**	-6.0802
aubr	38.6250	-18.8701	43.2866
bas	-3.0429	48.7898	22.5328
brg	12.6985	31.2745	4.0889
eurl	5.6474	18.6707	23.2267
eurr	5.9638	-18.3498	-9.5665

Landmark	CV1 Coefficients		
	X	Y	Z
fobl	17.0586	-57.6912	-12.5981
fobr	36.2666	0.4273	10.7934
glb	-42.5216	-33.9264	33.1273
lam	-25.6423	-8.2354	-36.8131
ops	-52.7758	-12.7690	-11.1470
porl	**112.5078**	**79.4493**	-23.1979
porr	-28.3845	40.4902	-27.7755
stpl	-17.8783	-5.7337	-2.3563
stpr	6.8951	20.0986	13.9503
xfbl	32.6557	19.6475	-7.5911
xfbr	2.7629	-8.7875	-15.5580

Table 81: CVA coefficients for the whole cranium analysis comparing the pooled Korean and pooled Japanese populations with the sexes separated (landmarks with the highest loadings are bolded).

Landmark	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
	X	Y	Z	X	Y	Z	X	Y	Z
alarl	-52.05	**93.94**	**-122.29**	55.23	61.85	-27.31	-52.83	**-142.38**	20.11
alarr	**-156.35**	**-156.88**	**160.87**	-3.47	-47.87	24.02	**-196.55**	39.11	-34.93
astl	-20.39	-3.02	31.78	-32.88	-34.56	7.53	-22.25	**-94.42**	2.02
astr	-38.47	18.02	-11.03	-7.21	-24.61	-48.12	-43.60	73.22	-21.11
aubl	88.81	-16.91	89.46	55.43	-16.80	-4.05	-20.77	14.26	**-103.38**
aubr	-42.47	61.67	-33.00	37.36	-22.05	-22.62	23.49	0.44	-0.84
bas	-20.23	16.45	-19.93	-30.83	6.85	-51.28	-42.32	16.02	-13.87
brg	-16.66	1.00	-37.28	-11.33	1.01	-18.38	5.66	-11.16	-13.26
dacl	66.17	22.95	-51.04	**-98.73**	10.34	19.57	-20.81	77.86	-36.28
dacr	9.80	-9.42	-12.19	-52.53	-78.24	26.13	47.54	-64.34	-2.85
ectl	-21.10	82.31	-31.44	-34.51	**-126.37**	-38.24	-9.03	**143.01**	26.42
ectr	23.37	-81.65	44.54	-37.16	**106.32**	-2.97	-26.10	**-118.53**	-72.92
eurl	-20.31	16.11	-15.37	51.36	-1.74	0.75	81.93	-28.82	-0.84
eurr	6.03	-9.67	9.99	-30.31	12.53	-7.08	18.94	42.82	-0.70
fmal	**157.85**	-42.28	-44.56	22.65	**149.38**	**-167.81**	-11.64	3.20	-32.59
fmar	88.06	-10.36	37.77	73.63	-78.64	22.13	-8.14	52.47	-1.08
fmtl	-34.51	0.46	5.06	35.38	0.22	78.20	48.30	**-106.55**	38.62
fmtr	-29.69	**97.32**	-21.43	-37.08	-11.14	-37.71	54.89	80.87	52.87
glb	72.12	67.95	24.73	**108.00**	**186.54**	-89.09	-55.29	73.31	45.81
lam	10.08	-46.00	16.70	3.20	10.92	-5.84	-15.07	-13.59	15.76
nas	-53.96	-37.91	14.41	-80.41	-89.43	89.57	21.54	6.45	-16.18
nlhil	53.64	33.05	4.98	-3.12	42.69	-12.28	-11.07	**162.90**	**117.14**
nlhir	**167.20**	70.62	-8.53	-26.27	-39.37	-29.08	**166.36**	-72.52	**-93.32**
obhi	-74.52	**-126.28**	**100.03**	50.64	14.68	-14.04	-55.08	-44.96	**178.11**
obhs	-1.94	39.49	-4.34	-48.86	24.46	3.59	34.62	-35.46	34.14
ops	72.97	-0.85	44.06	30.60	8.20	55.90	17.49	10.54	-15.64
porl	**-97.74**	-30.05	-78.31	-48.47	-1.32	11.98	22.58	6.11	45.97

Landmark	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
	X	Y	Z	X	Y	Z	X	Y	Z
porr	-9.43	-52.01	-0.99	10.04	28.44	34.53	4.10	5.89	105.40
stpl	31.10	4.00	5.16	26.52	-8.84	-8.65	**-133.13**	89.71	**104.66**
stpr	-12.45	-0.93	-26.15	85.65	8.56	45.44	-65.64	-1.51	-43.46
wfbl	-51.74	-16.42	1.89	88.90	**-107.82**	18.42	**122.43**	-22.84	-11.51
wfbr	-56.77	-51.01	4.85	-0.45	19.84	-22.01	24.22	-70.02	-12.66
whmi	70.65	37.05	-0.45	-6.47	38.30	11.34	31.82	-19.92	-29.73
whms	-86.26	**-132.18**	**117.87**	9.71	-21.77	97.41	-24.86	-3.67	-96.51
xfbl	-8.36	-5.73	-7.09	**-107.71**	39.29	11.29	2.22	-2.84	-8.93
xfbr	58.76	9.01	14.64	-59.98	-14.10	-12.87	18.91	-71.42	-22.14
zygool	-5.91	74.14	**-101.85**	1.97	-3.92	-20.84	45.15	-14.39	**-129.37**
zygoor	-65.31	84.01	**-101.52**	11.49	-41.92	82.49	21.99	41.20	27.05

Table 82: CVA coefficients for the facial region analysis comparing the pooled Korean and pooled Japanese populations with the sexes separated (landmarks with the highest loadings are bolded).

Landmark	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
	X	Y	Z	X	Y	Z	X	Y	Z
alarl	-36.33	51.65	-24.99	24.50	44.54	2.17	5.17	57.33	1.09
alarr	-34.67	**-86.13**	37.45	-15.45	-62.24	8.80	**104.01**	23.41	18.65
dacl	52.14	13.38	-21.62	-57.75	-19.89	10.22	-15.52	-11.54	35.41
dacr	-8.76	13.61	-17.47	-58.22	-3.27	-17.41	-53.65	-23.20	12.04
ectl	-5.03	**99.26**	20.63	45.80	-76.82	-13.40	18.49	-35.01	-39.25
ectr	46.80	-38.58	8.46	10.35	25.92	0.31	-4.91	23.92	31.81
fmal	73.99	-43.38	12.89	16.68	53.37	-56.67	**-83.66**	45.14	21.49
fmar	38.61	-22.57	49.39	44.39	-4.89	0.83	-5.64	-48.18	4.77
fmtl	7.04	1.04	-21.71	46.72	14.73	11.95	9.48	3.48	-2.08
fmtr	26.73	59.51	-2.40	4.97	17.73	-21.24	30.04	-26.01	-0.58
glb	19.84	-19.52	16.43	71.03	**106.67**	-18.15	18.96	-45.52	-49.47
jugl	19.43	-27.62	-18.57	-46.01	1.31	9.89	6.17	29.86	-11.98
jugr	-69.58	-16.26	-42.10	-4.18	5.07	-2.16	-26.84	-21.82	-30.07
nas	-31.92	-6.66	-21.66	-46.63	-74.01	65.38	3.19	19.13	-5.88
nlhil	40.06	-0.13	-3.17	9.93	26.43	-10.87	-23.89	-59.21	-90.03
nlhir	64.26	34.87	24.34	28.99	7.22	-23.59	**-123.65**	-2.23	61.29
obhi	-56.11	-54.92	50.66	12.74	-20.78	-14.42	25.37	75.04	**-149.75**
obhs	-17.59	28.33	-17.32	-48.04	13.86	-14.41	8.62	36.73	-41.07
wfbl	-43.56	10.31	8.34	8.92	-37.87	0.74	18.76	-49.80	-3.86
wfbr	-9.07	-15.36	6.54	-17.36	-16.96	-8.51	43.05	75.88	21.01
whmi	11.84	-11.90	-7.42	33.15	-3.70	17.46	-40.62	69.33	-4.11
whms	-44.04	-74.28	34.14	-29.14	-37.92	**106.99**	39.08	-16.69	60.74
zygoml	-11.83	-2.25	17.62	-20.90	30.84	-23.11	43.16	-67.85	32.90
zygomr	0.05	12.15	26.15	5.66	-10.52	9.79	40.20	1.54	32.84
zygool	5.35	42.36	-52.38	-3.46	40.95	-36.37	-28.77	-61.55	**126.22**
zygoor	-37.68	53.08	-62.23	-16.66	-19.78	15.80	-6.57	7.84	-32.13

Table 83: CVA coefficients for the cranial vault analysis comparing the pooled Korean and pooled Japanese populations with the sexes separated (landmarks with the highest loadings are bolded)

	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
Landmark	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
astl	-5.35	6.42	-12.37	26.06	-8.56	-34.00	-5.10	34.25	-56.23
astr	-11.13	19.99	-4.47	20.10	47.63	-4.25	-6.65	-7.87	36.31
aubl	**119.77**	**94.31**	3.98	-70.16	11.35	-14.12	5.39	74.87	24.45
aubr	-38.54	8.23	-49.78	21.09	-49.44	-9.62	**-92.61**	53.83	4.42
bas	2.12	-35.15	1.88	26.11	43.53	84.26	30.81	40.40	-4.16
brg	-14.06	-34.28	-9.08	1.51	-5.38	-16.08	-11.21	8.03	-8.78
eurl	-22.64	-17.31	-25.69	-49.62	3.43	0.98	9.56	1.61	-25.29
eurr	2.84	18.00	14.32	19.97	1.59	5.55	71.13	-1.31	31.51
fobl	-3.66	42.80	-1.31	8.91	-66.39	-19.52	49.58	6.97	-69.92
fobr	-40.31	7.35	-16.33	-5.50	38.63	-44.33	-51.41	-48.86	56.21
glb	28.81	39.78	-21.17	-35.81	13.71	47.72	-24.73	-6.65	-11.63
lam	22.96	10.11	45.22	-9.65	6.10	22.68	-4.36	-14.66	-10.62
ops	40.94	-5.90	14.08	-43.44	-52.42	-4.18	18.80	7.06	40.12
porl	**-102.20**	**-92.19**	30.60	62.47	-18.81	15.38	-30.05	-55.46	-1.63
porr	21.82	-34.43	25.47	-34.57	38.94	-3.06	44.16	-84.83	-13.79
stpl	6.62	14.94	-4.97	-48.63	36.10	-31.10	81.02	-76.97	53.39
stpr	-24.18	-32.26	-14.56	**-92.25**	-51.98	6.91	**99.07**	53.27	4.45
xfbl	-4.47	-22.21	13.40	**95.16**	1.71	19.91	-75.21	4.83	-11.82
xfbr	20.67	11.61	10.80	**108.26**	10.25	-23.12	**-108.19**	11.50	-36.99

Table 84: CVA coefficients for the whole cranium analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese (landmarks with the highest loadings are bolded).

	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
Landmark	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
alarl	-58.27	57.75	-79.85	-4.03	-11.73	-103.33	29.33	147.08	-22.41
alarr	**-171.06**	**-113.40**	**137.13**	-17.23	-65.42	94.75	-37.82	**-114.79**	-30.12
astl	-29.37	-5.54	16.64	-7.61	-32.68	33.28	13.99	13.93	26.75
astr	-44.60	26.79	-6.61	18.70	-16.77	-38.06	-46.14	29.08	19.25
aubl	94.59	3.11	**111.95**	-52.62	-42.13	-87.21	**113.37**	-26.65	70.11
aubr	-55.33	45.82	-17.00	15.96	18.80	-19.80	26.86	51.12	-56.83
bas	-8.75	32.11	-23.33	-77.41	-29.29	13.20	70.38	18.21	-39.27
brg	-14.36	5.64	-32.44	-8.35	1.40	-8.83	-1.23	-32.21	-35.25
dacl	99.82	16.40	-14.75	**-124.94**	42.98	-76.24	61.62	-11.95	-61.02
dacr	62.14	5.62	-55.66	**-197.97**	-13.07	40.57	**104.28**	-79.93	**127.82**
ectl	-80.58	87.85	14.70	-0.23	19.26	-26.00	**239.66**	-43.90	**-163.03**
ectr	-44.76	-94.49	53.28	83.84	-1.38	-57.78	**151.68**	-21.65	45.12
eurl	-7.40	-1.58	-26.11	33.10	36.05	17.63	-60.76	2.18	6.26
eurr	29.80	6.59	17.18	-37.42	-25.34	-14.47	-32.67	0.43	2.57

Landmark	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
	X	Y	Z	X	Y	Z	X	Y	Z
fmal	**117.20**	7.14	-66.26	**144.48**	-49.92	-21.40	44.53	-28.00	-0.58
fmar	67.92	-13.54	17.56	94.23	-14.72	84.62	-11.11	30.27	-36.03
fmtl	15.17	-18.10	-0.62	82.90	17.82	-62.39	**-375.68**	-14.67	**191.66**
fmtr	32.17	**146.01**	-23.91	-22.49	-66.55	20.02	**-232.90**	-6.39	-30.81
glb	64.71	87.27	36.39	20.66	20.77	-46.11	64.70	3.93	32.15
lam	21.43	-37.16	14.68	-26.66	-13.16	1.07	-3.18	-37.93	24.01
nas	**-104.17**	-53.53	37.42	70.78	-3.62	-35.59	30.00	28.69	8.41
nlhil	56.13	95.69	-3.52	26.62	-13.58	28.91	-65.23	**-105.60**	39.88
nlhir	**170.01**	5.31	-26.67	52.95	65.39	24.19	37.89	**114.45**	-27.01
obhi	-51.28	-47.57	-5.32	-32.53	**-164.27**	**108.65**	-83.18	**-107.73**	338.32
obhs	17.89	-4.97	-19.06	-32.41	18.37	87.34	-36.38	**155.27**	-84.14
ops	65.44	0.92	37.43	38.76	3.41	17.71	14.74	-5.88	21.93
porl	**-113.32**	-53.39	-81.04	69.47	29.94	34.53	**-110.09**	30.79	-63.89
porr	-15.80	-59.92	-17.97	28.63	47.95	53.63	-26.09	-57.15	21.66
stpl	17.14	26.84	27.52	19.48	-30.88	-19.20	-8.23	1.59	-17.44
stpr	-26.81	-23.51	-39.97	1.33	41.23	10.48	55.27	24.22	30.23
wfbl	-42.92	-32.76	0.74	-27.84	32.00	14.58	62.69	-58.46	-13.42
wfbr	-67.22	-60.12	-12.42	9.48	-10.90	40.06	4.08	22.29	-11.75
whmi	78.03	6.54	0.38	-20.26	52.20	-13.41	65.06	53.38	10.11
whms	-87.18	**-142.69**	**127.08**	14.82	-14.86	47.41	-86.55	32.15	-56.43
xfbl	-12.36	-7.98	-20.39	-52.49	12.32	32.72	49.38	-10.10	2.12
xfbr	66.31	9.07	38.61	0.41	-10.76	-56.52	-35.27	-10.43	-16.04
zygool	-2.12	71.05	-81.91	-22.95	86.10	-7.61	35.33	-91.37	**-145.83**
zygoor	-38.23	26.75	-33.86	-61.17	85.02	**-111.36**	-22.36	**105.77**	**-107.05**

Table 85: CVA coefficients for the facial region analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese (landmarks with the highest loadings are bolded).

Landmark	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
	X	Y	Z	X	Y	Z	X	Y	Z
alarl	-30.13	36.56	-26.72	4.09	23.05	-15.95	-15.04	-58.27	-23.55
alarr	-53.57	**-78.19**	51.73	3.02	-65.91	-3.26	-1.26	34.46	37.06
dacl	21.10	-2.25	-8.73	-63.96	45.19	-29.93	**-88.03**	10.95	13.16
dacr	-25.81	25.70	-38.27	**-119.66**	-14.97	14.09	**-115.34**	40.45	-45.49
ectl	-27.29	38.67	50.37	30.55	-17.10	-47.35	**-109.51**	**-94.47**	60.17
ectr	-7.64	-16.52	17.76	**124.85**	10.60	-36.80	-54.43	**79.61**	-10.81
fmal	62.53	-16.30	-8.22	76.42	-6.36	-25.48	-11.93	-16.24	13.32
fmar	52.41	4.99	27.42	24.55	-7.51	51.42	2.33	68.23	-11.58
fmtl	59.44	15.15	-29.72	43.10	7.45	-37.61	**164.60**	34.08	-91.45
fmtr	49.25	56.20	-13.29	8.19	-15.05	26.18	**90.87**	-61.16	31.87
glb	25.47	41.19	21.21	59.52	20.54	-32.49	-32.07	31.09	-9.54
jugl	3.94	-3.18	1.12	-41.92	-33.35	0.16	-12.43	47.22	46.22

Landmark	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
	X	Y	Z	X	Y	Z	X	Y	Z
jugr	-31.47	-27.94	-45.43	-50.41	24.47	-0.97	65.73	-27.56	-23.30
nas	-39.29	-46.27	12.78	4.10	-7.20	-6.90	57.84	-17.37	-0.54
nlhil	50.22	40.37	4.11	0.24	-51.45	-5.14	18.35	10.66	1.87
nlhir	**78.52**	8.90	-12.37	32.90	66.12	46.21	-5.75	-16.55	-9.02
obhi	-18.97	5.31	-30.88	-53.00	**-173.39**	**141.63**	34.53	64.68	**-118.20**
obhs	-20.28	-6.02	-20.09	-18.27	23.02	12.43	49.34	-92.31	20.96
wfbl	-39.03	0.41	3.74	-33.74	1.96	21.19	-31.12	30.78	6.33
wfbr	-25.46	-28.58	-2.39	0.13	-21.77	13.44	-8.80	-26.93	6.14
whmi	28.31	-61.44	-1.67	-18.37	**113.50**	-14.15	-39.63	-4.77	-26.51
whms	-54.47	**-94.10**	62.16	19.85	17.30	51.44	59.02	7.58	-18.67
zygoml	-20.32	48.11	-4.94	10.12	-62.81	12.63	18.95	31.23	-19.54
zygomr	-1.57	10.84	33.52	-12.35	-39.40	2.25	-26.09	-44.22	31.27
zygool	-7.60	45.68	-17.13	5.54	**88.99**	-68.05	-31.61	15.14	**108.16**
zygoor	-28.28	2.70	-26.06	-35.49	**74.07**	-68.98	21.46	-46.30	31.65

Table 86: CVA coefficients for the cranial vault analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese (landmarks with the highest loadings are bolded).

Landmark	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
	X	Y	Z	X	Y	Z	X	Y	Z
astl	-1.04	-12.89	-9.56	-27.32	31.83	25.07	-5.96	12.74	12.04
astr	-22.44	17.35	-12.79	5.19	-22.54	8.07	21.14	-35.45	9.79
aubl	**155.33**	**113.89**	-12.49	8.63	-20.15	22.79	-14.51	-21.73	-51.96
aubr	-32.34	14.23	-34.04	-14.50	13.16	-23.38	55.82	0.98	33.42
bas	40.03	-52.41	-49.31	**-64.62**	-0.81	32.65	**-79.53**	**72.65**	0.25
brg	-10.47	-25.56	-9.10	-8.73	-18.16	2.88	-9.82	3.64	-24.75
eurl	-21.92	-30.18	-1.84	27.79	7.52	-41.63	40.72	-27.26	-17.06
eurr	5.08	24.81	-4.57	-13.45	-0.38	25.24	37.42	25.08	8.15
fobl	-41.59	**61.33**	15.54	33.74	5.67	-5.85	20.53	-57.48	-42.02
fobr	-16.35	2.79	13.33	-46.62	-3.29	-32.22	-39.46	12.47	54.73
glb	14.05	25.33	-31.72	51.18	22.40	-9.42	-37.89	-10.48	25.82
lam	25.43	7.92	28.76	7.72	0.78	21.97	-6.81	-17.79	-14.77
ops	25.74	12.22	-2.83	**60.01**	3.62	24.04	20.05	-10.02	-3.05
porl	**-140.77**	**-91.24**	55.90	10.53	-7.03	-36.38	36.50	8.38	36.74
porr	0.65	-57.16	40.70	45.34	14.96	-13.19	-39.22	24.44	-22.05
stpl	14.04	19.18	-9.57	13.18	-14.38	18.48	12.71	28.78	-0.46
stpr	-6.98	-31.92	8.03	-6.99	7.22	-37.07	-37.11	-29.50	1.56
xfbl	-7.178	-36.16	9.45	-51.82	19.04	-0.17	-24.95	6.03	1.08
xfbr	20.72	38.47	6.11	-29.26	-39.47	18.13	50.35	14.51	-7.46

Table 87: CVA coefficients for the whole cranium analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese with only females (landmarks with the highest loadings are bolded).

	CV1 Coefficients			**CV2 Coefficients**			**CV3 Coefficients**		
Landmark	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
alarl	**-262.33**	**257.41**	-95.18	121.87	-105.88	**-253.59**	**-229.06**	-27.33	-74.33
alarr	**-479.76**	-175.17	108.23	53.05	113.47	95.30	-66.53	-78.75	**213.51**
astl	-19.00	-54.30	18.92	11.73	-50.34	49.94	-89.70	-107.68	-126.55
astr	-121.90	170.34	70.22	-17.91	15.51	-50.89	75.98	13.15	53.69
aubl	123.42	15.14	199.77	58.58	-64.74	-43.40	66.84	130.67	150.22
aubr	-142.29	29.27	-25.82	69.42	49.95	-44.51	-8.02	-91.34	-170.66
bas	60.58	-19.55	-1.79	-121.38	8.31	-0.10	90.95	37.80	31.05
brg	-7.61	-27.27	-41.28	8.62	-18.36	-10.60	5.96	30.38	42.12
dacl	114.29	-77.34	-50.67	169.81	-82.25	-52.64	**-380.66**	-25.16	64.02
dacr	124.46	119.43	-135.25	156.50	-33.04	57.56	**-423.59**	138.86	**-293.06**
ectl	35.90	**337.70**	117.14	-181.97	**314.47**	-43.46	**-225.64**	156.53	194.32
ectr	-92.31	**-475.66**	-33.51	189.28	-150.30	-19.68	-160.08	-159.20	-18.38
eurl	-51.50	-32.22	-21.15	24.89	41.55	37.52	11.88	14.31	-30.39
eurr	88.63	15.56	16.59	-42.87	-0.19	-26.71	-21.26	15.43	49.66
fmal	**311.63**	-17.00	-162.11	**347.35**	-67.30	**-235.82**	-62.70	-145.55	195.26
fmar	178.96	123.93	-48.94	-152.37	-7.02	138.07	8.85	29.37	-126.17
fmtl	**-290.48**	-176.11	164.01	**-232.33**	-120.91	79.39	**600.59**	53.17	**-299.86**
fmtr	-131.26	**510.05**	-45.97	-103.44	52.14	-46.23	**399.89**	-18.77	46.26
glb	19.48	22.62	78.60	-103.18	80.85	-43.67	26.79	107.59	-3.50
lam	-4.93	-87.31	28.43	-3.58	-56.71	33.18	53.93	37.33	-21.71
nas	4.82	-148.13	152.71	-3.44	89.88	-36.05	18.43	-33.31	143.88
nlhil	**320.07**	-93.43	105.03	-101.95	113.59	93.84	160.27	-15.09	152.42
nlhir	**504.25**	166.10	**-212.29**	14.91	-35.00	88.89	7.75	-5.64	-188.37
obhi	**-249.95**	-192.56	**384.47**	-136.64	-65.32	259.16	186.44	-183.42	98.98
obhs	-128.65	-94.72	-19.79	-27.85	83.27	212.95	132.65	-112.54	-106.44
ops	18.91	80.87	0.11	-0.05	-25.75	53.71	-85.86	-56.43	-29.98
porl	-105.89	-85.29	-72.12	15.41	44.10	-39.07	37.09	-26.64	-63.06
porr	59.57	-64.48	-110.11	-20.72	61.14	57.79	56.40	87.13	145.76
stpl	4.02	87.18	67.26	110.23	-52.22	8.23	190.06	-71.72	-5.72
stpr	-55.01	-9.49	-19.90	113.17	52.88	-11.10	75.65	-6.22	57.41
wfbl	-61.28	97.89	-48.47	145.88	-53.67	8.66	-138.00	15.38	53.02
wfbr	-15.24	**-261.78**	-16.97	73.88	3.89	20.33	-50.50	1.25	88.60
whmi	194.53	-35.87	60.70	-25.43	106.66	-54.40	-163.26	-46.62	-27.77
whms	**-236.61**	-90.38	150.12	134.65	**-313.30**	42.06	63.18	107.13	-95.93
xfbl	134.92	-80.27	-111.31	**-260.50**	12.44	-4.58	**-227.38**	51.70	54.96
xfbr	96.62	29.37	96.33	-176.07	2.38	-29.78	-94.29	-23.03	-9.71
zygool	107.43	**277.16**	**-760.75**	-7.14	111.74	-141.93	93.48	**337.50**	**-289.56**
zygoor	-46.50	-41.68	**214.74**	-100.40	-55.93	-148.34	63.48	-130.24	**260.86**

Table 88: CVA coefficients for the facial region analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese with only females (landmarks with the highest loadings are bolded).

	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
Landmark	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
alarl	-97.62	**107.63**	-34.95	-0.90	-95.49	-37.64	-70.11	-30.16	12.41
alarr	**-183.05**	**-173.69**	49.15	5.27	-9.32	59.53	30.23	57.56	26.29
dacl	-0.45	-60.52	-46.25	-14.30	41.56	-67.02	-87.91	30.87	19.26
dacr	-3.17	**110.12**	-11.78	**-145.12**	-54.50	-1.54	**-118.76**	-32.26	-63.27
ectl	4.88	**187.67**	**147.43**	-12.49	27.23	-3.92	**-107.28**	**-139.06**	50.86
ectr	-64.80	**-172.60**	-1.99	**151.57**	24.36	-20.84	**-126.53**	72.71	32.44
fmal	91.24	-78.31	23.87	93.36	-11.97	-51.93	-95.46	-54.69	87.05
fmar	47.86	10.97	-86.36	10.46	39.74	77.09	-27.97	42.44	-29.30
fmtl	-67.69	-89.03	75.31	**154.33**	-35.41	-96.28	**258.30**	52.46	**-122.81**
fmtr	-87.37	**207.00**	-45.71	80.11	45.84	1.73	**252.15**	-49.98	48.87
glb	94.70	38.11	41.17	3.96	43.27	-2.30	-83.85	-10.22	29.71
jugl	68.30	-34.74	-59.71	-47.47	-39.10	19.39	25.97	58.75	64.39
jugr	23.66	-7.24	6.75	-24.45	-2.52	-51.19	54.10	-39.89	-60.93
nas	-67.99	-76.20	15.01	-28.22	56.96	21.69	80.28	44.53	38.07
nlhil	**182.67**	4.44	85.31	-30.56	21.89	2.37	48.41	-76.17	32.21
nlhir	**252.05**	93.38	**-128.65**	23.69	6.49	28.05	-26.54	18.98	-51.02
obhi	-18.97	**-134.89**	**110.47**	-83.46	-26.62	**231.19**	**100.76**	79.39	-97.02
obhs	-93.64	-56.26	-65.45	51.66	-40.35	57.23	92.40	-20.17	-80.24
wfbl	-9.38	73.02	18.64	-95.47	36.97	36.71	-87.08	-33.36	-8.29
wfbr	20.72	-75.28	10.39	-64.58	-73.28	9.60	-73.09	34.34	13.91
whmi	34.18	**-119.58**	29.40	-62.88	99.23	-26.24	-39.32	-56.50	-17.79
whms	-85.57	-48.58	-14.73	58.01	-68.81	26.50	4.06	43.70	-38.07
zygoml	-46.10	40.57	12.20	12.36	-12.53	-16.87	-30.07	85.83	21.17
zygomr	-21.74	46.78	-2.51	-23.97	-68.32	25.27	-35.39	-33.88	-12.93
zygool	24.17	**216.43**	**-246.01**	29.56	**105.29**	**-150.48**	20.99	48.92	37.08
zygoor	3.13	-9.20	**119.02**	-40.46	-10.58	-70.10	41.69	-94.12	67.95

Table 89: CVA coefficients for the cranial vault analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese with only females(landmarks with the highest loadings are bolded).

	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
Landmark	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
astl	39.63	38.67	-13.24	2.11	5.05	-49.89	81.43	0.90	-92.42
astr	54.86	-38.34	57.98	-27.16	18.67	13.14	-20.26	30.31	14.31
aubl	**-142.25**	**-133.49**	2.06	**-110.14**	-8.56	-32.72	**-91.95**	-78.47	34.41
aubr	35.49	24.04	30.63	-60.95	35.07	30.47	-68.77	**93.63**	-22.54
bas	-64.01	48.45	9.41	**103.50**	34.06	-19.12	20.99	-8.99	19.42

brg	19.56	56.96	2.65	20.76	8.28	-11.41	18.10	-17.79	31.47
eurl	35.91	32.36	-32.65	26.55	-2.17	33.10	**-121.74**	3.90	8.21
eurr	16.42	-17.85	26.30	53.72	-15.08	6.29	**-121.07**	-12.01	10.38
fobl	59.03	-9.18	-50.22	-6.40	-55.18	-18.72	-64.92	57.11	64.70
fobr	-7.80	-45.14	20.70	22.72	5.25	57.26	-35.77	-55.51	-54.11
glb	-3.61	-15.16	30.05	-45.63	-23.25	3.73	27.75	2.68	-41.57
lam	-18.45	-14.85	-52.78	-10.72	-20.40	-29.69	51.20	21.98	31.37
ops	-24.03	-18.54	47.60	-18.76	3.16	-38.16	67.18	3.44	3.84
porl	**107.39**	89.84	-74.01	26.43	31.91	**95.33**	68.53	**96.52**	-30.85
porr	-23.34	23.61	-19.44	2.76	-56.70	-23.83	**115.48**	**-140.01**	22.17
stpl	74.30	-76.17	78.02	-24.32	-17.41	-4.59	-64.31	-41.64	37.91
stpr	74.81	67.32	-37.85	-9.06	14.69	23.18	58.47	65.36	-62.49
xfbl	**-100.87**	44.79	-18.80	29.96	9.08	-32.22	**108.40**	7.76	-13.89
xfbr	**-133.03**	-57.31	-6.41	24.64	33.54	-2.17	-28.71	-29.16	39.70

Table 90: CVA coefficients for the whole cranium analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese with only males (landmarks with the highest loadings are bolded).

	CV1 Coefficients			**CV2 Coefficients**			**CV3 Coefficients**		
Landmark	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
alarl	22.27	-120.36	83.80	24.92	-93.95	**144.16**	-37.48	**198.10**	-99.56
alarr	**124.57**	**134.11**	**-165.05**	77.62	**146.69**	**-155.91**	24.32	**-137.97**	36.01
astl	19.56	-23.10	-17.46	35.51	14.48	-44.38	9.54	13.91	12.79
astr	22.00	13.88	17.98	-23.51	26.57	48.99	12.94	-7.42	27.43
aubl	-90.24	21.46	**-104.34**	92.23	52.52	**132.91**	**174.97**	12.68	**111.76**
aubr	66.64	-69.00	-26.35	15.50	-18.54	-25.51	68.29	25.57	-96.03
bas	44.91	-35.26	28.95	80.52	69.65	-36.60	**141.05**	51.53	-44.26
brg	9.67	-19.40	27.58	17.93	-1.51	8.76	-7.36	-12.77	-47.31
dacl	**-155.56**	-22.67	35.82	**219.91**	-3.37	19.99	-44.26	22.52	-94.22
dacr	**-102.75**	1.62	4.78	**307.32**	-86.25	11.83	-53.57	-98.95	**141.65**
ectl	67.53	-88.45	16.05	-0.18	-24.90	-8.00	**260.81**	**-105.41**	**-174.52**
ectr	-14.29	40.74	**-102.25**	8.66	27.28	**144.15**	**128.99**	-23.91	73.11
eurl	27.02	-7.82	26.63	-44.08	-33.34	-22.27	-83.13	8.08	16.54
eurr	-33.03	-1.27	-16.13	56.52	35.13	25.86	-57.84	-1.27	3.05
fmal	**-178.13**	45.50	79.06	2.17	24.12	-27.96	-33.76	-77.54	**114.99**
fmar	-78.42	11.22	-15.55	**-138.58**	6.04	-64.01	18.16	74.79	**-140.37**
fmtl	-24.48	-21.19	30.56	**-263.28**	-26.35	96.07	**-298.37**	51.70	**150.90**
fmtr	-40.39	**-115.43**	27.19	-65.83	78.04	-58.45	**-174.63**	-97.58	-7.08
glb	-93.16	-79.70	-52.79	-45.03	-61.81	81.52	**127.79**	-8.03	66.79
lam	-31.88	32.46	-14.28	26.69	8.46	13.99	-33.20	-38.27	14.89
nas	**157.69**	39.36	14.17	**-103.17**	80.28	26.86	84.97	34.40	26.38
nlhil	-59.69	-70.79	68.38	-88.25	-16.68	-30.06	-39.85	**-217.52**	82.95
nlhir	-79.10	9.50	-30.42	-84.91	-17.78	7.84	10.52	**198.37**	-49.54
obhi	32.84	25.65	83.21	1.69	**178.46**	**102.91**	-43.19	**-117.93**	**422.42**

Landmark	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
	X	Y	Z	X	Y	Z	X	Y	Z
obhs	-14.82	-5.38	36.04	37.11	55.69	-89.75	18.05	**163.87**	**-188.69**
ops	**-101.99**	8.98	-43.87	-90.95	-29.34	-0.04	-35.82	-22.30	49.71
porl	**147.04**	49.53	74.70	**-100.53**	-22.85	-57.70	**-156.17**	13.92	-75.09
porr	39.53	80.81	56.89	-73.54	-47.27	-46.21	-70.44	-32.09	24.46
stpl	-45.58	5.18	-0.42	-24.25	22.80	39.79	51.33	-51.55	-57.57
stpr	46.31	24.41	46.82	-12.08	-27.87	-22.94	**102.41**	57.54	58.38
wfbl	**115.90**	-12.02	-23.38	43.08	-51.79	-62.41	-29.89	-77.02	-3.96
wfbr	**123.43**	82.47	25.98	9.22	-14.12	2.54	-42.57	72.66	25.18
whmi	-83.07	-37.49	-10.38	26.37	-39.16	5.26	48.25	83.31	11.49
whms	89.72	**151.88**	**-162.97**	-21.25	-9.71	**-118.61**	-69.19	32.90	-73.24
xfbl	22.73	3.02	7.83	55.50	-20.86	-47.15	31.14	3.55	15.11
xfbr	-89.07	-30.07	-41.53	-14.62	0.65	64.26	-64.58	-16.17	-31.36
zygool	56.85	30.61	-75.00	33.46	-84.94	-16.77	72.61	-99.72	**-176.46**
zygoor	79.45	-53.00	**109.78**	22.09	-94.48	-42.96	-10.84	**124.02**	**-126.74**

Table 91: CVA coefficients for the facial region analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese with only males (landmarks with the highest loadings are bolded).

Landmark	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
	X	Y	Z	X	Y	Z	X	Y	Z
alarl	-13.81	65.75	-19.55	-16.63	83.60	-20.42	-4.79	-59.53	-38.94
alarr	-23.17	-77.33	43.89	-20.84	**-122.06**	16.97	-27.72	3.46	19.29
dacl	30.50	-26.41	-13.97	-87.65	48.82	9.39	-77.09	-3.08	13.10
dacr	-26.63	37.45	-28.28	**-134.62**	-11.78	8.97	-78.61	78.24	-37.17
ectl	-20.59	12.78	42.28	58.58	-14.66	-41.62	**-125.97**	**-91.15**	60.33
ectr	18.69	39.62	33.26	63.98	-12.00	-50.30	-49.10	**116.01**	-26.54
fmal	**90.91**	-7.36	-23.47	2.39	-19.46	21.57	9.47	19.83	-23.90
fmar	79.59	3.41	48.92	45.48	-20.70	31.36	20.14	27.57	27.48
fmtl	64.88	33.70	-41.98	32.93	15.48	-40.26	**143.66**	33.05	-77.04
fmtr	35.66	32.79	-25.70	5.37	-17.11	43.40	41.38	-48.38	12.63
glb	31.35	36.76	9.77	**116.26**	28.33	-23.71	2.38	54.60	-22.12
jugl	4.39	-1.05	9.41	-10.69	-13.13	0.54	-10.93	41.55	41.55
jugr	-25.54	-36.58	-67.66	-40.24	20.59	6.46	50.88	-32.01	-22.25
nas	-41.41	-44.22	-0.85	3.21	-27.78	-16.84	29.74	-59.29	-14.85
nlhil	32.46	38.64	-2.64	19.40	**-92.82**	10.55	27.68	14.24	14.15
nlhir	32.33	-12.17	-6.52	78.35	**108.76**	8.78	32.44	9.28	-1.42
obhi	-17.39	56.32	**-96.89**	-33.21	**-215.99**	68.49	7.71	27.93	**-140.13**
obhs	-34.45	-14.32	-8.11	-24.43	25.17	-49.05	32.37	**-130.97**	70.94
wfbl	-61.24	14.74	11.14	-14.06	-34.15	12.15	-11.72	47.07	11.29
wfbr	-36.97	-31.76	-3.90	13.51	14.72	21.11	12.17	-36.93	-2.77
whmi	26.26	-56.35	4.24	-17.52	**120.09**	-5.58	-36.40	-27.00	-28.81
whms	-43.76	**-105.82**	76.26	-0.13	60.35	69.13	68.60	20.05	-24.77

Landmark	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
	X	Y	Z	X	Y	Z	X	Y	Z
zygoml	-23.78	53.62	-12.63	1.20	-82.74	37.55	27.71	33.83	-29.16
zygomr	-6.40	1.75	53.19	-5.81	-31.74	-14.87	-21.90	-35.26	42.41
zygool	-35.21	-8.11	53.06	-0.45	86.68	-76.81	-68.06	35.96	**129.50**
zygoor	-36.66	-5.83	-33.28	-34.36	**103.51**	-26.97	5.97	-39.06	39.26

Table 92: CVA coefficients for the cranial vault analysis comparing the four populations of Joeseon Dynasty, Edo Period, Modern Korean, and Modern Japanese with only males(landmarks with the highest loadings are bolded).

Landmark	CV1 Coefficients			CV2 Coefficients			CV3 Coefficients		
	X	Y	Z	X	Y	Z	X	Y	Z
astl	15.77	-12.00	-32.08	-34.88	45.07	8.08	26.80	5.21	-25.52
astr	-9.60	23.67	2.69	-1.55	-30.57	16.10	11.02	-23.81	12.16
aubl	**188.96**	**137.84**	-4.80	10.31	-19.80	33.37	-69.31	-69.13	-73.26
aubr	-13.20	17.80	-47.75	-22.64	32.25	-20.15	18.27	59.00	66.13
bas	53.39	-56.27	-45.67	**-93.15**	22.70	10.63	**-111.82**	75.27	-6.71
brg	-7.06	-13.48	-14.31	-12.39	-21.09	5.50	-2.82	5.47	-6.83
eurl	-36.34	-25.72	-12.45	52.83	4.87	-43.77	4.22	-33.58	-13.82
eurr	17.50	23.90	5.22	-4.15	-3.86	41.06	-1.49	27.11	9.14
fobl	-31.01	73.57	-26.26	81.10	-16.47	-13.30	-9.62	-22.77	-18.24
fobr	-44.22	-3.32	24.97	-43.63	3.95	0.52	-42.49	-19.64	55.01
glb	7.77	29.77	-30.72	46.69	12.40	-16.01	-40.16	-17.62	2.87
lam	22.91	7.18	26.17	17.16	-11.00	13.83	27.46	-9.62	-13.45
ops	21.15	0.34	24.77	75.56	3.89	26.46	49.34	-16.70	-8.71
porl	**-176.07**	**-110.52**	60.05	-23.88	1.27	-27.76	86.12	44.39	48.56
porr	-24.57	-65.75	49.39	42.70	-8.29	-22.01	11.81	-22.66	-30.77
stpl	41.27	-9.64	18.92	40.58	-38.51	20.45	-12.46	45.23	-14.60
stpr	14.92	-12.56	-10.66	24.87	31.78	-46.74	-49.29	-36.95	7.93
xfbl	-25.26	-30.68	0.87	**-95.87**	37.04	-19.66	15.30	-5.64	24.36
xfbr	-16.31	25.86	11.65	-59.66	-45.61	33.39	89.12	16.44	-14.24