Review Informing the Design of 3D Food Printing for People with Swallowing Disorders: Constructive, Conceptual, and Empirical Problems

Bronwyn Hemsley
The University of Technology
bronwyn.hemsley@uts.edu.au

Stuart Palmer
Deakin University
stuart.palmer@deakin.edu.au

Abbas Kouzani
Deakin University
abbas.kouzani@deakin.edu.au

Scott Adams
Deakin University
bronwyn.hemsley@uts.edu.au

Susan Balandin
Deakin University
Susan.Balandin@deakin.edu.au

Abstract

The aim of this review was to examine 3D food printing literature, its focus on problems and solutions, and its capacity for problem-solving in relation to the provision of texture-modified food for people with swallowing disorders (dysphagia). In June 2016 and 2018 the first and fourth authors searched 4 scientific databases with the key terms in 3D food printing and dysphagia to locate relevant peer reviewed journal articles for review. In total, 16 papers were included, and examined for: (a) problems, solutions, and potential for problem-solving capacity expressed in 3D food printing literature to date, and (b) applications of 3D printed foods in specific populations with swallowing disorders. Future research and development of 3D food printing technologies could consider empirical and conceptual problems, along with the multi-dimensional nature of special nutritional or swallowing needs. Taking these issues into account would facilitate the translation of findings into real-world outcomes and benefits.

1. Introduction

Aspiration pneumonia, malnutrition and choking are common health problems for people with disability [1] and older people with swallowing disorders (dysphagia) [2]. Dysphagia is highly prevalent among people with disability, and older people, in particular those with additional health issues such as strokes [2], motor neurone disease, or dementia [3]. Dysphagia is managed in large part by introducing modified diets that reduce the risk of unsafe mealtimes [4] but which are viewed by stakeholders as unappetizing, and socially unacceptable, impacting on quality of life [5,6]. The relatively new field of 3D food printing is claimed to hold great promise for people with dysphagia and those who support them, and at the same time represents a new area for collaboration between engineering and health.

3D food printing is known within the field of engineering as a type of additive manufacturing [7] or food layering manufacture [8]. Ventola (2014) [9] reviewed medical applications of 3D printing in detail, and Huang et al. (2013) [10] reviewed the societal impacts of 3D printing. Although neither reviews mentioned 3D food printing, Huang et al. (2013) [10] suggested that additive manufacturing is "well suited to produce customized products, it is expected to play a significant role in personalized healthcare to improve the safety, quality, and effectiveness of healthcare for the general population." (p. 1200).

The rapid growth in 3D printer technologies and applications with non-food items [11, 12] has led to optimism and an expectation of benefit when it comes to 3D printing of food materials [13]. Reflecting its relatively recent appearance in 3D printing literature, 3D food printing is still considered to be at the prototyping research and development stage [12]. A narrow range of food types - chocolate and sugar - have been produced commercially, and further expansion in relation to 3D printing of these foods is expected to be driven at least in part by a growing 'maker' movement, of 'prosumers' (i.e., consumers who produce) [12]. Recent reviews of 3D printing advances in technology and capability [12], and 3D food printing [13, 14, 15, 16] have discussed the potential future applications and implications of 3D food printing. However, to date no one has

URI: https://hdl.handle.net/10125/60009
ISBN: 978-0-9981331-2-6

addressed the feasibility or safety of these applications for people with special nutritional needs or swallowing disorders.

Pallottino et al. (2016) [14] stated that "new technologies are developing incredibly fast in this sector, making it hard to predict future trends. Indeed, the food print sector appears very difficult to describe." (p. 732). Furthermore, there are calls for meaningful and rational decisions about advancing 3D food engineering, design, and food science research [17, 18]. An important element of 3D food printing development is its aim to develop the printing of a wider range of natural and nutritious foods, including foods that contain carbohydrates, proteins, and fats [17] which could be put to a range of uses.

While development of 3D printed foods is aimed at the general population, it might also be driven, at least in part, by a motivation to address significant food problems [18], including: (i) provision of safe and enjoyable meals for people with dysphagia; and (ii) provision of large scale individually-tailored foods for people with special nutritional requirements related to age, setting (e.g., in hospital, residential care), health conditions, or other requirements (e.g., gluten-free, high protein, low salt, diabetic diet) [19]. According to Sun et al. [16] Serizawa et al. (2014) [20] "developed a 3D edible gel printer using a syringe pump and dispenser to make soft food for the elderly who cannot swallow the food well." (p. 1613). Apart from noting the potential significance of 3D food printing in addressing world food problems, to date the 3D food-printing literature is not well grounded in the relevant research literature for each of these health-related problem areas. Additionally, there is a lack of information demonstrating how future 3D food printing technology could address these problems. There is, however, an awareness that any efforts to provide solutions will require a systematic approach and plan for all stages of food design, supply, and provision on a large scale [12, 17]. Therefore, the aim of this review was to identify the problems, solutions, and problem-solving capacity of 3D food printing research towards the provision of foods for people with specific dietary requirements related to swallowing disorders (dysphagia).

The health problem of dysphagia was selected because (a) as populations age, problems with ensuring seniors have safe and enjoyable meals increase; and (b) malnutrition, poor health related to aspiration pneumonia, and preventable death from choking are common in older people and people with lifelong disability (e.g., cerebral palsy, severe intellectual disability) [1,2]. People with severe swallowing disorders, as assessed by health professionals, often require 'smooth food' or puree textures for safe swallowing. In this review, a 'research as problem solving' approach [21] based on the work of Larry Laudan's philosophy of scientific progress [22] was applied to the 3D food printing literature. Laudan's 'research as problem solving' philosophy considered problems as 'absence of knowledge', solutions as 'knowledge', and the problem-solving capacity of the research as the adequacy of the solution to address the significant problem. Laudan (1978) [22] postulated that scientific progress relied more on the problem-solving capacity of the research, than on the determination of whether a finding was 'confirmable' 'true' or 'justified'. Oulasvirta and Hornbæk (2016) [21] built on Laudan's (1978) [22] work to conceptualize problems of engineering design research in three categories, as: empirical problems (examining unknown phenomena, unknown factors, and unknown effects); conceptual problems (examining previously un-connected phenomena in interaction, as implausibility, inconsistency, and incompatibility); and constructive problems (producing understanding, with four sub-categories of 'no known solution', 'partial ineffective or inefficient solution', 'insufficient knowledge or resources for implementation or deployment' or 'established solution') [21 p.3]. This model "offers a rich, generative, and 'discipline-free' view that "may also help unify efforts across nominally disparate traditions in empirical research, theory, design, and engineering" [21, p.1]. By considering the problem-solving capacity of 3D food printing to date in relation to swallowing disorders or dysphagia, it is possible to identify gaps in knowledge and the capacity of research to solve problems, and both inform directions for future research and increase the problem-solving capacity of the research.

2. Methods

This review considered the peer-reviewed literature on original research, critical reviews, dissertations, and reports. First in June 2016, and updated in June 2018, the first and second authors searched 5 scientific databases (Elsevier Science Direct, Elsevier EI Compendex, IEEE Xplore, Web of Science, and Wiley Online Library) with the key terms '3D' 'print' and 'food' in various combinations and narrowed the search with terms relating to 'swallow' 'dysphagia' 'mealtimes' 'meals' 'special diet' to find peer reviewed journal articles, summaries, or reviews on developments in 3D food printing and mentioning future applications in relation to special dietary needs, including dysphagia [23]. On a reading of title and abstract, the first and fourth authors excluded any that did not refer to 3D printing of foods or were not a full-length papers. Papers were also excluded for not providing information on the application of 3D food printing in people with dysphagia or swallowing disorders or older people in general or being journalistic style reviews. Most of the full texts retrieved were reviews in the form of a critical summaries of 3D printing, so these were examined for any citations of relevant peer-reviewed journal articles.

In total, the search methods yielded 16 articles for inclusion in the review that related both to 3D food printing and also referred to applications for people with dysphagia or swallowing disorders [8,12, 13,14,15,16,17,18,24,25,26,27,28,29,30,31]. Data were extracted from the included articles as follows: first author, year, type of paper, aims and contribution, and results relevant to swallowing disorders and texture-modified foods. This information is available from the authors. Each study was also examined for problem-solving capacity, constructive problem sub-type, food structure(s) featuring in the article, 3D food printing technologies used, post-processing needed, included study source, and other sources (i.e., for foods with no known solution). The most prevalent problem type featured in the studies was the 'Constructive' problem type.

3. Results

3.1. Characteristics of the included articles

The field of 3D food printing for people with swallowing disorders is new with a rapid rise in publications since 2012. The studies included were relatively recent, dated 2012 (*n* = 1), 2015 (*n* = 5), and 2016 (*n* = 6), and 2017 (*n* = 4). However, recent reviews of the 3D food printing literature draw heavily upon non-peer-reviewed promotional industry material, websites, forums, short conference abstracts, and book chapters [e.g., 12, 13, 15, 16, 27]. Despite numerous claims that 3D printed food will be a solution for people with swallowing disorders [see 27], we found very few original research reports on foods printed [28, 24, 25] and no scientific evidence that 3D printed foods had yet been shown to improve mealtimes or nutrition for people with swallowing disorders (see Table 1 for relevant quotes). The multidisciplinary nature of research in 3D food printing to date is evident in multidiscipline authorship teams. Nevertheless, the goal of solving the problem of providing safe and enjoyable 3D printed meals for people with dysphagia remains aspirational. The literature reviewed was aimed at solving 'constructive' problems (all studies), with some evidence of interest in both 'empirical' and 'conceptual' problems in additive manufacturing [17], food science [18], and food engineering [29]. In the light of complexities regarding mealtime safety and enjoyment for people with swallowing disorders [31, 32, 33] and older people [34,35] the fields of dysphagia management and the multiple disciplines involved (e.g., speech pathology, dietetics and nutrition, gastroenterology, occupational therapy, respiratory medicine, gerontology) need to be involved in collaborative research.

3.1. Summary of findings of included studies.

The focus and relevant finding in relation to development of 3D printing food for people with swallowing disorders is presented in Table 1. These findings provide substantial impetus for future research in the field of 3D food printing for people with swallowing disorders, including the possibility of '3D printing in the home' and by consumers [28]. In this context, it is important that the engagement of older people with swallowing disorders is considered in the research and development of 3D printed foods.

3.2 Empirical and conceptual problems addressed in the 3D food printing literature

In the 3D food printing literature, there is very little attention to the substantial changes and adaptations in food customs and behaviour needed for widespread uptake and use of 3D printed food for people with swallowing disorders at risk of malnutrition, aspiration pneumonia or death from choking. The combination of 3D printing technology problems and human health conditions related to swallowing problems comprise a conceptual problem. We located no studies examining the utility or feasibility of 3D printed foods for people with special nutritional needs, including swallowing disorder.

Factors informing the conceptual problems of 3D food printing for people with dysphagia [1] potentially include but are not limited to: (a) the *health condition* impacting on the person's swallowing, (b) *food cultures:* the supply, preparation, and consumption of food and mealtimes are cultural constructs, wrapped in layers of cultural, religious, and personal meaning (c) *the activities and participation of eating and drinking* including the whole process of taking food or drink into the mouth, chewing and swallowing safely. Eating and drinking are complex sensori-motor activities, related to several body structures and functions, and affected by many physical, mental, and emotional states and health conditions.

The field of dysphagia assessment and management, initially driven by the bio-medical model of health, is a well-established discipline built around studies on assessment and treatment of the individual with dysphagia [23]. There is, accordingly, much attention paid to the quality and safety of the texture-modified foods, and the need to standardize both food textures and terminologies to improve food service provision and research comparability on dysphagia worldwide [31, 4]. There is also established commercialization of ready-made and standardised texture modified foods and fluids [31]. With its potential for standardizing food texture and production, 3D food printing could offer some future benefit to the problems associated with safely creating appropriately texture-modified foods in residential care settings.

Dietary managers and cooks in residential care settings report difficulty using set recipes, inconsistent interpretation of guidelines on texture modification, lack of consistency in terms for modified foods, and for texture, and wanting to improve the visual appeal of texture-modified foods [36]. The problem of modification of food and liquid textures for adults with dysphagia has a long history and is reviewed systematically by Steele and colleagues [4]. Provision of the incorrect food texture can result in adverse events including choking and death. Staff and families are often confused about food textures, consequently serving the incorrect food, and people with swallowing problems die from choking as a result of having unsupervised access to solid foods [37,38,39]. 3D food printing could address both conceptual and constructive problems with standardization of the appropriate food texture, according to a prescription model (e.g., being prescribed safe and appropriate food textures by an expert in swallowing disorders such as a speech pathologist).

The problem of food provision in residential care settings is complex and relates to much more than only the food texture. There is recognition that the safety and quality of life of people with dysphagia hinges on more than the individual's health condition or swallowing abilities. Dysphagia management is moving towards the more inclusive bio-psycho-social models of health and disability ([41] that take account of the social impact of swallowing disorders and the environmental factors that impact upon mealtime enjoyment and safety, as reflected in the International Classification of Functioning, Disability and Health (ICF) [42]. According to the ICF [42], a person's health condition can be associated with disability arising from the interaction of several factors including impairments of body structures and functions, and restrictions and limitations in activities and participation, all affected by a range of personal and environmental factors. Relating the ICF [42] to 3D food printing, both the equipment or technology of the 3D printer, the food substrates, and the human computer interface in production would be considered environmental factors, while the person's own food preferences, values, and beliefs about the 3D printed food would be personal factors; the act of the person with dysphagia being involved in the designing, creating, and eating of the 3D printed food would be considered to comprise activities and participation; and the 3D printed foods created would need to meet the needs of the person's body structure and function related to their individual health condition.

Currently, the literature on 3D food printing is primarily concerned with the environmental factors of the 3D printer tools and technologies, with little attention to the role of food scientists [30] and applied health scientists including speech pathologists and occupational therapists. There is little attention yet to the personal factors that might influence people with swallowing disorders or their families, carers, or service providers to use of 3D printed foods, and no mention of how people with swallowing disorders or their supporters would engage in the activity or participation in 3D printed food design or preparation.

3.3 Constructive problems addressed

The articles included in this review show a strong focus on the problem of how to design/create/produce 3D printed foods that are the same or potentially better than foods prepared by conventional methods [17] and that are appealing and make good use of colour and shape [14]. Early prototypes of 3D food printing started with foods and materials that yield strong structures and food shapes (e.g., chocolate, sugars, cookies), and consequently design and creation of a range of nutritious food continues to be problematic.

Applying the framework put forward by Oulasvirta and Hornbæk [21], creating ways to develop 3D printed foods that are the same or better than conventional foods can be considered a 'constructive' problem in that (i) there are *unknown factors* and effects in the production of 3D printed foods, that can be subject to physical and replicable tests of food composition, such as structural stability, temperature, and nutritional content; and (ii) there are *partial or ineffective solutions*, and *insufficient knowledge* for implementation or deployment. The 'solutions' under examination are in the scope of engineering design and technology, creating more ways to develop more 3D printed food types using a wider range of food products [16, 30]. Appearing in the literature and reviewed by multiple authors [12, 14, 15,16,30] this area of inquiry and design is rapidly gathering strength in its 'problem-solving capacity' as more natural foods and food products are added to the list and more suitable engineering technologies are found that enable combinations of food textures, flavours, and colours to the 3D food printed [14, 26].

Reviewing the design of 3D food constructs via additive manufacturing technology, Godoi et al. (2016) [17] proposed a model outlining the connections between the properties of food printing material, and factors which have to be considered in 3D food printing. This classification allows for easy identification of the appropriate material property to modify if specific printing properties are desired. The model presents "materials properties and factors to consider for the rational design of 3D food structures" (p. 52) considering applicability, printability, and post-processing, and taking into account properties of food substrates (physical-chemical properties, rheological properties, and structural and mechanical properties). Godoi et al. (2016) examined the interactive factors essential for rational choice of 3D printing techniques in the design of food, providing detail on (a) food properties and binding mechanisms of constituents of foods and feasibility for food printing: carbohydrates, proteins, and fats; (b) additive manufacturing techniques, and (c) choices of techniques, including models of printability, applicability, and post-processing reality.

Liquid-based deposition techniques were found to be more suited for printing of foods with a combination of carbohydrates, proteins and fat. In addition, Godoi et al. (2016) [17] investigated the interaction between carbohydrates, proteins and fats in relation to their impact on food printing. They reported a number of findings including: (i) high molecular weight polymeric carbohydrates are difficult to print without modification, (ii) derived proteins such as gelatin may be highly suited as an additive to improve the suitability for food products for 3D printing and (iii) melting points of materials is modified by the number of carbon atoms in fatty acids. The authors concluded that there was a lack of research investigating foods with high levels of nutritional value, in particular in the field of powder-binding bed-printing techniques.

Both commercial and research-based 3D printers have been employed to carry out the food printing investigations [15]. These printers operate based upon a number of different additive fabrication techniques including: (i) high and low temperature extrusion, (ii) selective hot air sintering and melting, selective laser sintering, liquid binding, and (iii) inkjet printing, among others. Most of the current 3D food printing experiments have however used extrusion-based printers [17]. In this technique, product is fabricated in a layer-by-layer approach in which each printed layer supports the succeeding layers. In addition to generic 3D printers, several purpose-built 3D printers have been developed specifically for food printing namely: ChefJet, Foodini (see Natural Machines, 2016), f3d, NASA printer, Choc Creator, Cake and Chocolate Extruder, Discov3ry Extruder, 3D Fruit Printer, 3D Everything Printer, Palatable-Looking Goop Printer, and Original Food Printer [43].

3.4 Puree foods as an example of a constructive problem in 3D food printing

The food problem most frequently cited in the swallowing literature and the 3D food printing literature reviewed is that the foods provided to people in residential care who have difficulty swallowing, are unappealing 'mush', resulting in decreased appetite, negative impacts on the enjoyment of meals, and reduced quality of life. The problem of the visual appeal of puree foods is a significant concern for authors reviewing the neuroscience of the effect of visual images of food, particularly on the 'hungry brain' [44]. Spence and colleagues [44] postulated that the visual appeal of food is perhaps even more important than smell, taste or texture, particularly if a person is hungry. Therefore, it is plausible that 3D food printers could be used to create foods that are both safe to eat and enjoyable (i.e., appealing in appearance, texture, and taste) for populations with swallowing disorders, and that this would help to address problems with appetite, safety, and quality of life associated with dietary restrictions to texture of 'puree food' only, and reduce risks of choking.

It is, however, important to note that food molds (shapes), once considered the solution to the problem of puree foods looking like 'mush', did not yield significant differences in ratings of appearance to standard puree, and were in fact rated by people with impaired swallowing as being more difficult to swallow [45]. With investment into 3D food printing specifically targeting older people's needs [12], there are as yet no public domain scientific reports of outcomes on the use of 3D printed foods in nursing homes.

Not all people with swallowing disorders require a puree diet. Indeed, many require soft texture foods [e.g., 6,31]. Families, carers, and residential care settings struggle more with provision of soft foods, as they fall between standard or normal fare, and puree, and it is not easy to create soft food that is of the exact consistency required accurately and repeatedly over time. 3D food printing could address this problem so that the food was always the same and easily tailored to meet each individual's need. There is a concern about the use of additives for enhancing the suitability of different food products for 3D printing. However, the papers by Kouzani et al. [24,25] indicate that there are a variety of food products which can be 3D printed without involving any additives. The need for more attractive-looking consistent texture-modified foods is impetus for further development in 3D printed food technology for all food textures and consistencies (e.g., 3D printed pasta, ravioli, mince and purees) to help meet the individualised food texture requirements of those with swallowing disorders.

4. Directions for Future Research

In relation to empirical problems, future research could address ways to create or elaborate upon the phenomena of humans using computer technologies and 3D printers to design and create foods in terms of unknown phenomenon (e.g., cultural aspects of developing and designing 3D printed foods), unknown factors (e.g., how can recommendations for dysphagia integrate provision of 3D printed foods that can be standardized but involve human computer interaction and unknown effects (e.g., what is the impact on the person with dysphagia and their family members or direct support workers, of introducing 3D printed foods). With no research to date addressing these questions, qualitative research methods that could be used include: user-centred design and observational studies (reactions to 3D printed foods or images of these; mealtime observations), perceptions and views of 3D printed foods, and perceived barriers to and facilitators for the adoption of 3D food printing technologies by people with dysphagia living in a variety of community settings. In relation to conceptual problems, further research is needed to understand how concepts such as the use of tools and technology for determining food textures works within safety frameworks, and the guidance for residential settings on food preparation and food safety.

In relation to constructive problems, the studies included in this review have focused on making food samples of single (monotonous) texture, nutrient, smell, and visual appearance. Despite the recent advancements and an increasing number of established solutions being found for 3D printed foods, in the context of the broad range of foods required to support human nutrition and hydration, research into 3D food printing is still in its infancy. Considering their conspicuous absence from the research literature to date, people with swallowing disorders and their family members or direct support workers (who assist them in meal preparation and consumption) must be included in user-centred research investigating 3D foods with modified food textures. Further research is needed before 'do-it-yourself' on-demand meals with tailored nutrients, texture, smell, and visual appearance can be designed and printed for use by consumers including people with special dietary requirements. The ultimate goal will be to have a 3D printer that could be placed in the kitchen [28] and operated with minimal effort - by choosing a meal from a list of options, filling the printer with the chosen ingredients, and pressing a print button to get a meal with the desired texture, nutrients, smell, and visual appearance.

Due to important opportunities in 3D food printing, it is anticipated that significant research efforts will be made in the coming years to create: (i) libraries of recipes for meals of specific texture, nutrients, and smell; (ii) libraries of 3D computer aided design (CAD) models for meals of specific visual appearances; consumer-friendly single-step and maintenance- free ingredient loading mechanisms; (iii) easy-to-use simple graphical user interfaces; mechanisms for automated selection and mixing of ingredients based on the chosen meal for nutrients control; (iv) libraries of optimized print parameters for each meal in the meal library; (v) integrated mechanisms for implementing all the ingredients pre-processing steps; (vi) integrated mechanisms for implementing all the meal post-processing steps; (vii) automated integrated printer cleaning mechanisms; (viii) an integrated multi-ingredient printing mechanism; (ix) an integrated multiple food fabrication mechanisms to speed up meal printing; (x) sensors for measuring standards of texture, nutrients, smell, and visual appearance during print; (xi) intelligent control algorithms that monitor the output of the sensors and control the print process for achieving the desired print quality; and (xii) low-energy components and circuitry to reduce the energy consumption of the printer and optimize the components of the printer to reduce the printer cost, size, and weight. These will help create a technology that will enable printing of on-demand ready-to-eat meals with enhanced nutrients, texture, smell, and visual appearance, and reduced complexity, maintenance, speed, power, and cost for consumers in general and specifically people with special dietary requirements.

Accordingly, more innovation, refinement, and automation are needed in all steps of 3D food printing process, inclusive of people with swallowing disorders, involving: (i) selecting ingredients, (ii) designing the meal, (iii) creating a 3D model of the printed meal using CAD software, (iv) presenting the CAD model to the printer's control software and selecting appropriate print parameters, (v) pre-processing the ingredients (e.g., steaming and pureeing the ingredients), (vi) preparing the printer (e.g., filling up printing ingredients), (vii) printing the meal, (viii) post-processing the printed meal (e.g., baking), (ix) presenting the food attractively on the serving plate, and (x) freezing, packaging, transporting, thawing, and re-heating the meal if desired.

It is also important to note that there are as yet no rigorous examinations of food safety in relation to 3D food printing [46]. Costa et al. (2017) [47] outlined food safety as a priority area in relation to 3D food printing, and proposed an incomplete list of potential hazards and subsequent risks as including: (a) formation of heat-generated compounds that could be hazardous to health, such as acrylamide and furans; (b) microbiological risks (shelf life, cartridge contamination, edible paper debris, improper cleaning); (c) physical risks (printer fragments breaking off); (d) variability and stability of ingredients (composition, shelf life, nutritional value, demixing); (e) recipe design (incompatible combination of ingredients); (f) food fraud through the marketing of sub-standard raw materials in cartridges; (g) change of eating habits; (h) ingredients not previously assessed could be available on a market that would be difficult to control; and (i) home print (wherever, whoever, whatever). (p. 262).
Older adults with dysphagia might be more vulnerable to the health impacts of safety incidents in relation to 3D printing of food, further research on its safety and ways to minimise the risks is warranted in the quest to develop 3D food printing options for this population.

5. Conclusions

The new era of research aiming to address health, safety and well-being issues associated with the eating of 3D printed foods must be both multi-dimensional and trans-disciplinary. Considering the multi-dimensional nature of food and mealtimes, and the food problems that 3D food printing might help to address, the disciplines to be drawn in to 3D food printing research need to expand beyond engineering to include: (i) food science, food design, and food technology; (iii) speech pathology, (iv) dietetics and nutrition, and (v) occupational therapy. Team members with legal expertise would also be useful in relation to both patenting and product safety, considering the innovation aspect of 3D food printing, and the lack of research on safety and risks in relation to 3D printed foods, as outlined by Costa et al. (2017).

The intersection of 3D food printing with the food problem of dysphagia (swallowing disorders) or special nutritional needs reveals new empirical, conceptual, and constructive problems to be addressed. There is little evidence yet of the formation of cross-disciplinary theories that take into account both fields of 3D food printing and dysphagia. This might reflect a need for (a) strengthening futuristic or progressive theory in the management of dysphagia, in the context of rapid advancement in the fields of food engineering and food science or 'enginomics'; and (b) increased attention in food science and food engineering research on literature relating to the health condition dysphagia. User-centred co-design research is now needed to determine ways to make 3D printed foods that are appropriate and acceptable for people on texture-modified diets and that are the same or better than texture-modified foods produced by conventional means. It is therefore important to determine the attitudes and views of people with dysphagia, their carers or support workers, and the several different health professionals involved in prescribing texture-modified diets, on the feasibility, acceptability, and safety of 3D printed foods being used as part of a dysphagia diet.

Table 1. Excerpt on findings of included studies.

Ref	Relevant finding or quote
[8]	"a very new process … within a suite of futurist food manufacturing technologies which view food raw materials from a non-food perspective." (p. 71).
[12]	"in the long-term, 3D food printing could be used for creating artificial food for people with swallowing problems or special nutritional needs. In this way, 3D food printing might contribute to a higher quality of life for certain target groups." (p. ix-x). … Chicken fillets, for example, are cooked, pureed and strained so that the jellified

	version can be safely eaten as it is supposed to melt in the mouth." (p. 35-36).
[28]	Design of a 'cookie' 3D printer. Peng reported that: "About 15-25% of aging population suffer from swallowing difficulties, and increase in personalized meal requirements creates an increasing market need for food mass customization." (p. viii).
[13]	"about 15-25% of the aging population suffers from swallowing difficulties and this creates an increasing market need for mass customization of food." (p. 27)
[15]	Citing a newsletter article by Gray (2010), Sun et al. (2015b) reported that "Printing pureed food proposed by TNO [The Netherlands Organisation for Applied Scientific Research] can help elderly people with chewing and swallowing problems." (p. 312).
[16]	The authors concluded that "3D food printing provides an engineering solution for customized food design and personalized nutrition control" (p. 1605)
[17]	The authors observed that: design of 3D food printing constructs "is strongly dependent on material properties and binding mechanisms." (p. 53). Furthermore, Godoi et al. (2016) contended that many challenges in 3D food printing field are "attributed to (1) process productivity and (2) product innovation and functionality." (p.53)
[24]	3D printing of a pavlova. The authors reported that: "the benefits offered by 3D food printing include custom design and production of visually appealing foods, making of foods for people with special needs (e.g., people with swallowing difficulties), reduction in design and fabrication time and cost, and decrease in dependency on skilled personnel." (p.1).
[26]	In the absence of any scientific peer reviewed journal articles, the authors reported on news items stating outcomes of the PERFORMANCE project and that 3D printed foods were entering the aged care market in Germany.
[27]	"News articles also covered the use of 3D printing to prepare more appealing meals for people with dysphagia (chewing and swallowing difficulties) or other eating difficulties … these reports included in the promissory theme of health, 3D food printing technologies were portrayed as

	either already in operation (as in the printed foods provided in nursing homes) or envisaged to take place in the near future. Claims to novelty rested on the attractive incorporation of healthy ingredients or soft-textured food products offered by the shaping capacities of the technologies. People with dysphagia, and more broadly, consumers looking to provide nutritious foods for themselves or their family members were represented as the main beneficiaries." (p. 44).
[14]	The authors reported that: "At the moment, new technologies are developing incredibly fast in this sector, making it hard to predict future trends … Despite the sales, the number of applications and the degree of freedom in the use seem to be still limited for the end user. (p.732)
[29]	They laid out a rationale for food engineering to "shed its historical mindset, and embrace new challenges and opportunities that the 21st century holds" (p. 2). Saguy (2016) opined that the discipline 'enginomics' and food engineers have an important role (among other roles) in relation to "consumers (safety, acceptability, special needs, sensations, pleasure, etc.)" and SR (food security, feeding the world, sustainability, growing population, water and land scarcity, ethics, values, etc.)." (p. 6).
[30]	"This technology also has the potential to revolutionize the food and related industries … and food scientists need to be at the forefront in exploring, researching, and developing applications for 3D printing in foods." The "3D printing of complex food products with customized shapes, flavors, textures, and colors is an obvious application" (p.8)
[18]	It states: "3D printing of food using food ingredients to generate products is a possible solution" to the "bland and mush appearance of food puree" being "unappetizing." (p. 8).
[25]	Design and production of 3D printed texture-modified puree food, reported "3D printing of visually appetizing puréed foods for dysphagia patients with high consistency and repeatability …one protein product (tuna), one vegetable product (beetroot) and one fruit product (pumpkin). The texture produced is described as 'pureed extremely thick' (p.1).

[31]	Citing Hod Lipson (2013) the authors drew attention to stability of 3D printed foods: "For 3D printing, all the ingredients are made into puree or powders in advance, thus the building performance should be evaluated after completion of the printing such as looks, object strength, and stability after heating." (Hod Lipson, M. K. (2013). Fabricated: The New World of 3D Printing. John Wiley & Sons, Inc., New York)

8. References

[1] Sheppard J J, Hochman R, Baer C, "The Dysphagia Disorder Survey: Validation of an assessment for swallowing and feeding function in developmental disability" Research in Developmental Disability, 2014, 35(5) pp. 929-942.

[2] C. Takizawa et al., "A Systematic Review of the Prevalence of Oropharyngeal Dysphagia in Stroke, Parkinson's Disease, Alzheimer's Disease, Head Injury, and Pneumonia", Dysphagia, 2016, 31, pp. 434-441.

[3] M. Kahlia, "Dysphagia and Aspiration Pneumonia in Patients with Alzheimer's Disease", Metabolism, 2005, 52(S2), pp. 36–38.

[4] C. M. Steele et al. "The Influence of Food Texture and Liquid Consistency Modification on Swallowing Physiology and Function: A Systematic Review", Dysphagia*,* 2015, 30(2), pp. 272-273.

[5] Balandin S, et al. "Understanding Mealtime Changes for Adults with Cerebral Palsy and the Implications for Support Services", Journal of Intellectual and Developmental Disability, 2009, 34, pp. 197-206.

[6] H. Keller, L. Chambers, and L. D. Niezgoda, "Issues Associated with the Use of Modified Texture Foods", Journal of Nutrition, Health and Aging, 2012, 16, pp. 195-200.

[7] F. Yang, M. Zhang, and B. Bhandari, "Recent Development in 3D Food Printing", Critical Reviews in Food Science and Nutrition, 57(14), doi:10.1080/10408398.2015.1094732.

[8] T. F. Wegrzyn, M. Golding, and R. H. Archer, "Food Layered Manufacture: A New Process for Constructing Solid Foods", Trends in Food Science and Technology, 2012, 27(2), pp. 66-72.

[9] C. L. Ventola, "Medical Applications for 3D Printing: Current and Projected Uses", P&T, 2014, pp. 39 704-711.

[10] S. H. Huang et al., "Additive Manufacturing and its Societal Impact: a Literature Review", International Journal of Advanced Manufacturing Technology, 2013, 67, pp. 1191–1203

[11] H. N. Chia, and B. M. Wu, "Recent Advances in 3D Printing of Biomaterials", Journal of Biological Engineering, 2015, 1, 9, 4. eCollection 2015.

[12] L. Bechthold. et al., "3D Printing A Qualitative Assessment of Applications, Recent Trends and the Technology's Future Potential", Expertenkommission Forschung und Innovation (EFI). 2015, www.econstor.eu/handle/10419/156627. Accessed 16th June 2018.

[13] J. Sun, et al., "3D Food Printing – An Innovative Way of Mass Customization in Food Fabrication". International Journal of Bioprinting, 2015, 1, pp. 27-38.

[14] F. Pallottino, et al., "Printing on Food or Food Printing: a Review", Food Bioprocess Technology, 2016, 9(5), pp. 725-733.

[15] J. Sun J, "A Review on 3D Printing for Customized Food Fabrication", Procedia Manufacturing, 2015, 1, pp. 308-319.

[16] J. Sun J, "An Overview of 3D Printing Technologies for Food Fabrication", Food Bioprocess Technology, 2015, 8 1605-1615.

[17] F. C. Godoi, S. Prakash, and B. R. Bhandari, "3d Printing Technologies Applied for Food Design: Status and Prospects", Journal of Food Engineering, 2016, pp. 179 44-54.

[18] J. Tian, B. C. Bryksa, and R. Y. Yada, "Feeding the World Into The Future – Food and Nutrition Security: The Role of Food Science and Technology", Frontiers in Life Science, 2016, pp. 1-12.

[19] B. de Roos, "Conference on 'Future food and health' Symposium II: Diet–gene interactions; implications for future diets and health, Personalised nutrition: ready for practice?" Proceedings of the Nutrition Society, 2013, 72, pp. 48–52.

[20] R. Serizawa R, et al., "3D Jet Printer of Edible Gels for Food Creation", Proceedings of SPIE Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring, 2014, 9–13 March 2014 San Diego.

[21] A. Oulasvirta and K. Hornbæk, "HCI Research as Problem-Solving", CH'I, 2016, 16 May 7-12 San Jose California USA.

[22] L, Laudan, "Progress and Its Problems: Towards a Theory of Scientific Growth", University of California Press, 1978.

[23] M. E. Groher, M. A. Crary, "Dysphagia: Clinical Management in Adults and Children", Elsevier, St Louis, 2016.

[24] A. Z. Kouzani et al., “3D Printing of a Pavlova”. *IEEE Region 10 Conference (TENCON)* Singapore 2016, pp. 2281-2285.

[25] A. Kouzani A Z, et al., “3D Printing of Food for People with Swallowing Difficulties”, The International Conference on Design and Technology (DESTECH 2016), Knowledge E. http://knepublishing.com/index.php/KnE-Engineering/article/view/591/1865. Accessed 23 May 2017

[26] Z, Liu et al., “3D printing: Printing Precision and Application in Food Sector. Trends in Food Science & Technology, 2017. 69, pp. 83-94.

[27] Lupton, D., “‘Download to Delicious’: Promissory Themes and Sociotechnical Imaginaries in Coverage of 3D Printed Food in Online News Sources”, Futures, 2017. 93, pp. 44-53.

[28] Z. Peng, “3D Food Printer: Development of Desktop 3d Printing System for Food Processing”, (Master of Engineering), National University of Singapore, Singapore, 2015.

[29] I. S. Saguy, “Challenges and Opportunities in Food Engineering: Modeling, Virtualization, Open Innovation and Social Responsibility”, Journal of Food Engineering, 2016, 176, pp. 2-8.

[30] F. Yang, M. Zhang, and B. Bhandari, “Recent Development In 3D Food Printing”, Critical Reviews in Food Science and Nutrition, 2017, 57(14), pp. 3145-3153.

[31] G. W. Smithers, “Food Science – Yesterday, Today, and Tomorrow”, Reference Module in Food Science: Elsevier, 2016.

[32] J. A. Y. Cichero et al, “The Need for International Terminology and Definitions for Texture-Modified Foods and Thickened Liquids Used in Dysphagia Management: Foundations of a Global Initiative”, Swallowing Disorders, 2013, 1(4), 280-291.

[33] C. M. Steele and J. A. Y. Cichero, “Physiological Factors Related to Aspiration Risk: A Systematic Review”, Dysphagia, 2014, 29(3), pp. 295-304.

[34] N. P. Hays, and S. B. Roberts, “The Anorexia of Aging in Humans”, Physiology & Behaviour, 2006, 88(3), pp. 257-266.

[35] V. Pouyet et al., “Attractiveness and Consumption of Finger Foods in Elderly Alzheimer's Disease Patients”, Food Quality and Preference, 2014, 34, pp. 62-69.

[36] C. M. Steele et al., “Mealtime Difficulties in a Home for the Aged: Not Just Dysphagia”, Dysphagia, 1997, 12(1), pp. 43-50.

[37] N. Ilhamto et al., “In-house Pureed Food Production in Long-Term Care: Perspectives of Dietary Staff and Implications for Improvement. Journal of Nutrition in Gerontology and Geriatrics, 2014, 33(3), pp. 210-218

[38] B. Hemsley B, “A Call for Dysphagia-Related Safety Incident Research in People with Developmental Disabilities”, Journal of Intellectual & Developmental Disabilities, 2015, 40, pp. 99-103.

[39] S. Jukes et al., “Evaluation of the Uptake of the Australian Standardized Terminology and Definitions for Texture Modified Foods and Fluids”, International Journal of Speech Language Pathology, 2012, 14, pp. 214-5.

[41] G. L. Engel, “The Need for a New Medical Model: A Challenge for Biomedicine. Science, 1977, 196, pp. 129-136.

[42] World Health Organisation (WHO), International Classification of Functioning Disability and Health (ICF)”, World Health Organisation, 2001. http://www.who.int/classifications/icf/en/. Accessed 23 May 2017.

[43] M. Molitch-Hou, “11 Food 3D Printers to Feed the Future. 3D Printing Industry”, 2014. http://3dprintingindustry.com/news/11-food-3d-printers-36052/. Accessed 23 May 2017

[44] C. Spence, “Eating with Our Eyes: From Visual Hunger to Digital Satiation. Brain and Cognition, 2016, 110, pp. 53-63.

[45] B. Stahlman et al., “Comparison Ratings of Puree Versus Molded Fruits: Preliminary Results”, Dysphagia, 2000, 15 (1), pp. 2-5.

[46] European Food Safety Authority (EFSA), “Outcome of the Stakeholders’ Consultative Group on Emerging Risks Submitted to EFSA, 2014 report of the Stakeholders’ Activities in the Areas of Emerging Risks”, EFSA Supporting Publications. European Food Safety Authority (EFSA), 2015. https://www.efsa.europa.eu/en/supporting/pub/en-747. Accessed 16th June 2018.

[47] M. C. Costa, et al., “Risk Identification In Food Safety: Strategy and Outcomes of the EFSA Emerging Risks Exchange Network (EREN), 2010-2014”, Food Control, 2017, 73, pp. 255-264.