Conference Paper

3D Printing of Food for People with Swallowing Difficulties

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Abstract

Dysphagia affects many people worldwide. Modifying foods to standard consistencies, and manual design and assembly of foods for the daily requirements of people with dysphagia is challenging. People with dysphagia may develop a dislike for pureed foods due to the unattractiveness of the appearance of the foods, the lack of variety in daily meals, and the diluted taste of meals. Three-dimensional (3D) food printing is emerging as a method for making foods for people with special mealtime needs. Very few efforts have been made to apply 3D food printing to improving the lives of people with special mealtime needs such as those with dysphagia. This paper presents the design and 3D printing of visually appetizing pureed foods for people with dysphagia with high consistency and repeatability. A tuna fish involving pureed tuna (protein), pureed pumpkin (fruit), and pureed beetroot (vegetable) is designed and then 3D printed. The steps involved in the design of tuna fish, preparation of purees, and printing of tuna fish are described. The obtained results are presented, and the findings of this research work are discussed.

Keywords: 3D food printing, dysphagia, visually attractive food, consistent texture, repeatable manufacturing

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1 Introduction

Three-dimensional (3D) food printing is emerging as a computer-aided-design (CAD) and additive-manufacturing approach for producing food products [1]. The benefits offered by 3D food printing include custom design and production of visually appealing foods, making foods for people with special mealtime needs, reduction in design and fabrication time and cost, and decrease in dependency on the skills of personnel (e.g., direct support workers). While several 3D food printing research works have been reported in the literature, the majority of these to date focus on experimenting with food printing. Very few efforts have been made to use 3D food printing to improve the lives

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of people with special mealtime needs such as those with dysphagia (swallowing difficulties). 3D food printing could be used to: (i) automate the production of pureed foods and thickened liquids, (ii) improve the consistency and repeatability of produced foods in term of texture and moisture, (iii) enhance the taste sensory experiences in texture-modified meals, and (iv) manufacture visually attractive pureed foods and thickened liquids for people with dysphagia.

Dysphagia affects the majority of people with stroke, cerebral palsy, motor neurone disease, Parkinson's disease and many other health conditions. Any conditions that affect the oral preparation of food, or oral movements, or the swallow reflex or movement of the pharyngeal muscles, can affect swallowing. In the management of dysphagia, and to enhance the safety and quality of meals, foods can be modified according to texture (e.g., soft, mashed, puree), and liquids can be thickened to increase their viscosity and give the person more time to co-ordinate the swallow. These strategies are used to prevent aspiration of food or fluid into the lungs, to increase the amount of food managed eaten, and to reduce the time or effort required for meals. Modifying foods and liquids for the daily requirements of people with dysphagia to standard consistencies using the conventional approaches can be challenging. In addition, people on long-term modified food diets may develop a dislike for pureed foods and thickened liquids due to the lack of variety in meals, the unattractiveness of their visual appearance, and the tastes being diluted because of liquids being added. This impacts on both health and quality of life for people with dysphagia, and increases the efforts required on their family members or service providers who must also repeatedly consider their food preparation and safety in provision of meals.

This paper presents 3D printing of visually appetizing pureed foods for people with dysphagia with high consistency and repeatability. The following foods are explored and then printed in the form of a fused tuna fish: tuna (protein), pureed pumpkin (fruit), and pureed beetroot (vegetable).

2 Existing 3D Food Printing Works

Several additive fabrication approaches have been employed to form 3D printers: extrusion, binding, lamination, and photopolymerization. While the majority of the 3D food printing trials have utilized extrusion-based 3D printers, Molitch-Hou [2] described a number of food printers developed specifically for food printing: ChefJet, Foodini, 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. These printers have been used to print experimental food products [2-3].

According to the literature, a number of 3D food printing research works have been carried out successfully. Hao et al. [4] developed a fabrication method known as chocolate additive layer manufacture for the layer-by-layer manufacture of personalised 3D chocolate products. Lipton et al. [5] demonstrated printing of multi-material constructs of turkey meat and celery. They also modified a cookie recipe and printed cookies that maintained shape during baking after the print. Marsden [3] described a number of food products produced recently including cheese and tomato pizzas, nuggets, cheeseburgers, vegetarian bean burgers, liquorice, and a chocolate Christmas tree. For example, a meat burger was printed from ingredients such as pork meat, beef, walnut, red berry jam, salt and pepper [3]. Kouzani et al. [1] 3D printed a pavlova with chocolate garnish. The work was carried out in the following steps: preparation of meringue, design of the pavlova, printing of the pavlova, baking of the pavlova, design of the chocolate garnish, printing of the chocolate garnish, and assembly of the pavlova with the chocolate garnish.

3 Materials and Methods

3.1 Materials

The ingredients used for making the tuna fish print were: 400g of butternut pumpkin, 400g of beetroot, and 425g of canned tuna in springwater. These ingredients were acquired from Woolworths, Australia.

3.2 3D Printer

The 3D printer used to print the tuna fish in this work was an EnvisionTEC GmbH Bioplotter (EnvisionTEC, Gladbeck, Germany) which is designed to print using a large variety of materials [6]. The bioplotter allows for a 3D CAD model to be created as a physical object using pressure controlled extrusion. Materials that are suitable for use in this printer range from viscous pastes to liquids, and are extruded from a standard 30CC barrel with a piston top and precision tip using pressure from an external nitrogen source. The pressure is applied to the barrel which is moved in three dimensions, this barrel deposits a strand of the print material onto the print bed to produce the object. The size of this strand is controlled by altering the speed of the print-head and the pressure applied to the material in the barrel. Designs are produced in an additive manufacturing manner where the CAD model is sliced into layers of fixed height and then printed one layer at a time with each layer being printed on top of the layer below. Using this method of fabrication, food product can be rapidly produced with a defined outer form and a preselected inner structure.

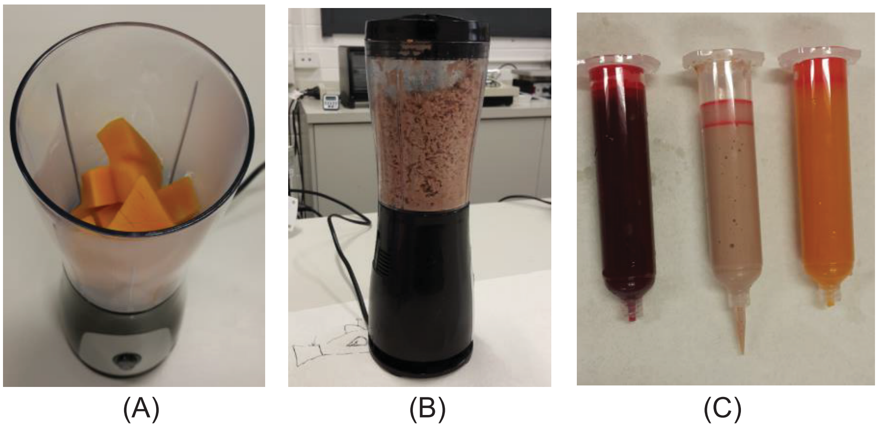

(A) (B) (C)

Figure 1: BLENDING OF (A) COOKED PUMPKIN, AND (B) CANNED TUNA. (C) THE THREE 30CC BARRELS LOADED WITH THE PUREES (FROM LEFT TO RIGHT: BEETROOT, TUNA, AND PUMPKIN).

3.3 Making Purees

Pumpkin Puree: A firm butternut pumpkin was used. It was cut in half, and seeds, pulp and skin were removed. It was then cut into small chunks. The pumpkin chunks were placed into a microwave safe bowl together with 50ml of water and covered with plastic wrap. They were cooked for 15 minutes on high in a microwave oven until tender. The pumpkin chunks were removed from the microwave oven and let to cool. They were pureed using a blender for about 5 minutes.

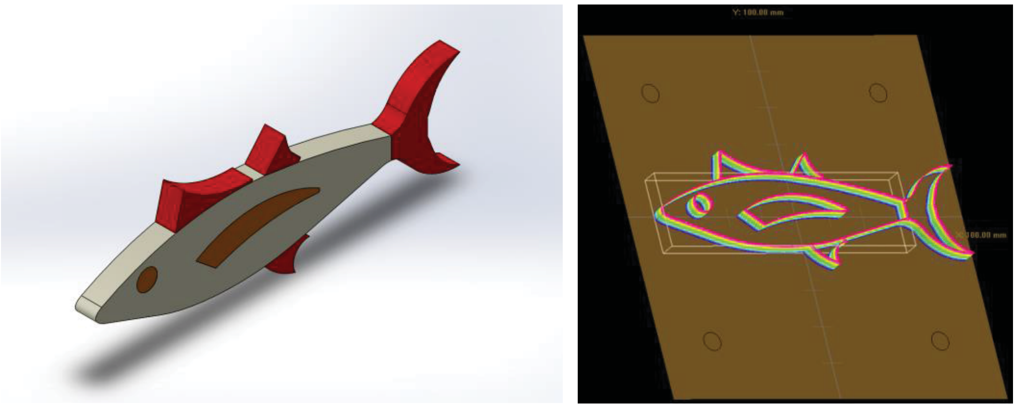
Beetroot Puree: The beetroots were washed, peeled, and then cut into small chunks. The beetroot chunks were placed into a microwave safe bowl together with 50ml of water and covered with plastic wrap. They were also cooked for 15 minutes on high in a microwave oven until tender. The beetroot chunks were removed from the microwave oven and let to cool. They were pureed using a blender for about 5 minutes.

Tuna Puree: The tuna and springwater were removed from the can. They were placed into a blender and then pureed using the blender for about 5 minutes.

Loading Purees into Barrels: Finally, the pumpkin, beetroot, and tuna purees were loaded into three separate 30CC 3D printer barrels and each covered with a piston top. Also, a precision tip was attached to each barrel's outlet (see Figure 1).

3.4 Design of Tuna Fish

A 3D CAD model of the tuna fish was created in Solidworks (Dassault Systemes SolidWorks Corporation, Velizy, France). The CAD model of the tuna fish whose size was 14 cm×14 cm is shown in Figure 2(A). A STL version of this CAD model was created and loaded into the bioplotter control software. The thickness of the tuna fish is set to 1cm during the post-processing of the CAD model with the bioplotter software.



(A) (B)

Figure 2: (A) 3D CAD MODEL OF THE TUNA FISH. (B) 3D MODEL OF THE TUNA FISH IN THE BIOPLOTTER SOFTWARE.

3.5 Printing of Tuna Fish

The operating parameters of the 3D bioplotter was determined through the manufacturer's procedure [6]. The parameters involve plastic tip size, speed, pressure, temperature, pre-flow delay, and post-flow delay. Table I shows the operating parameters for printing the pumpkin, beetroot, and tuna. These parameters were determined through an empirical tuning step before the fabrication. This mix of material volume and deposit speed meant that the design could be produced rapidly (under 3 minutes) while still allowing for settling between the print layers.

In order to fabricate the tuna fish, the following procedure was followed: (1) load the 3D Model STL file into the bioplotter software (see Figure 2(B)). (2) select the appropriate build area and material (150 mm×150 mm, and 500 μm). (3) Reposition the model into a location where it can be printed. (4) slice the model into layers of the appropriate thickness (500 μm). (5) export to the Visual Machine plotting software. (6) turn on the bioplotter. (7) assign the appropriate material to the part. (8) assign the appropriate internal pattern to the part. (9) save the part. (10) insert the material cartridge and the needle tip into the low-temperature printing head. (11) assign the appropriate material and needle tip to the print head in the Visual Machine software. (12) calibrate the print head. (13) purge and clean the print head. (14) carry out the print. (15) remove the print from the stage and turn off the bioplotter.

4 Results and Discussions

The complete 3D printed tuna fish is shown in Figure 3. The taste of the printed tuna fish was compared to that of a dish including three scoops of pumpkin, beetroot, and tuna purees assembled by a skilled cook. Three people including the skilled cook tasted both

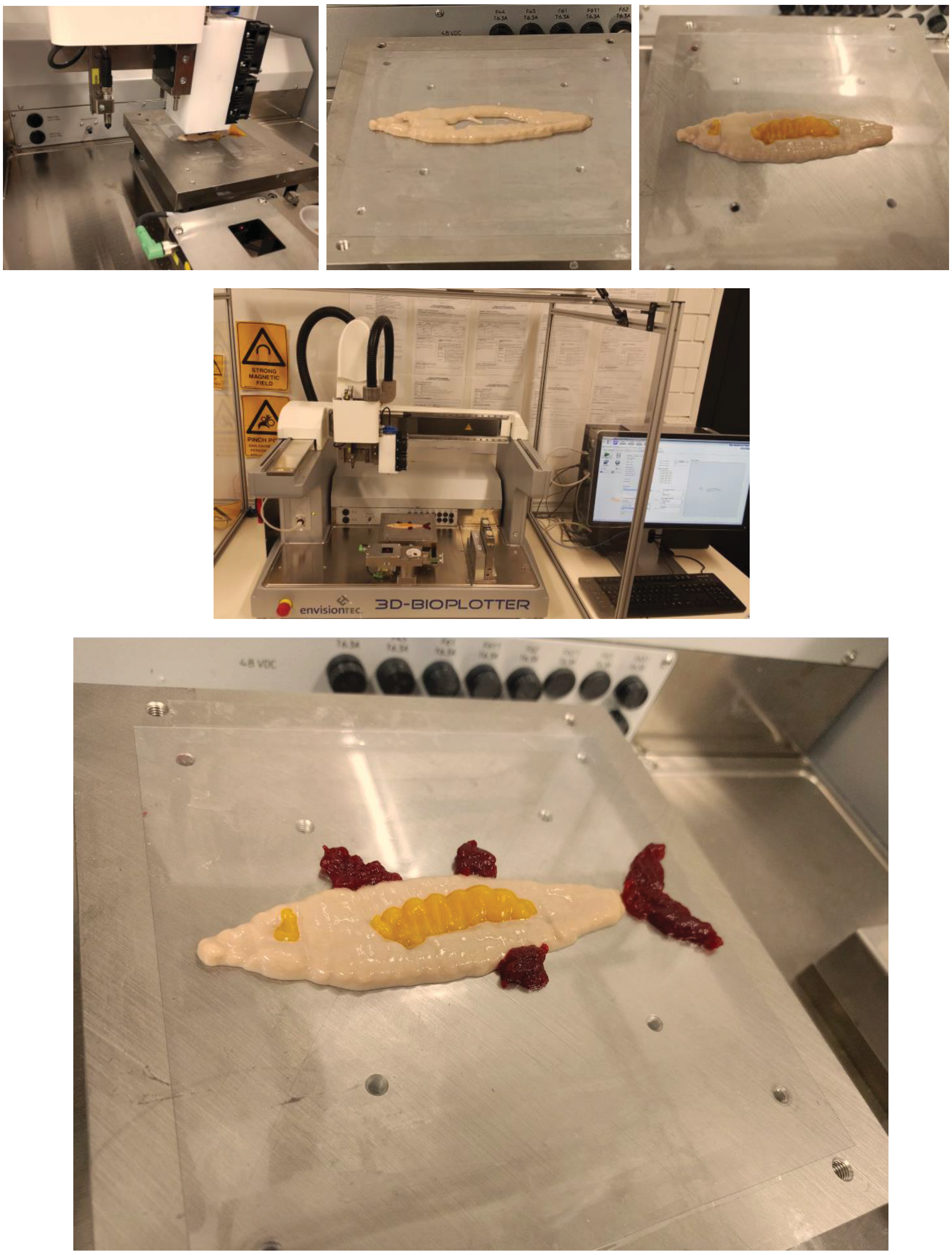


Figure 3: 3D PRINTED TUNA FISH.

dishes and found that the tastes of both dishes were the same. A number of findings were discovered while fabricating the tuna fish.

Firstly, a number of different printing surfaces were trialled to determine which would lead to the most successful print. It was discovered that the traditional surfaces of greaseproof paper and aluminium foil had too little surface friction to allow for successful attachment of the first printed layer. The surface discovered to be highly suitable for both printing and cooking was a transparency film of cellulose acetate. Secondly, the viscosity of the purees needs to be set in such a way that the residual

Parameter	Pumpkin	Beetroot	Tuna
Plastic tip size	500 µm	500 µm	500 µm
Speed	20 mm/s	40.2 mm/s	25 mm/s
Pressure	0.3 bar	0.3 bar	0.2 bar
Temperature	20°C	20°C	20°C
Pre-flow delay	0.04 s	0.04 s	0.04 s
Post-flow delay	-0.09 s	-0.09 s	-0.09 s

Table 1: Bioplotter parameter settings

pressure from the printing barrel does not extrude the material. A very low pressure was used to deposit the materials (0.2 to 0.3 bar).

The method outlined in this paper has a potential to automate the production of pureed foods and thickened liquids, improve the consistency and repeatability of produced foods, enhance the taste sensory experience in the meal, and create visually attractive pureed foods and thickened liquids for people with dysphagia.

5 Conclusion

This research demonstrated a method based on CAD and additive manufacturing for the design and fabrication of 3D food products. The method was used to 3D print a tuna fish consisting of tuna, pumpkin, and beetroot purees. The method reduced the design and fabrication time and cost, decreased the dependency on a skilled cook, and enhanced the visual appearance, consistency and repeatability of the foods produced that could potentially be enjoyed by people with dysphagia who require pureed food.

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