Chapter

Optimization of Maxillofacial Prosthesis

Faraedon M. Zardawi and Kaida Xiao

Abstract

Today, both additive manufacturing (3D image technology and 3D printing) had been developed dramatically and involved virtually in all fields of medicine and surgery. It has been widely applied in surgical and prosthetic reconstruction of the craniofacial defects. The aim of this chapter is to characterize and assess the mechanical and optical properties of 3D colored printed soft tissue facial prostheses produced by Z-Corp-Z510 and infiltrated with Sil-25 maxillofacial silicone polymers. Mechanical properties assessed according to ASTM specifications for tensile strength, tear strength, hardness and percentage elongation. Furthermore depth of infiltration plus quality of infiltration was assessed. Scanning electron microscopy SEM was applied for this purpose to determine the characteristic of interaction and incorporation between the starch powder particles and the silicone polymers. Finally, method of color reproduction and evaluation for the printed prostheses are recommended.

Keywords: maxillofacial, anaplastology, rapid prototyping and facial prostheses, skin color

1. Introduction

Anaplastology is a multidisciplinary branch of medicine that deals with artificial reconstruction of a disfigured, absent or anatomically malformed part of the face or body by fabricating a customized facial or somatic prosthesis for the patient [1]. The prostheses provide descriptive evidence for steps of fabrication of these devices, including location, retention, support, time, materials, and form [2, 3]. Prostheses are artificial devices which either implanted or attached to the body to replace or restore a body part that might be congenitally missing or might have been lost due to tumor ablation or external trauma [4]. Facial disfiguration is considered a challenge for the patient; as it negatively interferes with the patient's self-image and ability coexist in a normal social life. Although the prosthesis is well appreciated by the patients, however, in many instances it does not restore function totally [1, 5]. Surgery can repair small defects, whereas, large defects could not be repaired surgically [6], Hence, prosthetic rehabilitation is frequently applied. This depends on a variety of factors including patient's age and systemic condition, size and site of the defect, patient's satisfaction and cost factors [7–9]. For example, an old patient with poor systemic health is not a good candidate for surgery, on the other hand, an impaired vision or a poor manual dexterity patient is not a good candidate for prosthesis as he will not be able to maintain the prosthesis properly.

Defects in the craniofacial region mostly lead to severe depression, even in some instances to self-isolation and rejection of life, hence, surgical reconstruction and/or prosthetic devises will be an insistent demand for a patient with facial disfiguration [10]. Esthetically appropriate Prosthetic rehabilitation of the patient is rather challenging requires multidisciplinary team for comprehensive care and optimal cost treatment functional and esthetic outcomes [11–14]. Oro-facial areas comprises a variety of vital and important structures, every so often surgical management of cancer in this region predominantly with widespread cancerous lesion require extensive removal of tissue—the cancerous lesion and part from the normal tissue around the lesion as a protective measure of surgical management of cancer. As a result of this aggressive surgical procedure many vital functions would be impaired such as esthetics, phonetics, mastication and vision. In these cases an extensive defect would be left behind that would most probably not be reconstructed surgically, alternatively prosthetic rehabilitation will be performed to improve patient's esthetics/function [15, 16]. Prosthetic rehabilitation of these patient provides comfort to the patients, improves their confidence and self-esteem. High level of satisfaction was recorded among patients wearing facial prostheses [17]. They experienced much better quality of life after wearing facial prostheses [16, 18].

The fabrication protocol of facial prostheses involves several intricate steps as described by many authors [19–21] including taking an impression or impressions, obtaining an accurate stone cast in order to carve an accurate wax model for the defect on that cast. The wax model then checked on the patient and transferred to the final material, which is mostly be a silicone polymers by process of flasking and deflasking after adding the basic skin color. Ultimate color matching is accomplished by adding extrinsic colors at the time of fitting and delivery.

Method of fabrication that is applied currently has shown several limitations. These are primarily related to the fabrication protocol, high technical expertise required, time, effort, cost plus retention and esthetic problems. These limitations make access to global patient's community almost denied, only a small number of these patients can get access to this sophisticated device, those who can afford the high cost of the prosthesis, whereas, people at the other poor global regions such as Africa and India they cannot easily obtain a good prosthesis.

In recent years, both additive manufacturing (also known as 3D printing) and 3D image technology had been developed dramatically and becomes more and more popular in medical science under the term of medical rapid prototyping (MRP). Medical Rapid prototyping was first described by Mankowich et al. in 1990 for imaging and producing anatomically accurate human parts models by rapid prototyping methods [22]. MRP then started to grow more and more to involve a wide range and fields in medicine including tissue engineering, dental implantology, craniofacial surgery and reconstruction and orthopedics.

Many aspects of this brilliant technology have still not been entirely functional for maxillofacial surgical/prosthetic rehabilitation. This technology has not been fully incorporated in producing maxillofacial soft tissue prostheses. However, some articles and few case reports applied this technology in the manufacturing process as producing accurate wax models for ear and other parts of the face using 3D printing machines to be replicated by the silicone polymers [23–27]. They were able to produce highly accurate anatomical models of the missing parts, nevertheless, the entire procedure found to become more time consuming and much costly than if the prosthesis made by hand alone.

In our previous studies, an innovated method of fabrication of soft tissue facial prostheses using 3D color printing technology have been developed using Z-Corp

Figure 1.
An overview of rapid manufacturing technology applied to fabricate soft tissue facial prostheses.

printer, printing in starch as a powder and colored ink as a water based binder, printing process based on computer aided design and manufacture CAD/CAM [28–30]. **Figure 1** summarize the current project that starts with 3D Data acquisition instead of using a complicated multiple impression techniques, then processing these date in a 3D computer aided design—CAD package, building a virtual 3D model for the prosthesis, color mapping then the printing process accomplished using Z510-3D color printer. After printing the robot models infiltrated with elastomeric silicone in order to achieve skin texture and softness. Furthermore, data can be saved for future printing of further copies on demand.

With above protocol, there is huge potential to replace the conventional technology by the rapid manufacturing technology with saving both time and cost. However, some more factors affect quality of prostheses significantly, including mechanical properties, infiltration and degree of skin color reproduction. In this study, these factors are investigated and further developed. Results are described in following sections.

2. Mechanical properties

The mechanical properties of facial prostheses is very important since it directly related to durability of the prostheses. For 3D printing technology we proposed, a starch powder were used to print soft tissue prostheses by a Z-Corp Z510 3D printer and infiltrated using silicone polymers as the post processing. The mechanical properties of the composite produced by Z-Corp printer is tested here by comparing its' mechanical properties with object produced by silicone polymer using conventional technology [31].

Test models that were printed from starch by Z Corp 3D printer and infiltrated with maxillofacial silicone polymer—Sil-25 are shown in **Figure 2**.

Mechanical test for conventional technology is simulated using pure silicone polymers and used as control samples (**Figure 3**).

Pure silicone samples were designed according to ASTM specifications for tensile strength (Dumbbell-shaped specimens [32]), tear strength (Trouser-shaped specimens [33]), hardness test [34], and percentage elongation using solid work

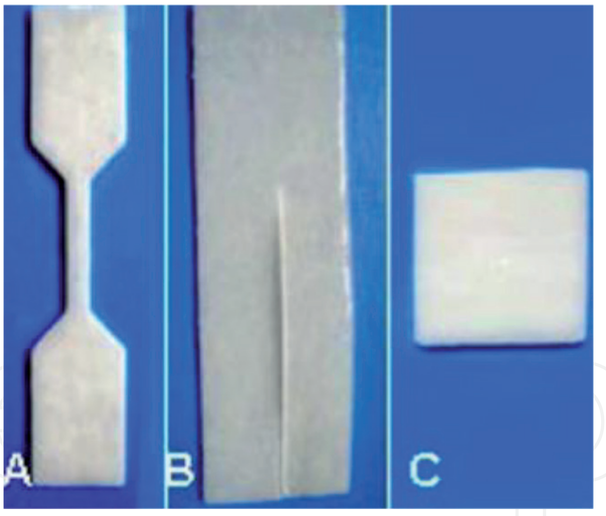

Figure 2.
Starch printed infiltrated silicone test samples for (A) dumbbell-shaped for tensile strength, (B) trouser-shaped for tear strength and (C) hardness test blocks.

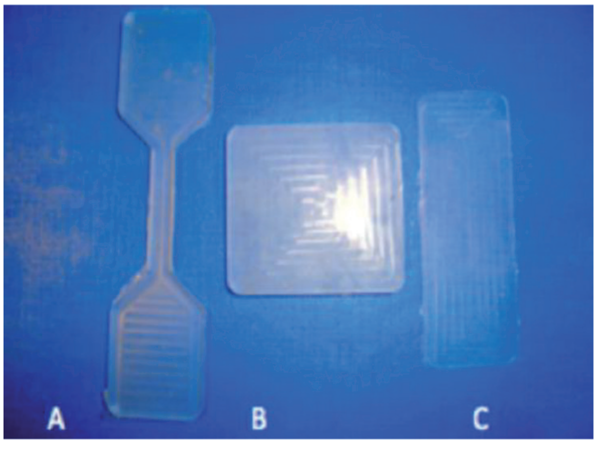

Figure 3.
Silicone polymers test samples for (A) dumbbell-shaped for tensile strength, (B) hardness test blocks and (C) trouser-shaped for tear strength.

2008 software for printing test samples and stainless steel molds were fabricated for the control samples (**Figure 4**).

Lloyd LRX tensile instrument applied to test tensile strength, tear strength and percentage elongation (**Figure 5**).

Shore Durometer Hardness Tester was applied to test the hardness of the 3D printed starch models infiltrated silicone polymers to be compared with pure silicone samples (**Figure 6**).

The collected data was analyzed using PASW statistics 18 to compare between the test group—3D printed samples and control group—pure silicone samples, Independent sample T test was utilized for the statistical analysis.

Table 1, Demonstrating the result of mechanical tests that reveals that test group—the 3D printed samples has significantly lower tensile, tear, and percentage elongation than control samples—pure silicone samples ($p < 0.05$). Whereas, a significant increase in the hardness of the printed samples compared to pure silicone samples ($p < 0.05$) as shown in **Table 1**.

The results indicated an increased hardness, and consequently the prostheses lose some flexibility, hardness is not the only issue that determine the flexibility, here the technology applied provide shell-like models and the prostheses built according to CAD/CAM is shell prosthesis showing high degree of flexibility than

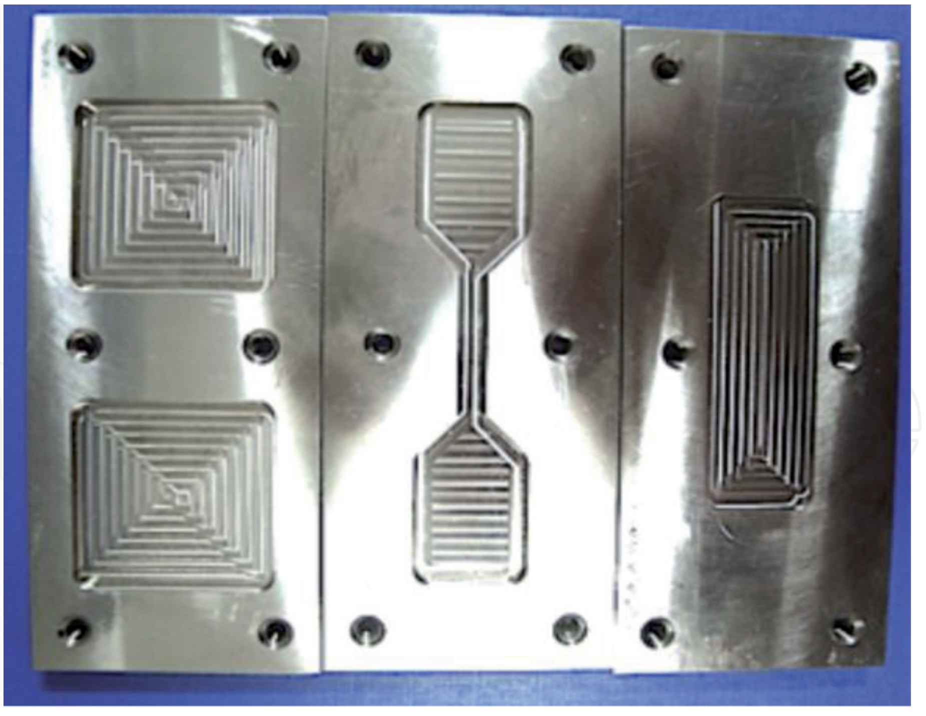

Figure 4.
Stainless steel molds for fabrication of control samples—pure silicone.

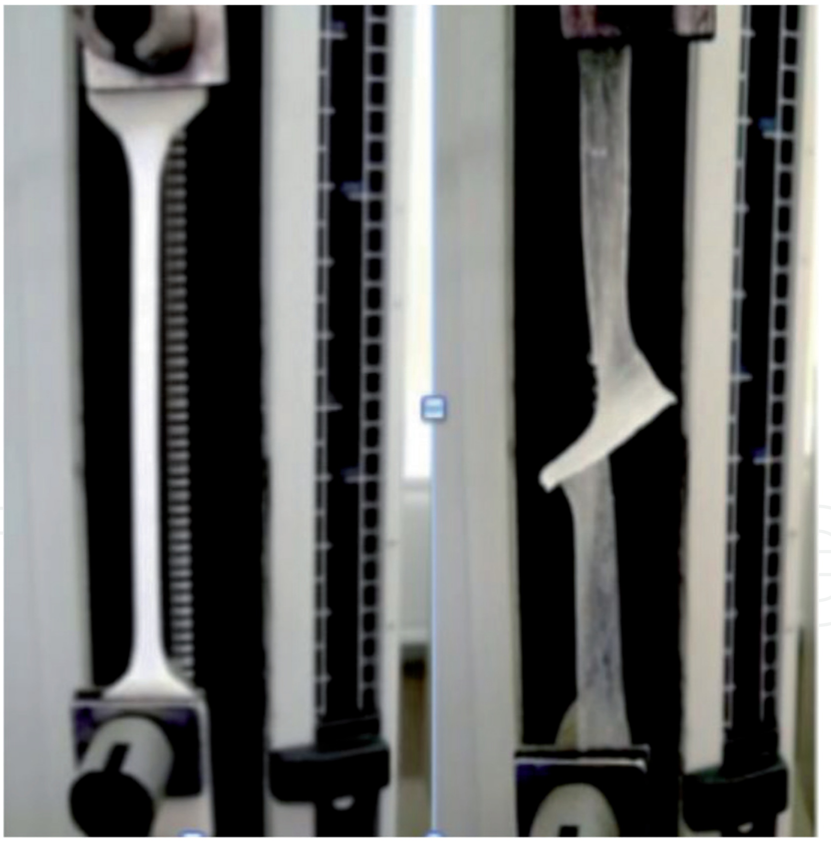

Figure 5.
Lloyd LRX tensile tester testing tensile and tear strength of the printed samples.

handmade prosthesis despite increased hardness of the printed prostheses compared to pure silicone prostheses as shown in **Figure 7**.

Lower values of tensile, tear strength and percentage elongation do not indicate a critical problem if the patient maintained and handled the prosthesis gently, as a matter of fact the prosthesis does not require a very high tensile or tear strength

Figure 6.
Hardness tester testing hardness of the printed samples.

Sample	Tensile stress (PSI)	Tear stress (N/mm)	Hardness	Elongation (%)
Silicone (Convectional)				
Average	455.98	10.77	30.89	480.75
SD	32.20	2.60	0.71	84.40
Silicone infiltrated starch (3D printing)				
Average	170.45	8.02	62.80	221.46
SD	36.10	1.68	2.782	51.44

Table 1.
Comparing the mechanical properties of the printed models with pure silicone models.

unless the patient stretch his/or her prosthesis and handle it harshly. The patient should follow the instruction for maintenance cautiously so that to extend the prosthesis service life.

Investigations of mechanical properties (tensile, tear, hardness and percentage elongation) of the printed samples were significantly different from control samples. In this study the results of the mechanical tests performed on tensile strength, tear strength, the percentage of elongation and hardness for the printed samples were found to be significantly different from the control samples. According to results obtained from this study, no one can suggest that the manufactured prosthesis does not last long or not better than the handmade prosthesis, because the ideal properties have not been standardized yet in terms of the mechanical properties.

Variation in mechanical properties of the test samples compared with controlled samples—pure silicone samples could be perhaps due to amount of starch in the test material, as starch provides a scaffold for the silicone polymer when it is used by Z-Corp printer to produce three dimensional 3D facial prostheses. The starch

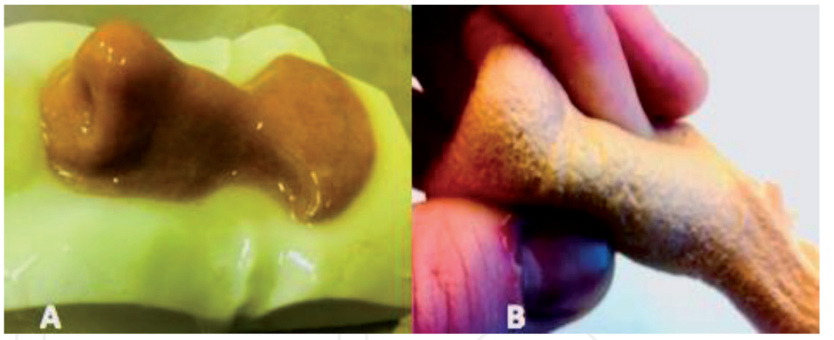

Figure 7.
(A) Method of infiltration leaving feather edged margin of the prosthesis. (B) Flexibility of printed prosthesis infiltrated silicone polymer.

acts as filler for the 3D printed prostheses, a filler when added to the silicone polymer may increases hardness, and reduces tensile and tear strength, of course that is depend on the type and amount of the filler [35, 36]. Therefore, it was necessary to measure the weight or volume ratio of silicone polymers—the infiltrate to starch—the filler. Furthermore, and in order to understand the variation in the mechanical properties and the general drawback in these properties it was necessary to investigate depth of penetration of the infiltrate (silicone polymers) inside the printed starch models the quality of this infiltration. Therefore, Proper protocols were designed for

1. Percentage of starch by weight within fully infiltrated models
2. Depth of infiltration inside printed starch models
3. Quality of infiltration and degree of coherence between the starch particles and the silicone polymers.

3. Infiltration

For 3D printing soft tissue prostheses process, the 3D printed starch models is infiltrated by silicone polymers in order to provide skin texture and required elasticity and softness. The infiltration process affects overall quality of prostheses and therefore investigated below in different aspects.

3.1 Silicone/powder ratio by weight

As the starch powder implicated in fabrication of 3 dimensional soft tissue prostheses, it was necessary to determine the average amount of this powder within the total weight of prosthesis and their percentages by weight in the final prosthesis. in this investigation, 8 printed blocks of the starch powder (45 × 45 × 4 mm) were produced by Z510 printer. The blocks weighed using a sensitive digital balance (Mettler AJ100). Then the samples infiltrated with Sil-25 maxillofacial silicone polymers according to infiltration protocol mentioned in the previous section (3 bars for 25 minutes left for 25 hours) final setting time. Then the infiltrated blocks weighed again and percentage of each component within an infiltrated block was determined. **Table 2** shows weight in gram, standard deviation and percentage of each component. The powder adds up to 40% of the total weight of the fully infiltrated blocks, whereas the silicone polymers comprising only 60%.

Weight in gram and SD		% By wight	
Starch	Starch + Silicone pressure	Starch	Silicone pressure
3.5 ± 0.04	8.50 ± 0.07	41.5%	58.5%

Table 2.
Percentage of silicone polymers and starch powder in fully infiltrated blocks.

3.2 Depth of infiltration of the silicone polymers into 3D printed facial prosthesis

As the printed starch models produced by the Z-Corp printer are solid and fragile, therefore, it was necessary to apply a specific protocol for infiltration of the silicone polymers into the printed models. For this purpose a set of 30 cubes measuring 20 × 20 × 20 mm were printed in starch, using Z-Corp (Z510) 3D printer, the starch cubes were infiltrated with Sil-25 maxillofacial silicone polymer under different conditions. One group served as control group, the cubes were infiltrated with Sil-25 maxillofacial silicone polymers, ratio (1–10) according to manufacturing standard. The cubes were then submerged in the polymer mixture and left under atmospheric air pressure at room temperature for a scheduled time, 5 minutes ($n = 6$), 10 minutes ($n = 6$), 15 minutes ($n = 6$), 20 minutes ($n = 6$) and 25 minutes ($n = 6$), and then left to set for 24 hours. The cubes then bisected with surgical blade No. 11. The inner part of the cube stained to color and highlight the non-infiltrated parts of the cubes in order to measure infiltration depth of the silicone polymers inside the cubes (**Figure 8**).

Three other groups were served as test groups, testing infiltration depth was repeated on 30 cubes measuring 20 × 20 × 20 mm for each test group, but in this group the cubes were placed in a pressure vessel under 1, 2 and 3 bars pressure for a similar time schedule, 5 minutes ($n = 6$), 10 minutes ($n = 6$), 15 minutes ($n = 6$), 20 minutes ($n = 6$) and 25 minutes ($n = 6$). After 24 hours the cubes were bisected and the inner part of the cubes colored then Traveling microscope (Mitutoyo TM) with X-Y coordinate, used to measure the infiltration depth, 12 measurements on each sectioned cube (**Figure 9**).

Result of this study is shown in **Figure 10** and **Table 3**, minimum depth of infiltration was detected under normal atmospheric pressure and room temperature, which was around 1 mm, this was slightly affected by length of time the cubes staid sank in the silicone polymers. Whereas, 2 and 3 bars pressure increased the infiltration depth of the silicone polymers significantly, which was also affected by length of time. Maximum infiltration depth was recorded for 3 bars pressure and at 25 minutes time. Results showed that pressure and time have significant effect on the depth of infiltration of the silicone polymers inside the powder cubes. Two ways ANOVA implied significant differences ($p < 0.05$) between the three groups of the current study, normal pressure, 2 and 3 bars pressure.

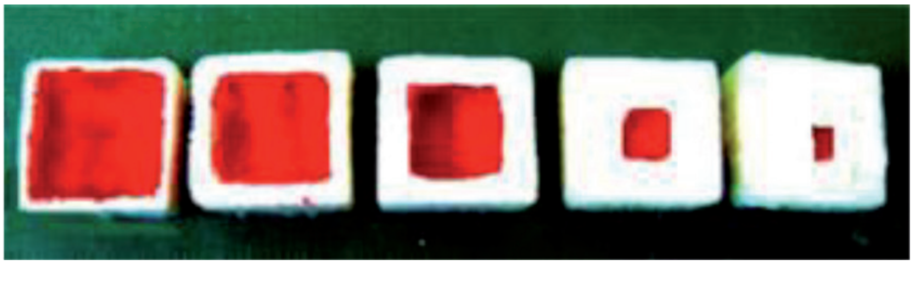

Figure 8.
Bisected cubes stained to identify the depth of infiltration of silicone polymers, the dye is taken up by the hydrophilic starch, whereas the infiltrated area is hydrophobic and does not take up the dye.

Figure 9.
Traveling microscope (Mitutoyo TM) with X-Y coordinate, used to measure the infiltration depth, 12 measurements on each sectioned cube.

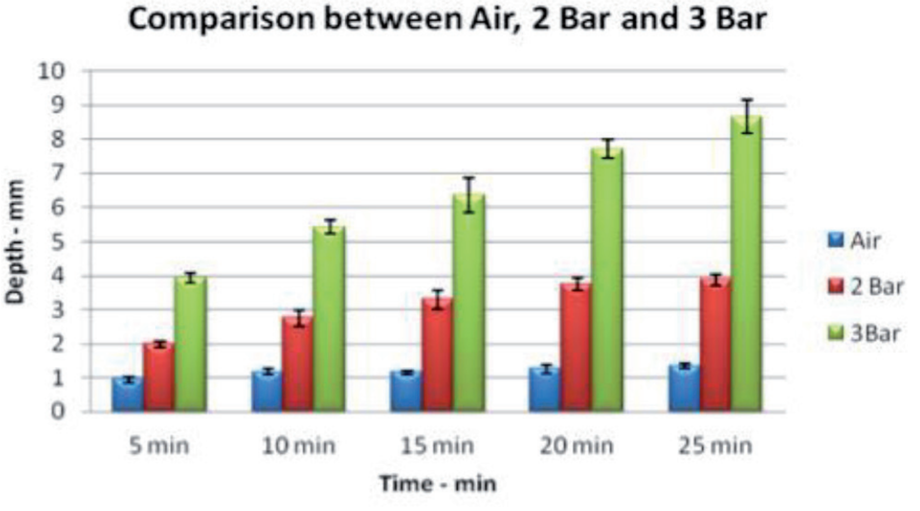

Figure 10.
Infiltration of Sil-25 under normal air, 2 and 3 bars pressure and 5-time schedule.

According to result obtained from this study, it can be concluded that infiltration depth of Sil-25 silicone polymers is significantly influenced by pressure applied. Under 3 bars and 25 minutes time, the infiltration depth recorded more than 8 mm from all sides, this would suggest that infiltration depth inside a prosthesis would be around 16 mm and reasonably this depth will be sufficient for soft tissue facial prostheses.

3.3 Quality of infiltration of the elastomer into 3D printed facial prosthesis

Evaluation of the infiltration quality of silicone polymers inside the 3D printed starch powder was required to characterize the interaction between the hydrophobic silicone polymers and the hydrophilic starch powder. It is acknowledged that the mechanical and optical properties of the 3D printed prostheses depend basically on material properties and characterization, which consequently determine the service life of the prostheses and determine its ability to resist the environmental factors such as UV from sunlight humidity, body secretion and weathering temperature. The previous section determined depth of infiltration of the infiltrate inside the printing powder, 8 mm penetration depth was achieved. However, we did not realize how consistent/homogeneous this infiltration was. Therefore, SEM was carried out to characterize an important aspect of 3D color printing facial prostheses and to detect any flaw in the structure of the composite that is utilized in fabrication of facial prostheses.

		Infiltration depth in (mm) and SD				
Infiltration time (minutes)		5 minutes	10 minutes	15 minutes	20 minutes	25 minutes
Silicone polymer	Pressure					
Sil-25	Air pressure	0.94 (0.08)	1.19 (0.01)	1.16 (0.05)	1.27 (0.13)	1.35 (0.08)
Sil-25	2 Bar	1.99 (0.10)	2.76 (0.23)	3.30 (0.28)	3.75 (0.19)	3.88 (0.17)
Sil-25	3 Bar	3.94 (0.15)	5.43 (0.20)	6.36 (0.51)	7.71 (0.27)	8.65 (0.49)

Table 3.
Infiltration depth of Sil-25 inside 3D printed starch blocks under different pressure and at different time schedule.

3.3.1 Slide preparation for SEM

Scanning Electron Microscopy SEM was applied for this purpose to prepare and obtain various samples of printed starch blocks infiltrated with two different maxillofacial silicone polymers (Sil25 and Promax 10) in order to examine the quality of the infiltration inside the starch printed blocks. SEM pictures of the printed blocks were compared with hand mixed of 40% starch powder and 60% Sil25 silicone polymers. Hand mixed blocks were prepared by mixing the starch and the silicone polymers for 1 minute to obtain a homogenous mixture, then the mixture poured into a 75 × 75 × 4 mm stainless steel mold, pressed and left for 24 hours in ambient temperature. Then slices from the three blocks were prepared using surgical blade number 11 and send for SEM to be examined with SEM of starch powder alone.

3.3.2 SEM interpretation

SEM analysis of the starch powder, 3D printed blocks infiltrated Sil-25 and Promax10 plus the hand mixed blocks are shown in **Figure 11**, the SEM of the powder and of the infiltrated powder blocks showed amorphous, non-crystalline shaped particles with different particle sizes varies from very small to relatively large particles. These particles appeared to be loosely arranged and randomly orientated with some spaces in between these particles and disorganized spreading of the starch powder within the silicone polymers leaving big gaps between the powder particles. Incorporation of starch powder with Sil-25 maxillofacial silicone and Promax10 under 3 bar pressure are seen in **Figure 11A** and **B**, showing almost similar distribution of the powder within the infiltrates. However, better incorporation and more homogenous distribution of starch particles within the silicone polymers in hand mixed of 40% powder incorporated into 60% infiltrate of silicone polymers by weight (**Figure 11C**). This could be attributed to the layer of binder on the outer surfaces of the printed blocks that might an obstacle for the infiltration process.

3.3.3 Final analysis of SEM

Figure 12 is a magnified SEM image (×707) of hand mixed starch powder and Sil-25 silicone polymers. Although at a lower magnification the sample apparently seems to be very properly infiltrated having smooth texture, however, under higher

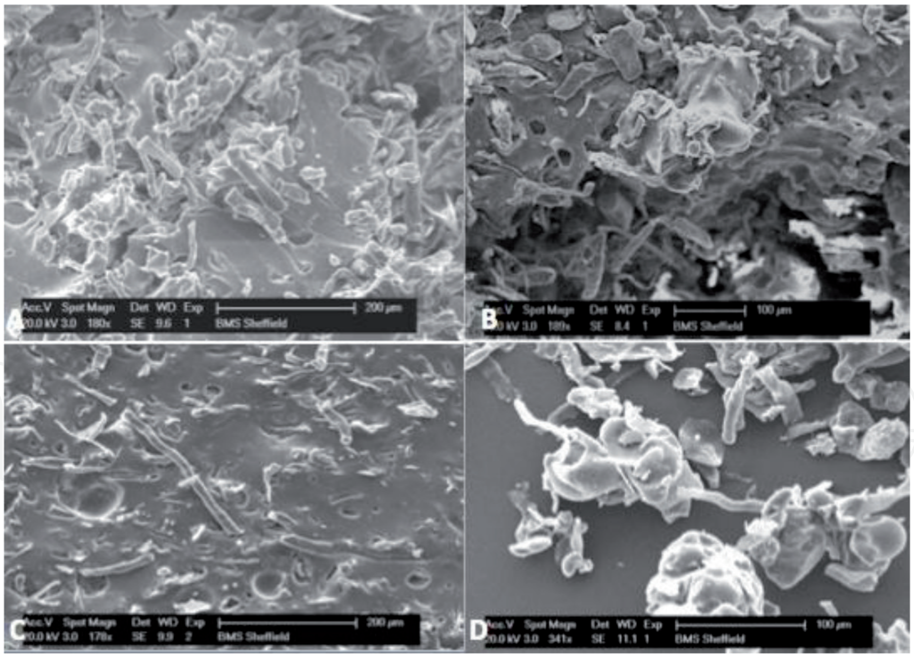

Figure 11.
SEM for (A) 3D printed starch block infiltrated Sil-25 SP (×180), (B) 3D printed starch block infiltrated Promax10 (×189), (C) hand mixed starch powder and Sil-25 SP (×178), (D) starch powder particles (×341).

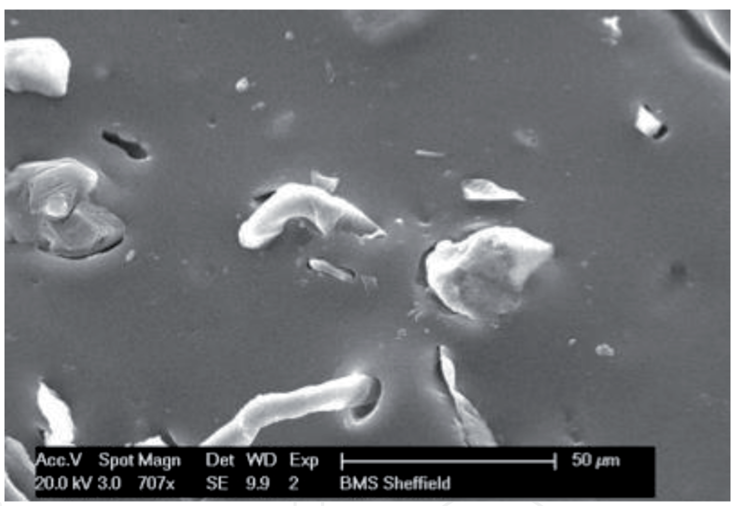

Figure 12.
SEM for Sil-25 hand mixed samples showing spaces around the starch particles (×707).

magnification the composite shows evidence of porosity and spaces between the powder particles and the silicone polymers within the composite. This phenomenon indicates lack of coherence and integrity between the hydrophobic silicone polymers and the hydrophilic starch powder, which, is related to the wettability and viscosity between silicone polymers that have low surface energy and strongly hydrophobic [37] and starch powder is hydrophilic in nature [38].

Furthermore SEM sections (**Figures 11C** and **12**) showing gaps and voids, which indicate tripping of air especially in central parts of the blocks under infiltration pressure. Lack of interaction and incorporation between the starch powder particles and the silicone polymers that are utilized by Z-Corp printer and employed for fabrication of soft tissue facial prostheses will influence the general properties and material's integrity, which my finally affect the durability of the prostheses. Therefore, it was necessary to test the mechanical properties of the 3D printed samples that are going to be used for fabrication of soft tissue facial prostheses.

4. Skin color reproduction

Skin color is vital for quality of facial prostheses. Previous research has focused on reproducing skin color and assess their color appearance difference under standard lighting conditions [39, 40]. The advent of new lighting technologies such as Halogen and LEDs generates new challenges for rendering skin on displays, in print, but most importantly, for synthetically generated skin prostheses, since ambient illumination can change the appearance of both natural and synthetic skin, but not necessarily in the same way [41]. Here skin appearance models not only need to take into account different ambient illuminations, but also the three-dimensionally geometry of the human face and differences in the methods for reconstruction—surgery, prosthetics or medical make-up/tattooing [42]. Therefore, to truly reproduce appearance of skin color under different illumination and objectively evaluate their color quality, follow steps are develop:

Step 1: Measurement of skin spectral reflectance of subject

The measurement of skin spectral reflectance would be affected by these various parameters, including the measurement instruments, measurement distance, measurement location, the instrument aperture size, the pressure applied to the skin by the instrument, as well as the gender and ethnic group [43]. Spectrophotometer is recommended for facial prostheses application, since it is independent of lighting applied and highly consistency [44].

Step 2: Develop spectral color profile for 3D camera

3D camera can be used to capture facial and body image. A spectral reflectance estimation need to conduct to transform camera RGB to spectral reflectance for each pixel of 3D image [45]. Spectral color database [46, 47]need to be used as training sample to obtain base function for spectral reflectance estimation.

Step 3: Develop spectral color profile for 3D printer

For 3D color printing, spectral color profile also needs to develop to transform spectral reflectance of human skin in each pixel of 3D image to printer CMYK value for color printing. Post printing processing also needs to conducted for infiltration process as described in previous section

Step 4: Color quality evaluation

To evaluate color quality of facial prostheses, the average CIELAB color difference (ΔEab) under several standard CIE illuminants needs to calculated. To test spectral reproduction, the root-mean-square error (RMSE) and goodness-of-fit coefficient (GFC) needs to apply [48].

5. Discussion

Drawback in the mechanical properties of the printed samples mostly attributed to the amount of starch (40%) and due to lack of coherence and integrity between the hydrophobic silicone polymers and the hydrophilic starch powder that form the scaffold for the test samples as Z Corp 3D printer utilizing starch powder for printing which led to draw back in the mechanical properties of the final product. Perhaps the prostheses will have a shorter service life than the conventional pure silicone prosthesis. However, printing several prostheses at time of printing could compensate the drawback in the mechanical properties. The technology applied enabled construction of several copies of the prostheses in a shorter time frame and at a lower cost than handmade silicone polymer prostheses. Another advantage of applying rapid prototyping is that producing the required thickness of the missing part that rendering a lightweight prosthesis, which is mostly valued by the patients (**Figure 13**).

Furthermore, designing a prosthesis by using 3D software package can also allow the anaplastologist to save the design and all patients data to utilize it for printing future copies of the prosthesis on the patients' demand and with only light modification in the design of the prosthesis if there is any tissue change at the site of the

Figure 13.
3D printed nasal prosthesis showing nostril opened due to controlled thickness of the prosthesis.

Figure 14.
Nasal prostheses produced by Z510-3D color printer.

defect [28]. Finally we believe that the many limitations of handmade prostheses regarding esthetics, high prosthesis cost, time, effort, hectic impression techniques and problems of retention plus high technical skill required for fabrication by anaplastologist could be generally reduced and consequently minimizing the social and psychological challenges that often-maxillofacial patients encountered in life.

At this stage, a fully computerized customized prosthesis is manufactured, using biocompatible materials [49]. The prosthesis matching the patient's skin color and having skin-like texture with accurate anatomical details of the patient, possessing a light weight with controlled thickness of the prosthesis that is well appreciated by the patients as shown in (**Figure 14**).

Despite the many advantages of this technology in constructing soft tissue facial prostheses, there were few limitations compared to handmade—conventional method of fabrication. These limitations were related to the mechanical properties of the final product [50]. The mechanical tests shows drawback in the mechanical properties, however, it is hard to judge how poorly that will affect the prosthesis on the patient; the only real way of testing mechanical and optical durability is when the prostheses test on the patients during the service life of the prosthesis. As the project was at the experimental stage of development it wasn't possible to perform these tests on patients [28]. More work should be done to determine how long the prostheses would last. So far it is obvious that the prostheses done need to be replaced regularly. Further investigations should be done on the printing materials in order to improve the mechanical properties and durability of the prostheses and to achieve optimal advantages of time compression technology and rapid prototyping for simple, full automated fabrication of facial prostheses.

6. Conclusion

Color matched maxillofacial prosthesis was fabricated using Z-Corp 510 color printer utilizing starch based biocompatible materials. According to the mechanical properties, the prosthesis should be replaced in a range of 6–12 months. The prosthesis could be used as interim prosthesis special after surgery while the patient is going through healing period. Furthermore the prosthesis could be used as definitive prostheses by compensating the draw back in the mechanical properties by taking the great advantages of this great technology that having the ability of printing several copies of the prosthesis at the time of printing at lower cost and rapid manufacturing of anatomically more accurate parts compared to handmade prostheses and applying more comfortable methods of data capturing, designing and manufacturing.

Author details

Faraedon M. Zardawi[1] and Kaida Xiao[2*]

1 University of Sulaymaniyah, Iraq

2 University of Leeds, United Kingdom

*Address all correspondence to: k.xiao1@leeds.ac.uk

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