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The effect of impression tray relief holes on tissue displacement: an *in vitro* simulation

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A mini-thesis submitted in partial fulfilment of the requirements for the degree of Master of Dental Surgery in the speciality of Prosthodontics in the Department of Prosthodontics, Faculty of Dentistry, University of the Western Cape.

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Co-supervisor: Prof Greta Geerts

Keywords

Impression tray

Relief hole

Simulation

Tissue displacement

Abstract

The effect of impression tray relief holes on tissue displacement: an *in vitro* simulation

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MChD (Prosthodontics) mini-thesis, Department of Prosthodontics, Faculty of Dentistry, University of the Western Cape.

Background:

Mobile fibrous tissue can cause excessive movement of a complete denture during function, causing discomfort for the patient. Extensive tissue displacement during definitive impression making can have a direct impact on the anatomical form on which the complete denture will be fabricated. When displaced mobile fibrous tissues return to their relaxed state, dislodgment forces might work against the denture base. As a result, the manner in which the tissues are recorded is critical to the retention and durability of the complete denture. The addition of relief holes to the custom tray allows impression material to escape and decreases the pressure exerted to the underlying alveolar tissue, hence minimizing tissue displacement.

Aim of the study:

To assess the degree of simulated fibrous tissue displacement on edentulous maxillary analogues when three dimensional (3D) printed custom impression trays with various relief hole sizes and quantities are utilised during a one-step secondary impression technique. To achieve this aim, impressions were digitally analyzed by superimposing the 3D digital control and test models for quantitative analysis utilising metrology software.

Methodology:

A total of 117 secondary impressions were made on 3D printed edentulous maxillary test models with simulated fibrous tissue during a one-step impression technique. Three groups of 3D printed custom impression trays with various relief amounts were fabricated: 1, 2, and 3. These groups were then subdivided into A, B, and C subgroups based on the diameter of the relief holes, which were 1mm, 2mm, and 3mm, respectively. Overall, nine custom tray configurations with various relief hole diameters and quantities were tested. The impression material used to make the test impressions was polyvinylsiloxane light body. Impressions were digitally analyzed by superimposing the 3D digital control and test models for quantitative

analysis utilizing metrology software. Cross-sectional measurements (millimeters) were recorded at four reference points on the superimposed control and test models to quantify the difference in vertical tissue displacement among the nine custom tray designs. The data was analysed in IBM® SPSS® Statistics Version 24 (IBM Corporation), and a one-way ANOVA test was used to determine the significant differences in tissue displacement among the groups. Following that, post hoc tests were performed to conduct multiple comparisons among the sample groups, with a significance of $p < .05$.

<u>Results:</u>

The results reveal that there is a difference in tissue displacement based on the diameter of the relief hole within each tray design group (1A/1B/1C, 2A/2B/2C, 3A/3B/3C). Similarly, there is a difference in tissue displacement based on the number of relief holes within each tray design group (1, 2, 3). The p-values for all groups are significantly less than 0.05, indicating a high level of significant difference. The amount of tissue displacement was significantly reduced by increasing the diameter and number of relief holes. The comparison of different tray designs clarifies the effect of diameter and number of relief holes on tissue displacement.

<u>Conclusion:</u>

Within the limitations of this study, it may be concluded that larger and more relief holes in the custom impression tray reduced displacement of maxillary fibrous tissue during a one-step secondary impression.

<u>Significance of the study:</u>

The findings of this *in vitro* study may contribute to the development of improved custom tray designs, with the recommendation that, when placed over fibrous tissue, the diameter and number of relief holes within a custom tray be increased to reduce the degree of displacement of compromised mobile tissue during a one-step impression technique.

Date: October 2023

Declaration

I declare that '*The effect of impression tray relief holes on tissue displacement: an in vitro simulation'* is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Full Name: Lauren Jade Brown-Steenkamp **Date:** October 2023

Signed: ……………

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Mr. Werner Hamman (Dental Fusion), for his assistance with the 3D printing of the custom impression trays.

Dedication

My husband, Ryan Steenkamp, your encouragement, love and support has given me all the strength I've needed during this journey. I could not have done it without you.

My sons, Kye and Kayd Steenkamp, I appreciate all of your patience, love, and support.

My parents, Clint and Marcelle Brown, you have always inspired me to pursue my goals and have always supported me in every way you could. I thank you for this.

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Chapter 1 – Introduction

Edentulous people who have worn complete dentures for a long time have alveolar tissue that varies in dimension, consistency, and degree of displacement. Mobile fibrous tissue, commonly referred to as "flabby tissue," is a prevalent clinical finding in complete denture wearers, most often affecting the anterior maxilla (Komiyama *et al.,* 2004).

According to Crawford and Walmsley (2005), the edentulous maxilla exhibits a greater prevalence of mobile fibrous tissue than the edentulous mandible. The specific explanation for the replacement of resorbed alveolar bone by mobile fibrous tissue is uncertain. It is considered, however, that it is tied to a number of relevant variables occurring concurrently.
The elastic properties of fibrous tissue bring about displacement under functional load, but it returns to its natural relaxed state once the force is withdrawn. Many patients have reported inadequately fitting dentures that are unstable and unretentive, causing pain while functioning as a result of this movement. As a result, the manner in which the mobile tissues are recorded during the impression-making process is important to the retention and stability of the complete denture (Shah *et al.,* 2017).

The extent of fibrous tissue displacement during definitive impression making is a continuous challenge for dentists. To minimise the amount of fibrous tissue displacement, definitive impression techniques employ a variety of modified custom tray designs, including the inclusion of a relief spacer and relief holes. *In vitro* studies have demonstrated that including relief areas within custom trays decreases hydraulic pressure build-up during impression making, resulting in minimal tissue displacement (Komiyama *et al.,* 2004; Reddy *et al.,* 2012).

The purpose of placing relief holes in custom trays is to enable the impression material release and to relieve pressure on the underlying tissues below the perforation (Klein and Broner 1985). As a result, strategically positioned perforations within custom impression trays should significantly reduce the amount of fibrous tissue displacement when used during the one-step impression technique.

Chapter 2 – Literature review

2.1 Impression techniques:

Definitive impressions for complete denture fabrication should always incorporate the basic principles of providing satisfactory denture base extension, acceptable retention, stability, preservation of underlying alveolar tissues, even stress distribution over primary support areas, and relief over compromised tissues (El-Khodary, Shaaban, and Abdel-Hakim 1985). Conventional management of mobile fibrous tissue includes the use of specialised impression techniques. According to the literature, there are three notions in impression making: mucostatic, mucocompressive, and mucoselective (Crawford and Walmsley 2005; Shah *et al.,* 2017).

The mucostatic approach attempts to record alveolar tissues without displacement; thus, the tissues stay relaxed. This concept solely takes into account the intaglio surface tension to enable denture retention. As a result of denture base instability, disruption of intaglio surface tension, and insufficient denture peripheral extension, the denture dislodges during function, and retention is lost. The mucocompressive technique is applying generalized pressure to the alveolar ridge while making impressions, allowing for appropriate extension of peripheral flanges and base adaption. Continuous pressure on the underlying supporting alveolar tissues, on the other hand, is thought to result in advanced alveolar ridge resorption (Crawford and Walmsley 2005; Shah *et al.,* 2017).

The mucoselective impression is the most commonly used concept because it combines mucostatic and mucocompressive principles. The mucoselective impression focuses functional stresses on the primary stress bearing areas of the alveolar ridge while decreasing functional stresses on compromised moveable fibrous tissues (Shah *et al.,* 2017). According to Boucher (1951), introducing a space in the custom impression tray over the mobile fibrous tissue enables regulation of the displacement of the tissue. Boucher (1951) further emphasised the need of relieving the median suture and incisive papilla in the custom impression tray, as this ensures uniform pressure distribution and prevents blood vessel constriction.

Over the years, dentists have designed a wide array of modified custom impression trays that incorporate relief holes, openings, and wax spacers to relieve hydraulic stress on the alveolar tissues. In the one-step impression technique, the mucoselective concept is employed together with a custom tray that includes relief holes and relief space over the mobile fibrous tissue. The impression is made using just one approach and a single impression material (Crawford & Walmsley 2005). There is no scientific evidence to suggest that one custom tray design is more precise than another; consequently, the clinician should consider the presenting clinical condition and elect a design accordingly.

2.2 An overview of studies on custom impression tray designs:

For many years, researchers have been interested in investigating the pressure produced during impression making. Following a review of the literature, it becomes apparent that only a few studies have explored the influence of various custom tray configurations on the pressure exerted across the edentulous alveolar ridges when paired with impression materials of varying viscosities (Woelfel, 1962; Frank, 1969; Masri *et al.*, 2002; Nishigawa *et al.,* 2003; Komiyama *et al.*, 2004; Reddy *et al.*, 2012; Chopra *et al.*, 2016; Fouladi *et al.,* 2016; Shin *et al.,* 2016; Shin *et al.,* 2019). The impression material used in the studies included polyvinylsiloxane elastomer, polyether elastomer, polysulfide, irreversible hydrocolloid, and zinc oxide eugenol.

When making a definitive impression, the placement of a spacer and relief holes in an impression tray is more important than the choice of an impression material, according to Woelfel (1962). Throughout the *in vitro* research, no special attention was given to the variance of the relief holes within the impression trays.

Frank (1969) examined the pressure exerted on the edentulous maxillary ridge and palate during impression making. Relief spacers and relief holes were either included or not included in the impression tray designs. Maxillary analogues were created using a soft silicone denture lining to mimic soft tissue. The *in vitro* study revealed that when custom impression trays with relief spacers were used, there was no statistically significant difference in pressure across the palate and alveolar ridge crest. The study provided no information about the size and number of relief holes used in the custom impression trays.

The positioning of relief holes in custom trays, according to Klein and Broner (1985), allows for the release of impression materials, thus reducing hydraulic pressure and displacement of underlying alveolar tissues. There are four relief holes in the anterior palatal location, six in the anterior flange from canine to canine, and four in the buccal flanges from the first premolar to the second molar.

Masri *et al.* (2002) discovered that the presence of relief holes, either with or without relief spacers, had no effect on the amount of pressure provided to the mucosa during impression making. The *in vitro* study showed that custom tray modifications can be insignificant and that the viscosity of impression materials has a greater influence on the amount of pressure applied to the mucosa. The three impression materials investigated were irreversible hydrocolloid, light-body and medium-body polyvinyl siloxane, and polysulfide.

According to Nishigawa *et al.* (2003), the rate of flow velocity of impression material in the custom tray may decrease at the relief region, and the relief hole may divert the flow away from the tissues. The relief space, according to the *in vitro* study, should be created immediately above the underlying tissues, and the relief hole should be placed to minimise flow at the tissue area. This *in vitro* investigation's conclusions were exclusively based on visual inspection, with no measurements of the pressures applied to the underlying tissues taken. The relief hole's volume and size were not stated.

Komiyama *et al.* (2004) used tiny pressure sensors situated on the maxillary region to evaluate the influence of varying relief hole diameters and spacer thicknesses on definitive impression pressure. This *in vitro* study found that a 1.4mm relief space and 1mm escape holes, especially in the mid palate area, lowered pressure over the alveolar mucosa. Despite the fact that the study looked at relief hole sizes ranging from 0.5mm to 2mm, the number of relief holes remained constant.

According to Reddy *et al.* (2012), regardless of the impression material employed, the insertion of a relief spacer in the custom tray can result in a significant decrease in the pressure exerted onto the simulated alveolar tissues. Light body polyvinylsiloxane elastomer and zinc oxide eugenol were used as impression materials in the investigation. The thickness of the relief spacers utilised in the custom tray was being investigated rather than the placement of relief holes.

Chopra *et al.* (2016) demonstrated in an *in vitro* investigation that the presence of relief spacers impacted the degree of pressure at various points on the simulated tissue, and that all impression materials produce pressure during maxillary edentulous impression making. The impression material used in the study included light body polyvinylsiloxane elastomer and zinc oxide eugenol. Relief holes of 2mm diameter were inserted in the custom trays, but no further examination into the variance in amounts was conducted.

Fouladi *et al.* (2016) investigated the effect of a relief hole and spacer thickness on pressure exerted on edentulous maxillary casts during impression making. Two bars were positioned in the mid palatal raphe and first molar regions of the cast. To decrease the pressure on the alveolar tissues in the area of relief, the authors advised a relief hole 1mm or greater in diameter and a spacer 1.5mm thick. As a result, it was found that increasing the relief hole diameter and spacer thickness significantly reduced the applied pressures. The outcomes of the *in vitro* investigation are confined to the various relief hole sizes, not the total number of relief holes.

Pressure accumulation in custom trays with different relief space thicknesses and impression materials was investigated by Iwasaki *et al.* (2016). Polyvinylsiloxane elastomers, polyether elastomers, and alginate were used to make the impressions. According to the findings of the *in vitro* study, using the mucoselective pressure concept when making the definitive impression reduces pressure build up and may result in a reliable impression of the alveolar ridge. The researchers did not investigate the effect of relief holes on fibrous tissue displacement when they were incorporated into custom tray designs.

Shin *et al.* (2016) conducted an in vitro study with silicone impression material and discovered that larger relief spaces in custom impression trays are significantly more effective than a localised escape hole in reducing simulated maxillary fibrous tissue displacement. Metrology software was used to superimpose the 3D digital models for investigation. Shin *et al.* (2019) found that employing low viscosity impression materials and spaced custom trays reduced displacement on simulated maxillary tissues. Light-body polysulfide, light-body polyvinylsiloxane, and zinc oxide eugenol paste were used as impression materials in the study. The impression tray designs in the *in vitro* study had relief holes, but there was no difference in size or quantity. The test samples were analyzed in the same manner as Shin *et al.* (2016).

The amount of mobile fibrous tissue displacement during definitive impression making has a direct impact on complete denture retention and stability. There has been limited investigation into how the placement of relief holes within custom impression trays impacts the degree of fibrous tissue displacement of the alveolar ridge in a one-step impression technique. According to studies by Masri *et al.* (2002), Iwasaki *et al.* (2016), Chopra *et al.* (2016), and Shin *et al.* (2019), light body polyvinylsiloxane impression material exerts the least amount of pressure onto the edentulous tissues when making an impression; thus, in this *in vitro* study, only light body polyvinylsiloxane impression material will be used for impression making.

To the best of the author's knowledge, no research has quantitatively analyzed simulated fibrous tissue displacement among different custom tray configurations based solely on the size and number of relief holes in a one-step impression technique utilizing light body polyvinylsiloxane as the impression material.

2.3 Silicone Simulation:

According to Okubo *et al.* (2017), silicone models are believed to be suited in clinical settings and in simulating the alveolar mucosa. Silicones' stiffnesses are compatible with biological tissues, making them suitable candidates for use as substrates in mechanobiology. Ecoflex™, a room-temperature cured silicone polymer with low viscosity, ideal clinical quality, and good reproducibility, is appropriate for simulating the flexible and elastic mobile fibrous maxillary tissue on the oral analogue (Liao *et al.,* 2020).

Ecoflex™ rubbers have been widely employed in numerous industries due to their great stretchability and durability, including cushioning, prosthetic appliances, and wearable strain sensors for epidermal electrical systems with mechanical compliance close to human skin (Liao *et al.,* 2020).

2.4 Digital fabrication and analysis:

According to a study by Sun *et al.* (2017), the recent development of digital technology has enabled the fabrication of custom impression trays which may be 3D printed, provide enhanced adaptation, and make impressions with a consistent thickness distribution when compared to manually constructed trays.

Modern 3D scanning technology allows for the superimposition of control and test 3D models utilising metrology software, allowing for more exact measurement of tissue displacement. Digital models provide easy measuring of 3D surfaces as well as quantitative evaluation. The superimposition of multiple images is essential for clinical and research purposes. It outperforms radiographically obtained models because impression fabrication or direct 3D intraoral scanning is a risk-free procedure with no radiation concerns. Stable reference points are required to appropriately register two (or more) serial images in order to detect and analyse changes in a region of interest (Vasilakos *et al.,* 2017).

This *in vitro* investigation was carried out using 3D printed resin edentulous maxillary analogues made of strategically designed silicone that simulates fibrous and natural tissues. The impressions were made in a controlled and structured manner, using light body polyvinylsiloxane impression material, 3D printed resin custom impression trays, and a precise 3D superimposition of digital control and test models to obtain realistic results. As 3D technologies and digital software advance, more precise comparisons will become possible, resulting in more realistic information. The outcomes of this *in vitro* study allow for a greater understanding of the effect relief holes have on fibrous tissue displacement when the size and number of relief holes in custom impression trays are modified during a one-step definitive impression technique.

Chapter 3: Aim and objectives

3.1 Aim:

The aim of this study was to assess the degree of simulated fibrous tissue displacement on edentulous maxillary analogues when 3D printed custom impression trays with various relief hole sizes and quantities are utilised during a one-step secondary impression technique.

3.2 Objectives:

1. To evaluate and compare the degree of simulated maxillary fibrous tissue displacement when different relief hole diameters of 1mm, 2mm and 3mm are placed in the 3D printed custom impression tray during a one-step secondary impression technique.

2. To evaluate and compare the degree of simulated maxillary fibrous tissue displacement when different relief hole amounts of 7, 14 and 21 are placed in the 3D printed custom impression tray during a one-step secondary impression technique.

3.3 Null-hypothesis:

Increasing the size and quantity of relief holes strategically positioned within 3D printed custom impression trays will have no significant effect on the degree of simulated maxillary fibrous tissue displacement during a one-step impression technique.

Chapter 4: Materials and methods

This chapter will describe the research design and methodology used to test the objectives and null-hypothesis mentioned in the preceding chapter.

4.1 Study design:

The study is an experimental *in vitro* investigation.

4.2 Sample size:

The sample size was calculated using RStudio Team (2020) RStudio: Integrated Development for R. RStudio, PBC, Boston, MA URL http://www.rstudio.com/. With a power of 80% and a 5% level of significance, a sample size of 117 with 9 groups equals to 13 samples per group with an effect size of 0.3 in each category as shown in Table 1. Table 2 displays the sample groups and sizes.

```
Balanced two-way analysis of variance sample size adjustment

              a = 3
              b = 3
sig.level = 0.05
          power = 0.8
              n = 13

NOTE: n is number in each group, total sample = 117
```

Table 1: Sample size calculation.

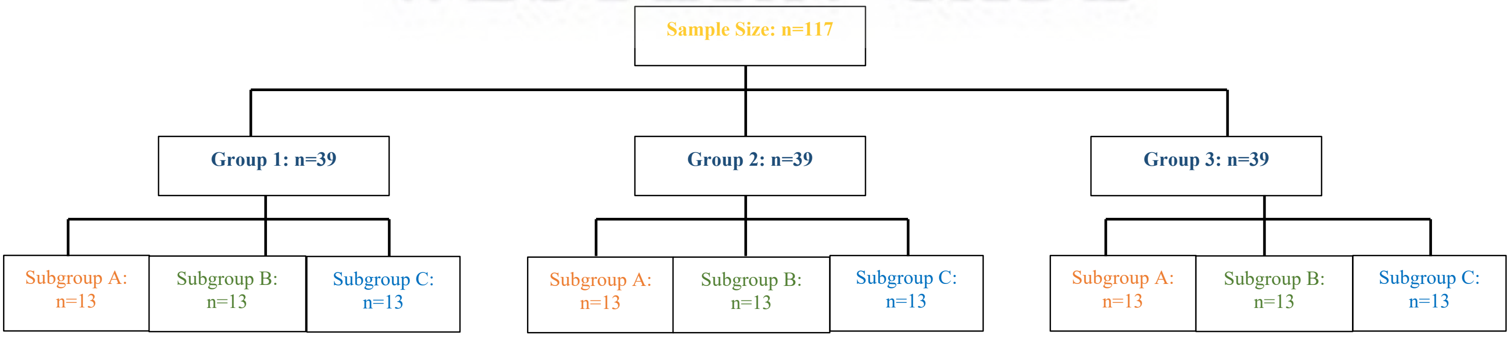

Table 2: Overview of sample groups and sizes.

4.3 Data sampling:

4.3.1 Fabrication of simulated fibrous tissue on 3D printed edentulous maxillary models:

The experimental units are 3D printed edentulous maxillary models with simulated fibrous and natural tissue made with Ecoflex™ (00-30) silicone. A standard edentulous maxillary stone cast (Figure 1) was scanned with MEDIT T510 desktop scanner and digitally captured as a standard tessellation language (STL) file using MEDIT Link 3.1.3 software (Figure 2). Following the digital capture of the control model, changes were made to the standard edentulous maxillary stone cast in order to prepare the model for the fabrication of the simulated fibrous and natural tissues. The adjustments included lowering the height of the anterior ridge crest by 3mm, the posterior ridge crest by 2mm, and the remaining buccal and palatal ridges by 1mm. The amount of reduction of the anterior and posterior ridge crests was meticulously measured with a calliper and marked on the stone cast to enable for precise ridge height removal (Figure 3a). Buccal and palatal reductions were performed by drilling 1mm depth holes (Figure 4a) with a conventional ball plain cut head 1mm tungsten carbide bur (Figure 4b) and equally reducing the surface. The reductions were done by the primary researcher.

The varied reductions show the different and strategic thicknesses of the simulated fibrous tissue anteriorly and natural tissue overlying the posterior ridge, buccal, and palatal region. Following completion of all reductions, retention holes were drilled into the buccal and palatal surfaces of the stone cast to aid in the interlocking of the simulated silicone tissue onto the experimental unit (Figure 5). The prepared stone cast was then scanned with MEDIT T51 desktop scanner and digitally captured into a STL file using MEDIT Link 3.1.3 Software (Figure 6). A total of 26 working resin models (Asiga Denta Model Resin) were printed using an Asiga Max UV 3D printer and Asiga Composer Version 1.3 software (Figure 7).

Figure 1: Standard edentulous maxillary stone cast.

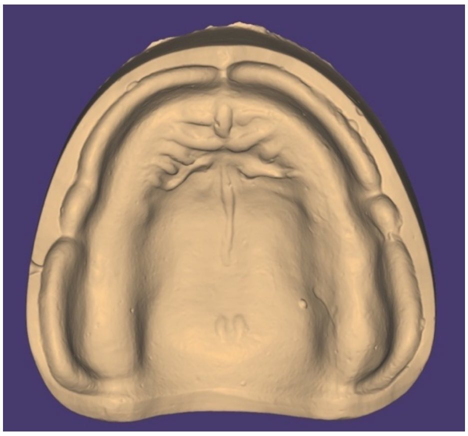

Figure 2: Digitally captured standard tessellation language (STL) file of maxillary edentulous stone cast.

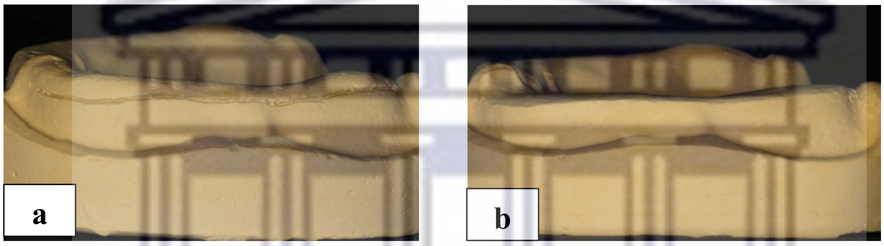

Figure 3: **a)** Anterior (3mm) and posterior (2mm) ridge crest reductions marked accordingly on the stone cast, **b)** anterior and posterior ridge crest after reduction.

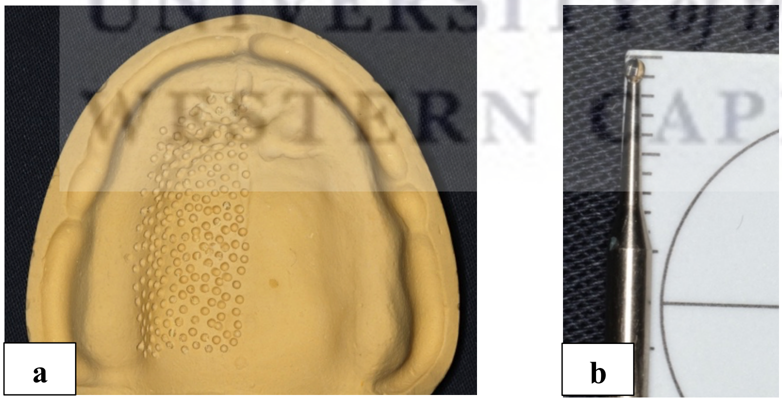

Figure 4: **a)** 1mm depth holes on the palatal region on the standard edentulous maxillary stone cast, **b)** standard ball plain cut head 1mm tungsten carbide bur used to make the depth holes.

Figure 5: Standard maxillary edentulous stone cast after reductions were made and placement of retention holes in the buccal and palatal regions.

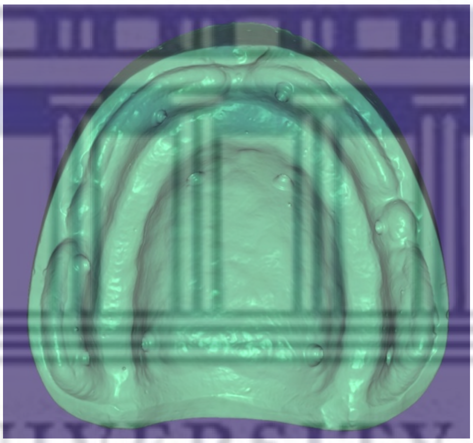

Figure 6: Digitally captured standard tessellation language (STL) file of maxillary edentulous stone cast after reductions were made and placement of retention holes in the buccal and palatal regions.

Figure 7: Working 3D printed resin model on which simulated fibrous and natural tissue will be fabricated.

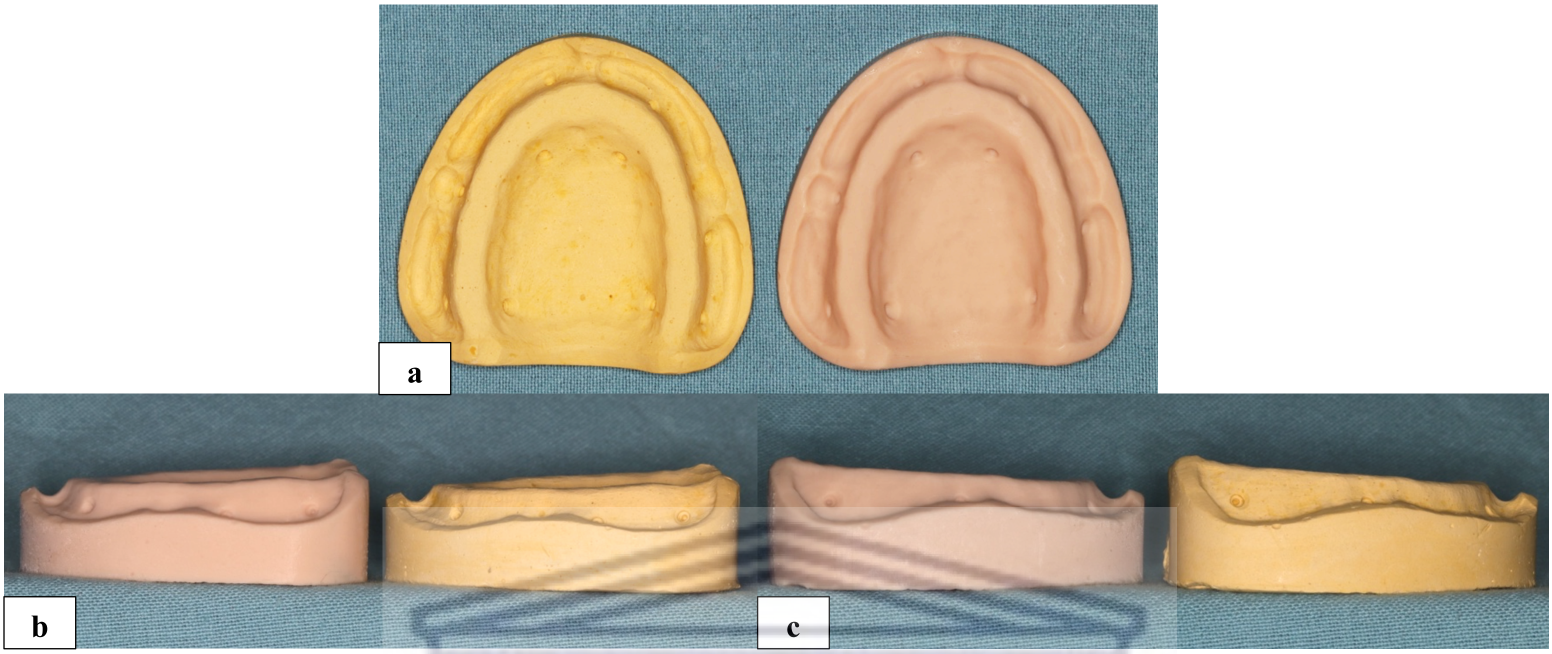

Figure 8: Prepared stone cast and 3D resin printed working model, **a)** occlusal, **b)** right, and **c)** left.

The standard edentulous maxillary stone cast's alveolar ridge, palate, and buccal anatomy were digitally replicated to fabricate a 3D printed resin (Imprimo LC Tray 385nm) template (Figure 9a) designed with the Exocad DentalDB Version 3.1 Riejeka Software. A total of 13 templates were printed and utilized to directly transfer the Ecoflex™ (00-30) silicone onto the 3D printed working models (Figure 8b). The template enabled for the exact reproduction of simulated fibrous and natural tissue onto the working casts.

According to Shin *et al.* (2019), Ecoflex™ (00-30) has a low tensile strength and physical characteristics similar to flabby tissue (Table 3). The principal researcher created simulated fibrous tissue for all 26 printed resin working models in a controlled environment. Because the principal researcher created new simulated silicone tissues for each impression, no simulated tissue was reused. This was done to avoid distortions within the silicone. The anatomy of the standard edentulous stone cast was replicated by the simulated working models (Figure 10).

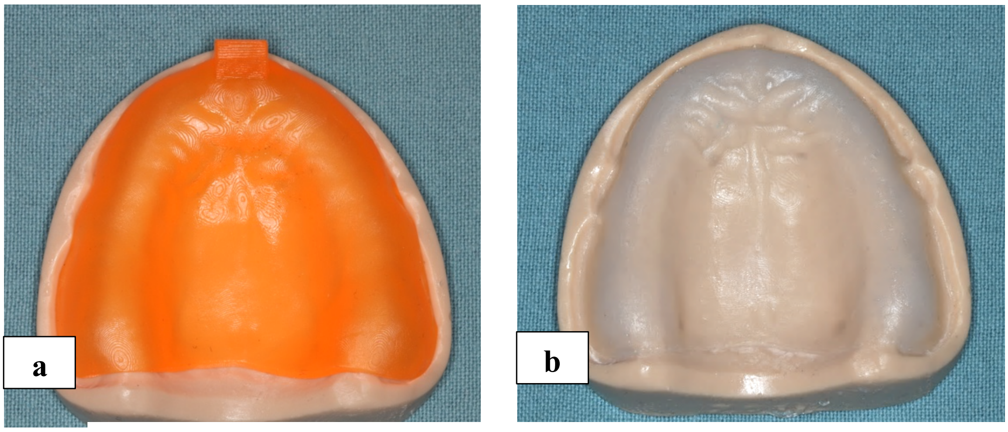

Figure 9: a) 3D printed resin template, **b)** simulated silicone fibrous and natural tissues.

Ecoflex™ 00-30	
Cure Time	4 hr.
Shore Hardness	00-30
Tensile Strength	200 psi
Elongation at Break	900%

Table 3: Properties of silicone used to fabricate simulated fibrous and natural tissues.

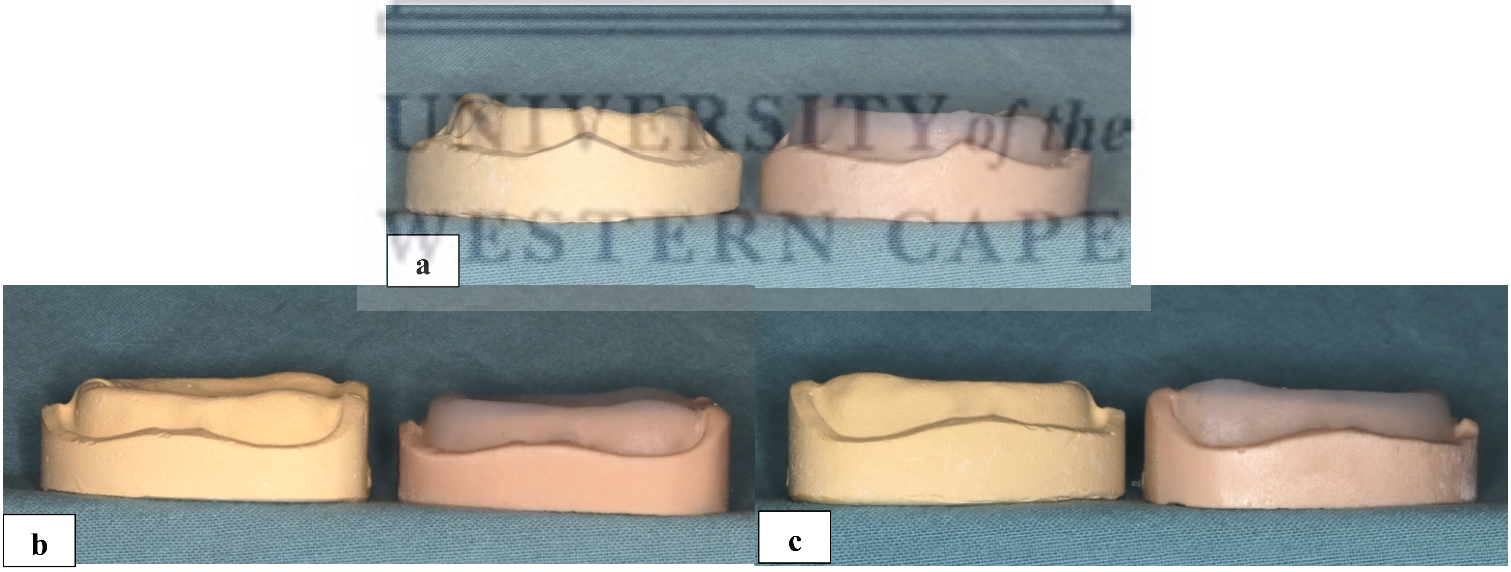

Figure 10: Standard edentulous maxillary control stone cast and simulated fibrous and natural tissue on 3D resin printed working models, **a)** frontal, **b)** right and **c)** left.

4.3.2 Custom impression tray designs:

The 3D printed resin custom impression trays used to make test impressions on the simulated working models duplicated the design of the template used to reproduce the simulated fibrous and natural tissues (Figure 11). There was no relief spacer or stop between the tray's intaglio surface and the simulated tissue because the tray's peripheral border served as a stop. A total of 117 custom trays were fabricated with Asiga Max UV printer and 3D printed resin (Imprimo LC Tray 385nm) using the Asiga Composer Version 1.3 Software (Figure 12).

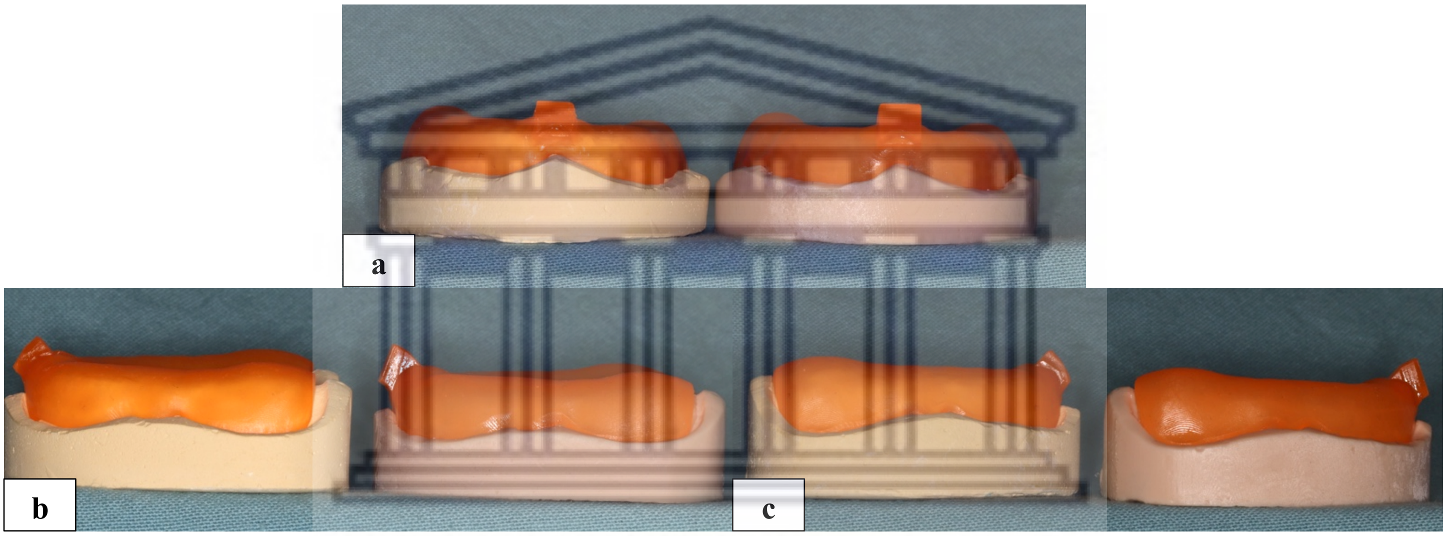

Figure 11: Standard edentulous maxillary control stone cast with 3D printed resin template (left) and working cast with simulated fibrous and natural tissue on 3D resin printed working models with custom impression tray (right), **a)** frontal, **b)** right, and **c)** left.

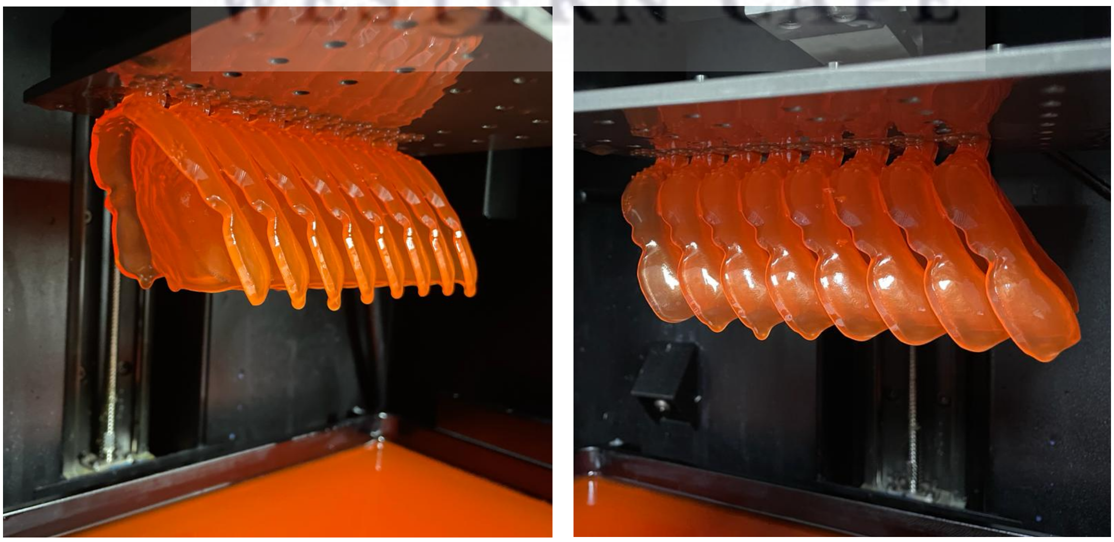

Figure 12: 3D printed resin custom trays.

Custom impression tray configurations were grouped into three groups, each with its own subgroup (Table 4). A jig (Figure 13) was made out of light cured acrylic resin (LC Intertray, Interdent) to precisely transfer the configurations onto the 3D printed custom trays in terms of the various relief hole quantity. The placement of the relief holes for all tray configurations was the responsibility of the principal researcher.

Group 1: tray design 1 **7 relief holes**	**Group 2: tray design 2** **14 relief holes**	**Group 3: tray design 3** **21 relief holes**
• **Subgroup A – relief hole size 1mm** • **Subgroup B – relief hole size 2mm** • **Subgroup C – relief hole size 3mm**	• **Subgroup A – relief hole size 1mm** • **Subgroup B – relief hole size 2mm** • **Subgroup C – relief hole size 3mm**	• **Subgroup A – relief hole size 1mm** • **Subgroup B – relief hole size 2mm** • **Subgroup C – relief hole size 3mm**

Table 4: Custom tray groups and subgroups

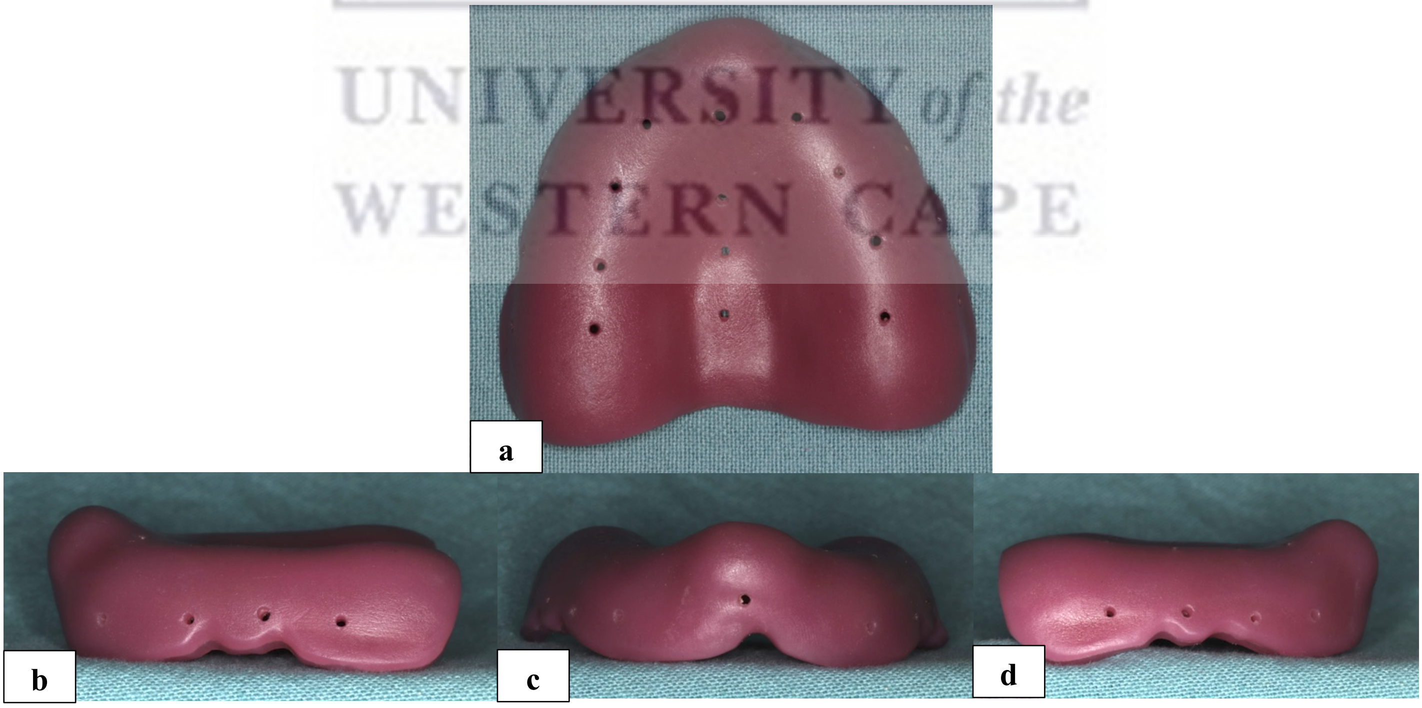

Figure 13: Light cured acrylic resin jig used to transfer tray design 1, 2 and 3 relief hole position precisely onto each impression tray, **a)** alveolar ridge and palate, **b)** right buccal, **c)** anterior buccal, and **d)** left buccal.

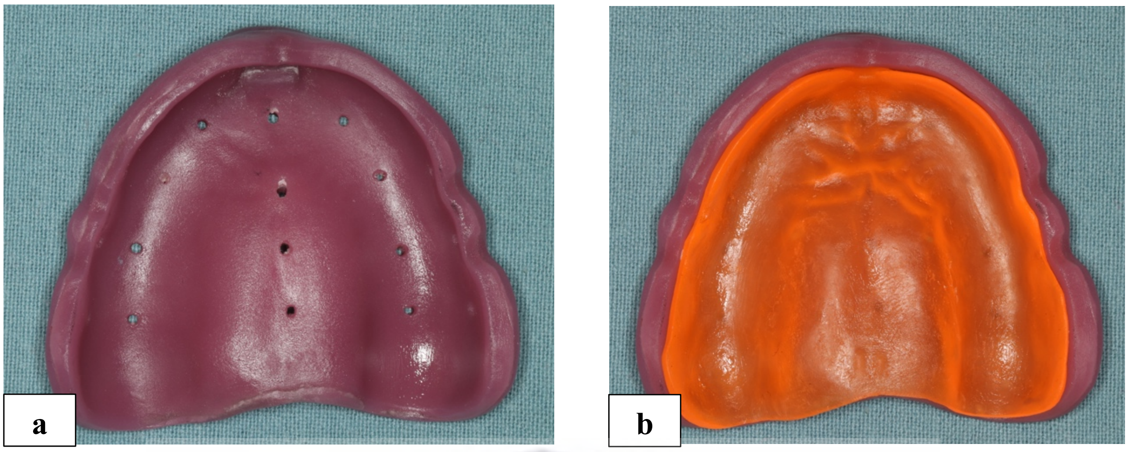

Figure 14: a) Fitting surface of light cured acrylic resin jig, **b)** 3D printed resin custom impression tray seated securely into the jig.

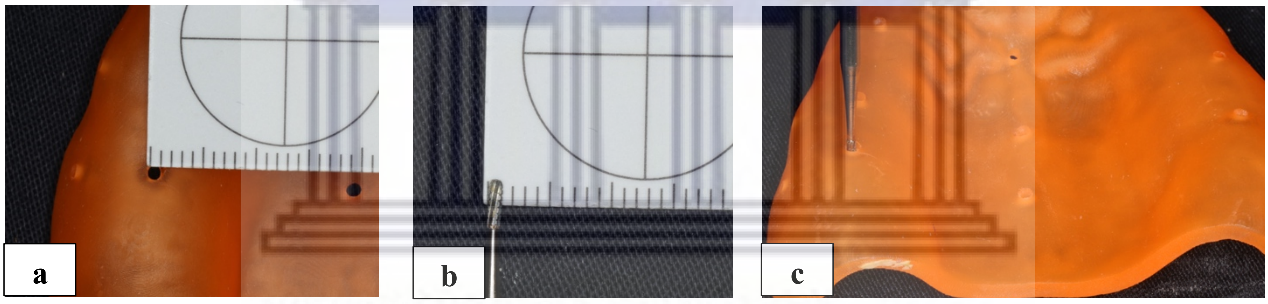

Figure 15: a) 1mm relief hole diameter, **b)** 1mm head diameter tungsten carbide bur, and **c)** relief hole corresponding with 1mm head diameter bur.

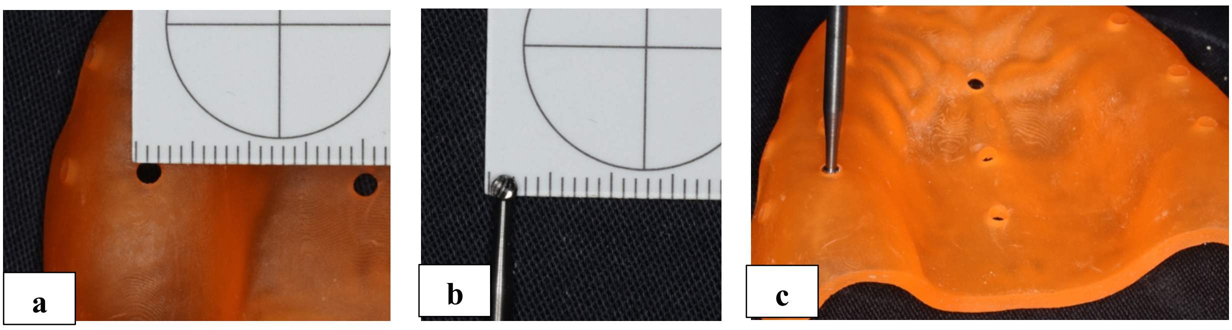

Figure 16: a) 2mm relief hole diameter, **b)** 2mm head diameter tungsten carbide bur, and **c)** relief hole corresponding with 2mm head diameter bur.

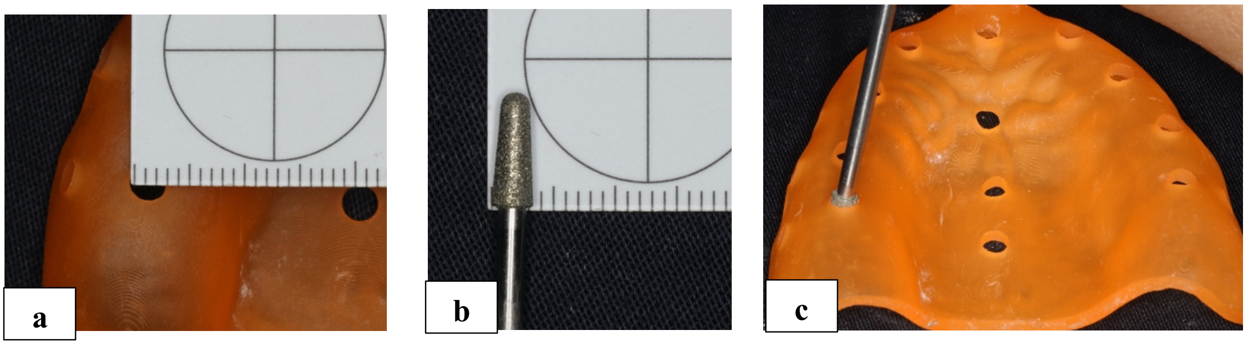

Figure 17: a) 3mm relief hole diameter, **b)** 3mm lower head diameter diamond bur, and **c)** relief hole corresponding with 3mm head diameter bur.

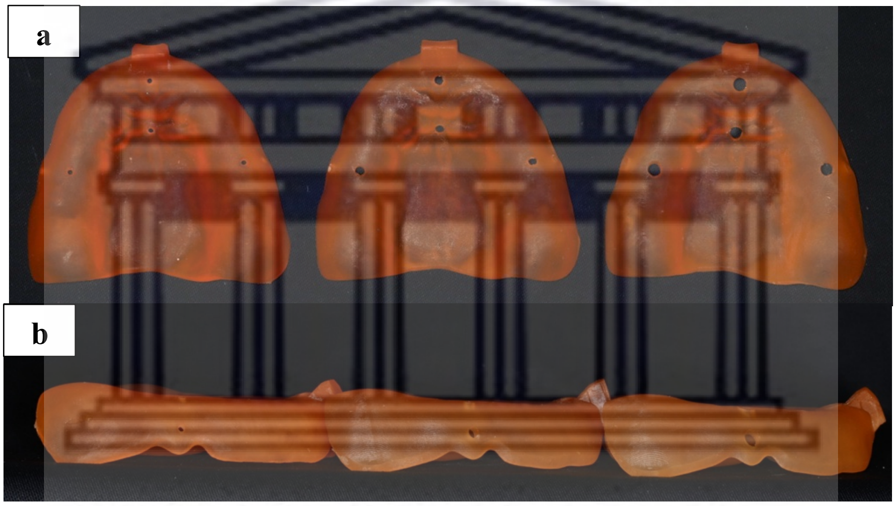

Figure 18: Tray design 1 (7 relief holes) with 1mm (left), 2mm (middle) and 3mm (right) relief hole diameters, **a)** alveolar ridge and palate relief holes, **b)** posterior and anterior buccal relief holes.

Figure 19: Tray design 2 (14 relief holes) with 1mm (left), 2mm (middle) and 3mm (right) relief hole diameters, **a)** alveolar ridge and palate relief holes, **b)** posterior and anterior buccal relief holes.

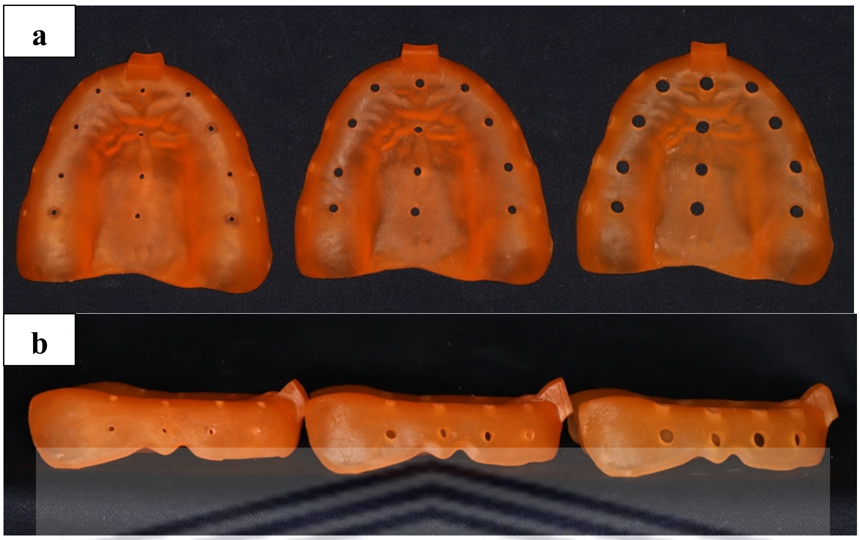

Figure 20: Tray design 3 (21 relief holes) with 1mm (left), 2mm (middle) and 3mm (right) relief hole diameters, **a)** alveolar ridge and palate relief holes, **b)** posterior and anterior buccal relief holes.

4.3.3 Making test impressions and fabrication of test casts:

Vaseline® was added to the surface of the simulated silicone tissue as a separating medium prior to creating the impression. The impression material utilized to make all of the test impressions was light body polyvinylsiloxane (ORMAPLUS®LV). Each impression was timed for 5 minutes from the moment the impression tray was loaded with the auto mix material and seated onto the simulated casts. The total working and setting time of the impression material was as specified by the manufacturer. The vertical seating itself of the impression tray was not timed.

All test impressions were made using a standard testing device (Figure 21). A seating jig built into the testing device's base allowed the 3D printed working models to be seated in the same position for each impression (Figure 22). The top seating plate had three pillars that sat directly on the impression trays' exterior surface in the areas of the second premolar/first molar ridge crest bilaterally and the posterior midpalate region. The seating plate was used to apply a continuous weight of 2,092kg (Figure 23) to the custom trays at three positions in a controlled way (Figure 24). The three points allowed for repeatable pressure application while also supporting and stabilizing the impression tray during the impression making process. All test impressions were poured with type III yellow dental plaster (Dentstone KD plaster) within 24 hours of taking the impressions.

The principal researcher and supervisor independently made the same number of 117 test impressions in the same controlled environment. This enabled researcher calibration as well as inter- and intra-observer reliability testing.

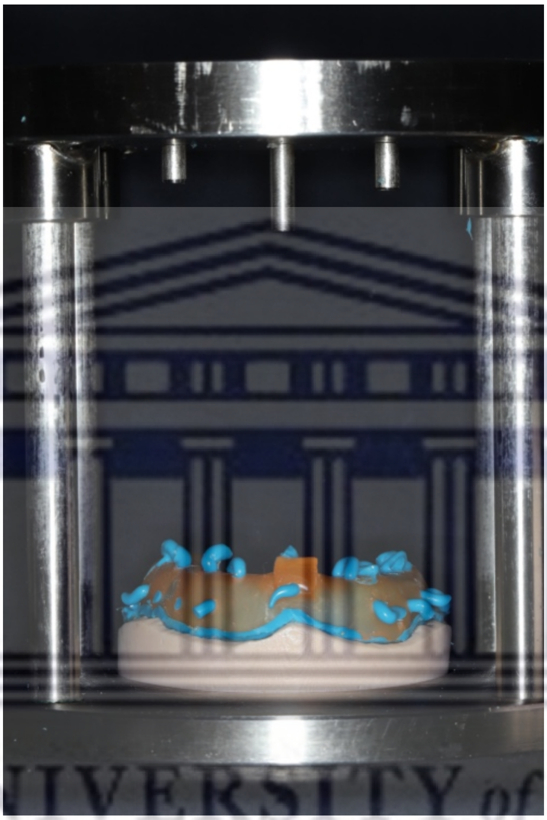

Figure 21: Standard testing device.

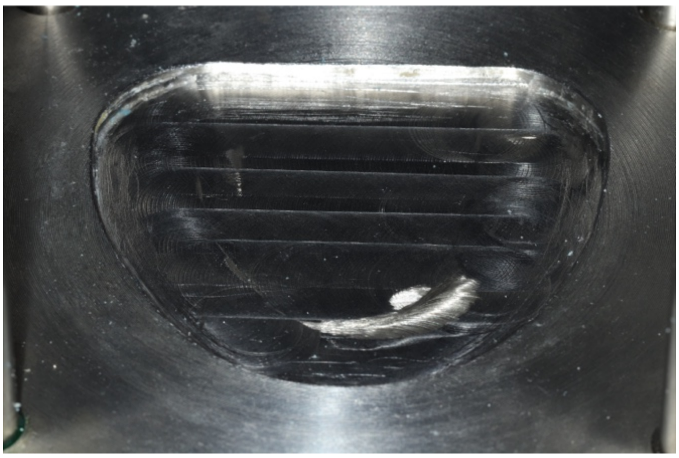

Figure 22: Seating jig within the base of the testing device allowed the 3D printed working models to be consistently seated in the same position for each impression.

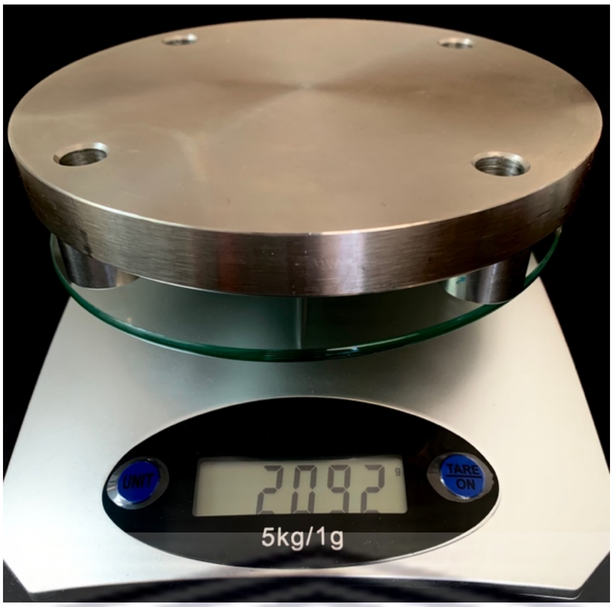

Figure 23: The seating plate applied a continuous weight of 2,092kg (2092g) onto the test impressions.

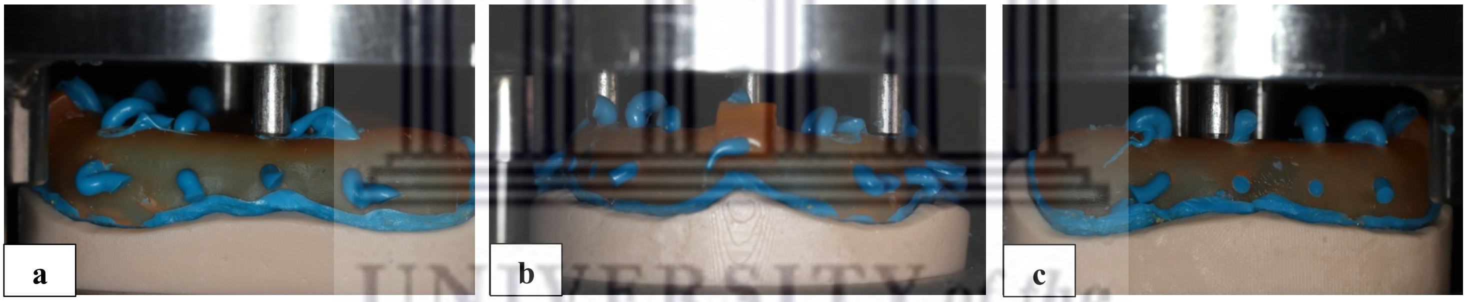

Figure 24: Three pillars and 2,092kg weight that seated directly onto the external surface of the impression trays in the areas of the second premolar/first molar ridge crest bilaterally and posterior midpalate region, **a)** right, **b)** frontal, and **c)** left.

4.4 Data and statistical analysis:

All 117 testing stone casts for the principal researcher and supervisor were scanned using MEDIT T510 desktop scanner and digitally captured as a standard tessellation language (STL) file using MEDIT Link 3.1.3 software to be analysed. To compare the amount of displacement of the simulated tissues after the test impressions were made, metrology software Exocad DentalDB Version 3.1 Riejeka was used to superimpose each digital test model onto the digital control model (Figure 25).

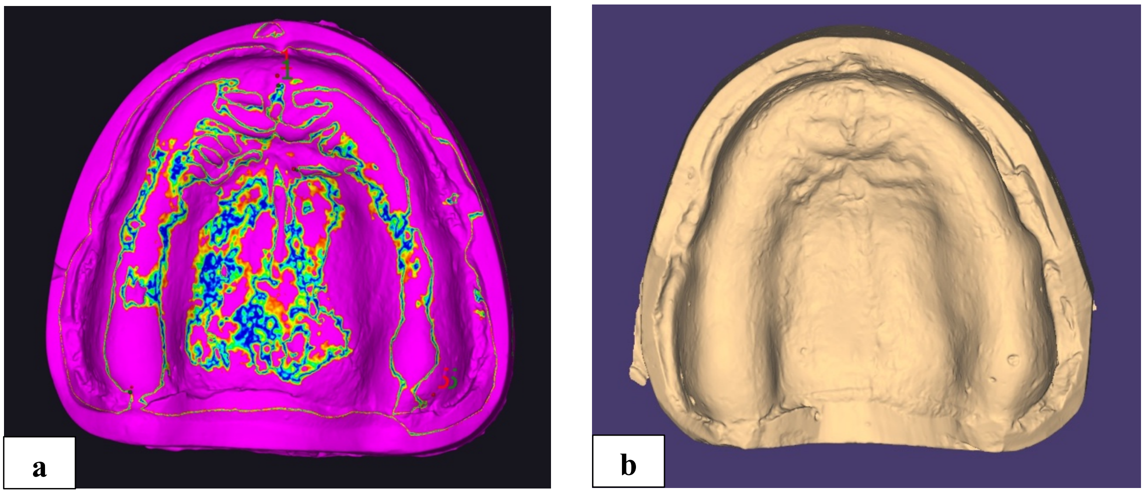

Figure 25: a and b) Superimposed control and test digital models.

Prior to scanning, four reference points were marked on the control stone cast (Figure 26). The midline of the anterior ridge, posterior ridge (left and right), and midpalate serve as reference points. Using the metrology software Exocad DentalDB Version 3.1 Riejeka, cross sectional measurements (millimetres) were taken at the reference sites of the superimposed digital control and test models to calculate the difference in vertical tissue displacement between the various tray designs (Figure 27).

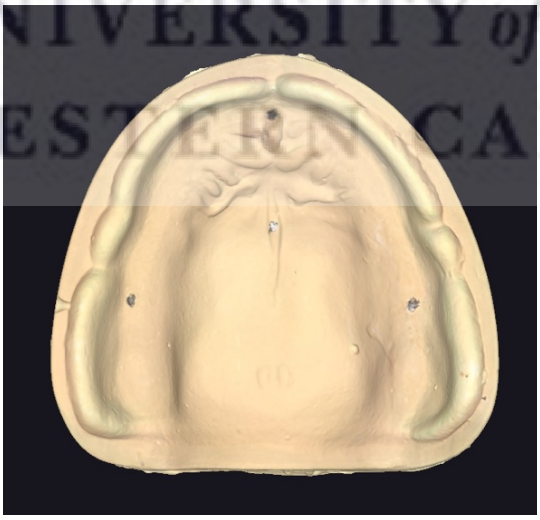

Figure 26: Four reference points marked on the control stone cast, midline of the anterior ridge, posterior ridge (left and right), and midpalate.

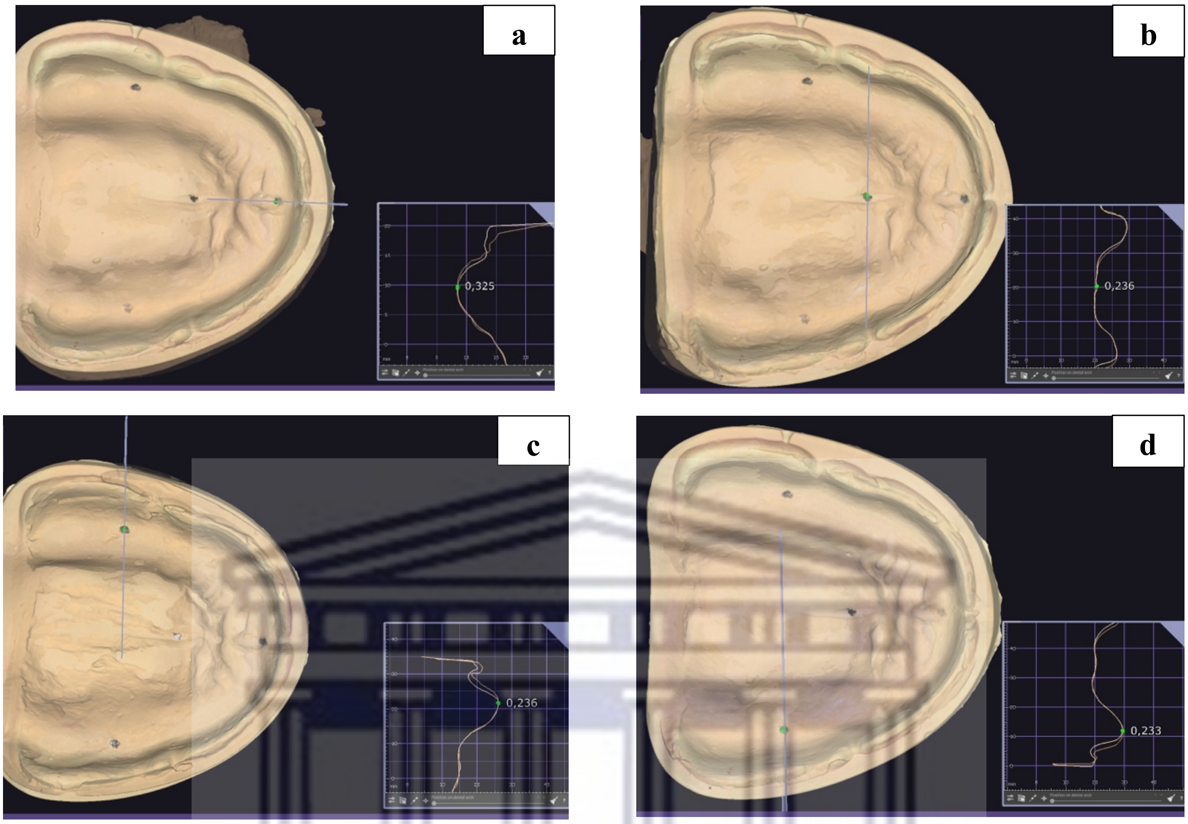

Figure 27: Cross sectional measurements (millimeters) at the reference sites of the superimposed digital control and test models to calculate the difference in tissue displacement between the various tray designs **a)** midline of the anterior ridge, **b)** midpalate, **c)** right posterior ridge, and **d)** left posterior ridge.

To prevent any confounding variables, all raw measurements were captured by the principal researcher and documented on a Microsoft Excel (Microsoft Corporation) spreadsheet for analysis (Tables 5-7). These measurements were the outcome variables that were employed in the data analysis.

The data was analysed in IBM® SPSS® Statistics Version 24 (IBM Corporation), and a one-way analysis of variance (ANOVA) was performed to investigate the association between the mean difference in tissue displacement in relation to the number and diameter of relief holes. Post hoc tests with the Bonferroni correction were performed to further analyse the variations in tissue displacement among tray designs with a significance of $p < .05$.

Chapter 5: Results

This chapter presents the study's findings.

5.1 Measurements of simulated fibrous tissue displacement for each group:

Tray Design: 1A (1mm)			Tray Design: 1B (2mm)			Tray Design: 1C (3mm)		
Model Number	Area Measured:	Measurements	Model Number:	Area Measured:	Measurements	Model Number:	Area Measured:	Measurements
1	Anterior Ridge:	0.350	1	Anterior Ridge:	0.240	1	Anterior Ridge:	0.163
	Palate:	0.349		Palate:	0.237		Palate:	0.160
	Left Posterior Ridge:	0.350		Left Posterior Ridge:	0.237		Left Posterior Ridge:	0.156
	Right Posterior Ridge:	0.352		Right Posterior Ridge:	0.239		Right Posterior Ridge:	0.158
2	Anterior Ridge:	0.348	2	Anterior Ridge:	0.239	2	Anterior Ridge:	0.160
	Palate:	0.347		Palate:	0.240		Palate:	0.159
	Left Posterior Ridge:	0.349		Left Posterior Ridge:	0.237		Left Posterior Ridge:	0.160
	Right Posterior Ridge:	0.348		Right Posterior Ridge:	0.239		Right Posterior Ridge:	0.159
3	Anterior Ridge:	0.350	3	Anterior Ridge:	0.238	3	Anterior Ridge:	0.159
	Palate:	0.346		Palate:	0.239		Palate:	0.160
	Left Posterior Ridge:	0.348		Left Posterior Ridge:	0.238		Left Posterior Ridge:	0.158
	Right Posterior Ridge:	0.349		Right Posterior Ridge:	0.240		Right Posterior Ridge:	0.159
4	Anterior Ridge:	0.349	4	Anterior Ridge:	0.240	4	Anterior Ridge:	0.158
	Palate:	0.350		Palate:	0.238		Palate:	0.160
	Left Posterior Ridge:	0.348		Left Posterior Ridge:	0.238		Left Posterior Ridge:	0.156
	Right Posterior Ridge:	0.347		Right Posterior Ridge:	0.239		Right Posterior Ridge:	0.158
5	Anterior Ridge:	0.349	5	Anterior Ridge:	0.239	5	Anterior Ridge:	0.160
	Palate:	0.347		Palate:	0.239		Palate:	0.157
	Left Posterior Ridge:	0.346		Left Posterior Ridge:	0.237		Left Posterior Ridge:	0.156
	Right Posterior Ridge:	0.347		Right Posterior Ridge:	0.238		Right Posterior Ridge:	0.157
6	Anterior Ridge:	0.347	6	Anterior Ridge:	0.239	6	Anterior Ridge:	0.158
	Palate:	0.350		Palate:	0.240		Palate:	0.159
	Left Posterior Ridge:	0.346		Left Posterior Ridge:	0.238		Left Posterior Ridge:	0.158
	Right Posterior Ridge:	0.346		Right Posterior Ridge:	0.240		Right Posterior Ridge:	0.157
7	Anterior Ridge:	0.347	7	Anterior Ridge:	0.241	7	Anterior Ridge:	0.161
	Palate:	0.350		Palate:	0.240		Palate:	0.157
	Left Posterior Ridge:	0.348		Left Posterior Ridge:	0.238		Left Posterior Ridge:	0.160
	Right Posterior Ridge:	0.348		Right Posterior Ridge:	0.239		Right Posterior Ridge:	0.158
8	Anterior Ridge:	0.350	8	Anterior Ridge:	0.239	8	Anterior Ridge:	0.159
	Palate:	0.345		Palate:	0.240		Palate:	0.160
	Left Posterior Ridge:	0.349		Left Posterior Ridge:	0.237		Left Posterior Ridge:	0.160
	Right Posterior Ridge:	0.347		Right Posterior Ridge:	0.239		Right Posterior Ridge:	0.159
9	Anterior Ridge:	0.347	9	Anterior Ridge:	0.240	9	Anterior Ridge:	0.160
	Palate:	0.348		Palate:	0.238		Palate:	0.157
	Left Posterior Ridge:	0.350		Left Posterior Ridge:	0.237		Left Posterior Ridge:	0.157
	Right Posterior Ridge:	0.350		Right Posterior Ridge:	0.238		Right Posterior Ridge:	0.159
10	Anterior Ridge:	0.352	10	Anterior Ridge:	0.238	10	Anterior Ridge:	0.158
	Palate:	0.349		Palate:	0.239		Palate:	0.155
	Left Posterior Ridge:	0.351		Left Posterior Ridge:	0.237		Left Posterior Ridge:	0.159
	Right Posterior Ridge:	0.350		Right Posterior Ridge:	0.239		Right Posterior Ridge:	0.157
11	Anterior Ridge:	0. 349	11	Anterior Ridge:	0.238	11	Anterior Ridge:	0.161
	Palate:	0.346		Palate:	0.239		Palate:	0.160
	Left Posterior Ridge:	0.349		Left Posterior Ridge:	0.237		Left Posterior Ridge:	0.158
	Right Posterior Ridge:	0.348		Right Posterior Ridge:	0.240		Right Posterior Ridge:	0.160
12	Anterior Ridge:	0.351	12	Anterior Ridge:	0.240	12	Anterior Ridge:	0.163
	Palate:	0.348		Palate:	0.238		Palate:	0.160
	Left Posterior Ridge:	0.350		Left Posterior Ridge:	0.237		Left Posterior Ridge:	0.158
	Right Posterior Ridge:	0.349		Right Posterior Ridge:	0.237		Right Posterior Ridge:	0.159
13	Anterior Ridge:	0.349	13	Anterior Ridge:	0.239	13	Anterior Ridge:	0.161
	Palate:	0.346		Palate:	0.240		Palate:	0.158
	Left Posterior Ridge:	0.349		Left Posterior Ridge:	0.237		Left Posterior Ridge:	0.159
	Right Posterior Ridge:	0.349		Right Posterior Ridge:	0.238		Right Posterior Ridge:	0.159

Table 5: Simulated fibrous tissue displacement measurements for all 13 samples in tray designs 1A/1B/1C.

Tray Design: 2A (1mm)			Tray Design: 2B (2mm)			Tray Design: 2C (3mm)		
Model Number	Area Measured:	Measurements	Model Number:	Area Measured:	Measurements	Model Number:	Area Measured:	Measurements
1	Anterior Ridge:	0.330	1	Anterior Ridge:	0.240	1	Anterior Ridge:	0.144
	Palate:	0.326		Palate:	0.235		Palate:	0.136
	Left Posterior Ridge:	0.326		Left Posterior Ridge:	0.236		Left Posterior Ridge:	0.137
	Right Posterior Ridge:	0.336		Right Posterior Ridge:	0.235		Right Posterior Ridge:	0.137
2	Anterior Ridge:	0.343	2	Anterior Ridge:	0.243	2	Anterior Ridge:	0.141
	Palate:	0.332		Palate:	0.238		Palate:	0.136
	Left Posterior Ridge:	0.320		Left Posterior Ridge:	0.236		Left Posterior Ridge:	0.135
	Right Posterior Ridge:	0.332		Right Posterior Ridge:	0.238		Right Posterior Ridge:	0.137
3	Anterior Ridge:	0.339	3	Anterior Ridge:	0.241	3	Anterior Ridge:	0.142
	Palate:	0.336		Palate:	0.239		Palate:	0.137
	Left Posterior Ridge:	0.322		Left Posterior Ridge:	0.238		Left Posterior Ridge:	0.135
	Right Posterior Ridge:	0.330		Right Posterior Ridge:	0.238		Right Posterior Ridge:	0.137
4	Anterior Ridge:	0.330	4	Anterior Ridge:	0.243	4	Anterior Ridge:	0.144
	Palate:	0.330		Palate:	0.236		Palate:	0.139
	Left Posterior Ridge:	0.322		Left Posterior Ridge:	0.235		Left Posterior Ridge:	0.135
	Right Posterior Ridge:	0.335		Right Posterior Ridge:	0.238		Right Posterior Ridge:	0.138
5	Anterior Ridge:	0.333	5	Anterior Ridge:	0.240	5	Anterior Ridge:	0.144
	Palate:	0.330		Palate:	0.238		Palate:	0.140
	Left Posterior Ridge:	0.323		Left Posterior Ridge:	0.237		Left Posterior Ridge:	0.136
	Right Posterior Ridge:	0.330		Right Posterior Ridge:	0.238		Right Posterior Ridge:	0.138
6	Anterior Ridge:	0.335	6	Anterior Ridge:	0.244	6	Anterior Ridge:	0.144
	Palate:	0.330		Palate:	0.238		Palate:	0.140
	Left Posterior Ridge:	0.326		Left Posterior Ridge:	0.235		Left Posterior Ridge:	0.138
	Right Posterior Ridge:	0.335		Right Posterior Ridge:	0.238		Right Posterior Ridge:	0.137
7	Anterior Ridge:	0.338	7	Anterior Ridge:	0.240	7	Anterior Ridge:	0.142
	Palate:	0.333		Palate:	0.235		Palate:	0.138
	Left Posterior Ridge:	0,328		Left Posterior Ridge:	0.233		Left Posterior Ridge:	0.140
	Right Posterior Ridge:	0.330		Right Posterior Ridge:	0.238		Right Posterior Ridge:	0.140
8	Anterior Ridge:	0.339	8	Anterior Ridge:	0.240	8	Anterior Ridge:	0.145
	Palate:	0.334		Palate:	0.239		Palate:	0.140
	Left Posterior Ridge:	0.326		Left Posterior Ridge:	0.238		Left Posterior Ridge:	0.138
	Right Posterior Ridge:	0.331		Right Posterior Ridge:	0.239		Right Posterior Ridge:	0.140
9	Anterior Ridge:	0.337	9	Anterior Ridge:	0.244	9	Anterior Ridge:	0.143
	Palate:	0.334		Palate:	0.238		Palate:	0.138
	Left Posterior Ridge:	0.324		Left Posterior Ridge:	0.238		Left Posterior Ridge:	0.137
	Right Posterior Ridge:	0.335		Right Posterior Ridge:	0.239		Right Posterior Ridge:	0.138
10	Anterior Ridge:	0.334	10	Anterior Ridge:	0.241	10	Anterior Ridge:	0.144
	Palate:	0.330		Palate:	0.237		Palate:	0.140
	Left Posterior Ridge:	0.322		Left Posterior Ridge:	0.237		Left Posterior Ridge:	0.139
	Right Posterior Ridge:	0.332		Right Posterior Ridge:	0.237		Right Posterior Ridge:	0.140
11	Anterior Ridge:	0.340	11	Anterior Ridge:	0.242	11	Anterior Ridge:	0.143
	Palate:	0.330		Palate:	0.239		Palate:	0.139
	Left Posterior Ridge:	0.324		Left Posterior Ridge:	0.235		Left Posterior Ridge:	0.140
	Right Posterior Ridge:	0.335		Right Posterior Ridge:	0.236		Right Posterior Ridge:	0.139
12	Anterior Ridge:	0.341	12	Anterior Ridge:	0.244	12	Anterior Ridge:	0.144
	Palate:	0.334		Palate:	0.237		Palate:	0.139
	Left Posterior Ridge:	0.324		Left Posterior Ridge:	0.236		Left Posterior Ridge:	0.140
	Right Posterior Ridge:	0.337		Right Posterior Ridge:	0.238		Right Posterior Ridge:	0.140
13	Anterior Ridge:	0.341	13	Anterior Ridge:	0.245	13	Anterior Ridge:	0.142
	Palate:	0.331		Palate:	0.239		Palate:	0.137
	Left Posterior Ridge:	0.325		Left Posterior Ridge:	0.238		Left Posterior Ridge:	0.139
	Right Posterior Ridge:	0.337		Right Posterior Ridge:	0.240		Right Posterior Ridge:	0.139

Table 6: Simulated fibrous tissue displacement measurements for all 13 samples in tray designs 2A/2B/2C.

Tray Design: 3A (1mm)			Tray Design: 3B (2mm)			Tray Design: 3C (3mm)		
Model Number	Area Measured:	Measurements	Model Number:	Area Measured:	Measurements	Model Number:	Area Measured:	Measurements
1	Anterior Ridge:	0.324	1	Anterior Ridge:	0.235	1	Anterior Ridge:	0.131
	Palate:	0.318		Palate:	0.230		Palate:	0.126
	Left Posterior Ridge:	0.315		Left Posterior Ridge:	0.229		Left Posterior Ridge:	0.119
	Right Posterior Ridge:	0.317		Right Posterior Ridge:	0.228		Right Posterior Ridge:	0.122
2	Anterior Ridge:	0.325	2	Anterior Ridge:	0.233	2	Anterior Ridge:	0.130
	Palate:	0.318		Palate:	0.229		Palate:	0.126
	Left Posterior Ridge:	0.315		Left Posterior Ridge:	0.229		Left Posterior Ridge:	0.120
	Right Posterior Ridge:	0.319		Right Posterior Ridge:	0.228		Right Posterior Ridge:	0.125
3	Anterior Ridge:	0.320	3	Anterior Ridge:	0.237	3	Anterior Ridge:	0.127
	Palate:	0.317		Palate:	0.230		Palate:	0.124
	Left Posterior Ridge:	0.315		Left Posterior Ridge:	0.229		Left Posterior Ridge:	0.117
	Right Posterior Ridge:	0.318		Right Posterior Ridge:	0.231		Right Posterior Ridge:	0.120
4	Anterior Ridge:	0.323	4	Anterior Ridge:	0.234	4	Anterior Ridge:	0.130
	Palate:	0.320		Palate:	0.231		Palate:	0.128
	Left Posterior Ridge:	0.317		Left Posterior Ridge:	0.228		Left Posterior Ridge:	0.120
	Right Posterior Ridge:	0.318		Right Posterior Ridge:	0.230		Right Posterior Ridge:	0.127
5	Anterior Ridge:	0.325	5	Anterior Ridge:	0.235	5	Anterior Ridge:	0.130
	Palate:	0.320		Palate:	0.229		Palate:	0.125
	Left Posterior Ridge:	0.319		Left Posterior Ridge:	0.230		Left Posterior Ridge:	0.119
	Right Posterior Ridge:	0.319		Right Posterior Ridge:	0.229		Right Posterior Ridge:	0.122
6	Anterior Ridge:	0.323	6	Anterior Ridge:	0.233	6	Anterior Ridge:	0.131
	Palate:	0.318		Palate:	0.230		Palate:	0.126
	Left Posterior Ridge:	0.316		Left Posterior Ridge:	0.228		Left Posterior Ridge:	0.120
	Right Posterior Ridge:	0.318		Right Posterior Ridge:	0.231		Right Posterior Ridge:	0.124
7	Anterior Ridge:	0.322	7	Anterior Ridge:	0.237	7	Anterior Ridge:	0.129
	Palate:	0.319		Palate:	0.232		Palate:	0.126
	Left Posterior Ridge:	0.317		Left Posterior Ridge:	0.229		Left Posterior Ridge:	0.119
	Right Posterior Ridge:	0.319		Right Posterior Ridge:	0.230		Right Posterior Ridge:	0.124
8	Anterior Ridge:	0.325	8	Anterior Ridge:	0.235	8	Anterior Ridge:	0.130
	Palate:	0.319		Palate:	0.230		Palate:	0.125
	Left Posterior Ridge:	0.316		Left Posterior Ridge:	0.229		Left Posterior Ridge:	0.120
	Right Posterior Ridge:	0.317		Right Posterior Ridge:	0.229		Right Posterior Ridge:	0.122
9	Anterior Ridge:	0.324	9	Anterior Ridge:	0.236	9	Anterior Ridge:	0.131
	Palate:	0.320		Palate:	0.232		Palate:	0.127
	Left Posterior Ridge:	0.319		Left Posterior Ridge:	0.230		Left Posterior Ridge:	0.121
	Right Posterior Ridge:	0.317		Right Posterior Ridge:	0.231		Right Posterior Ridge:	0.125
10	Anterior Ridge:	0.322	10	Anterior Ridge:	0.235	10	Anterior Ridge:	0.128
	Palate:	0.319		Palate:	0.230		Palate:	0.124
	Left Posterior Ridge:	0.317		Left Posterior Ridge:	0.228		Left Posterior Ridge:	0.119
	Right Posterior Ridge:	0.319		Right Posterior Ridge:	0.231		Right Posterior Ridge:	0.124
11	Anterior Ridge:	0.325	11	Anterior Ridge:	0.233	11	Anterior Ridge:	0.130
	Palate:	0.320		Palate:	0.229		Palate:	0.126
	Left Posterior Ridge:	0.318		Left Posterior Ridge:	0.229		Left Posterior Ridge:	0.122
	Right Posterior Ridge:	0.318		Right Posterior Ridge:	0.230		Right Posterior Ridge:	0.125
12	Anterior Ridge:	0.320	12	Anterior Ridge:	0.230	12	Anterior Ridge:	0.132
	Palate:	0.318		Palate:	0.229		Palate:	0.126
	Left Posterior Ridge:	0.316		Left Posterior Ridge:	0.227		Left Posterior Ridge:	0.120
	Right Posterior Ridge:	0.319		Right Posterior Ridge:	0.230		Right Posterior Ridge:	0.123
13	Anterior Ridge:	0.324	13	Anterior Ridge:	0.235	13	Anterior Ridge:	0.130
	Palate:	0.319		Palate:	0.231		Palate:	0.125
	Left Posterior Ridge:	0.317		Left Posterior Ridge:	0.229		Left Posterior Ridge:	0.119
	Right Posterior Ridge:	0.319		Right Posterior Ridge:	0.230		Right Posterior Ridge:	0.124

Table 7: Simulated fibrous tissue displacement measurements for all 13 samples in tray designs 3A/3B/3C.

5.2 Analysis of variance:

A one-way analysis of variance was performed to investigate the association between the mean difference in tissue displacement in relation to the number and diameter of relief holes. The aim of the analysis was to see if there were any significant differences in tissue displacement among the tray designs used in the study. The tissue displacement was assessed at four separate reference points: the anterior ridge, the palate, and the left and right posterior ridges.

5.2.1 One-way analysis of variance performed for tray designs 1A/1B/1C:

Variable	Tray design 1A		Tray design 1B		Tray design 1C				
	M	*SD*	*M*	*SD*	*M*	*SD*	$F(2, 36)$	$\eta 2$	*P*
Anterior ridge	.349	.001	.239	.0009	.160	.001	56856.06***	1.0	.001
Palate	.347	.001	.239	.001	.158	.001	51822.88***	1.0	.001
Left posterior ridge	.348	.001	.237	.0004	.158	.001	76006.16***	1.0	.001
Right posterior ridge	.348	.001	.238	.0008	.158	.0009	81928.24***	1.0	.001

Table 8: Mean differences of 1A/1B/1C at the four reference points.

Table 8 displays the ANOVA performed to evaluate the association between tissue displacement (the dependent variable) and tray designs 1A/1B/1C (the factor variable). For each of the reference points examined, the ANOVA results revealed significant differences in tissue displacement across tray designs 1A/1B/1C: anterior ridge $F(2, 36) = 56856.062$, $p < .001$, palate $F(2, 36) = 51822.885$, $p < .001$, left posterior ridge $F(2, 36) = 76006.169$, $p < .001$, and right posterior ridge $F(2, 36) = 81928.243$, $p < .001$.

5.2.1.1 Post hoc comparison for tray designs 1A/1B/1C*:*

Post hoc tests with the Bonferroni correction were performed to further analyze the variations in tissue displacement among tray designs 1A/1B/1C.

Anterior ridge 1A/1B/1C:

There were significant differences in tissue displacement among the tray designs 1A/1B/1C in the anterior ridge ($p < .001$):

1. 1A vs. 1B: the mean difference in tissue displacement between 1A and 1B was 0.109846. 1A showed a significantly higher tissue displacement compared to 1B.
2. 1A vs. 1C: the mean difference in tissue displacement between 1A and 1C was 0.189000. 1A showed a significantly higher tissue displacement compared to 1C.
3. 1B vs. 1C: the mean difference in tissue displacement between 1B and 1C was 0.079154. 1B showed a significantly higher tissue displacement compared to 1C.

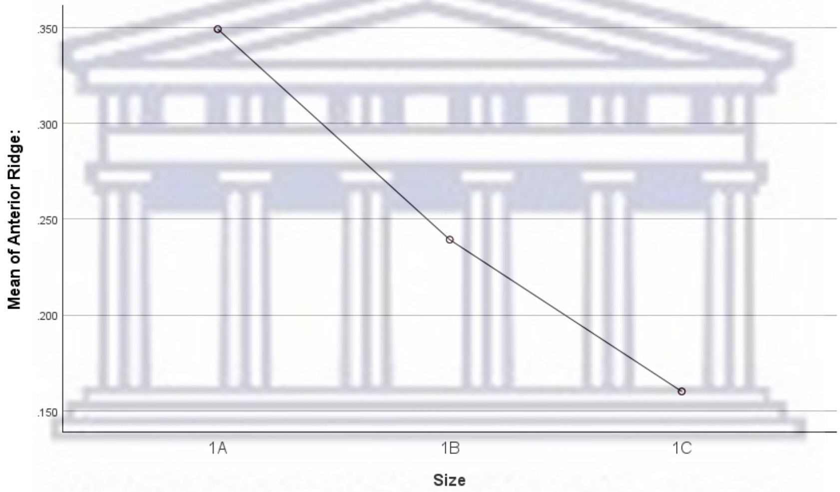

Figure 28: Mean plot for anterior ridge 1A/1B/1C.

Palate 1A/1B/1C:

There were significant differences in tissue displacement among the tray designs 1A/1B/1C in the palate ($p < .001$):

1. 1A vs. 1B: the mean difference in tissue displacement between 1A and 1B was 0.108769. 1A showed a significantly higher tissue displacement compared to 1B.
2. 1A vs. 1C: the mean difference in tissue displacement between 1A and 1C was 0.189154. 1A showed a significantly higher tissue displacement compared to 1C.
3. 1B vs. 1C: the mean difference in tissue displacement between 1B and 1C was 0.080385. 1B showed a significantly higher tissue displacement compared to 1C.

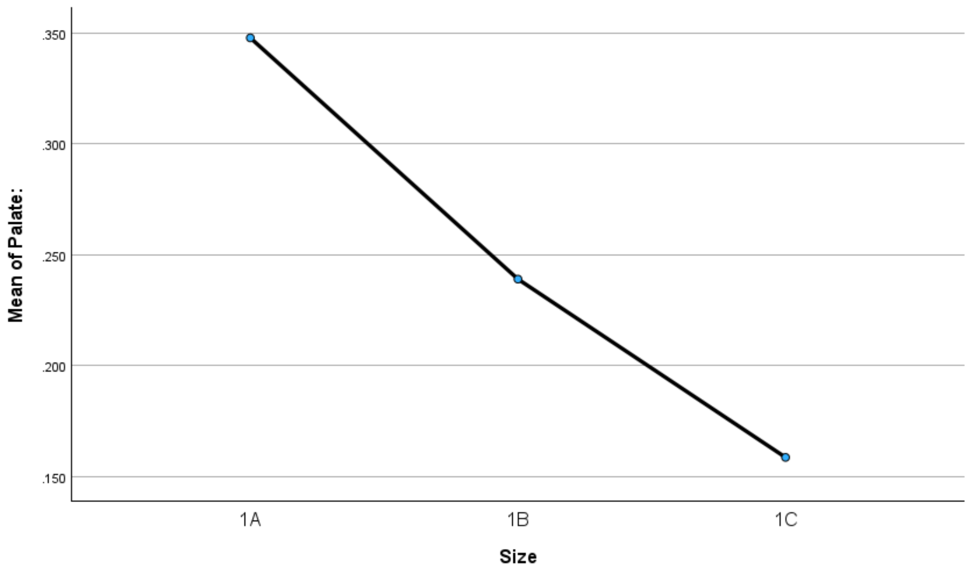

Figure 29: Mean plot for palate 1A/1B/1C.

Left posterior ridge 1A/1B/1C:

There were significant differences in tissue displacement among the tray designs 1A/1B/1C in the left posterior ridge ($p < .001$):

1. 1A vs. 1B: the mean difference in tissue displacement between 1A and 1B was 0.111385. 1A showed a significantly higher tissue displacement compared to 1B.
2. 1A vs. 1C: the mean difference in tissue displacement between 1A and 1C was 0.190615. 1A showed a significantly higher tissue displacement compared to 1C.
3. 1B vs. 1C: the mean difference in tissue displacement between 1B and 1C was 0.079231. 1B showed a significantly higher tissue displacement compared to 1C.

Figure 30: Mean plot for left posterior ridge 1A/1B/1C.

Right posterior ridge 1A/1B/1C:

There were significant differences in tissue displacement among the tray designs 1A/1B/1C in the right posterior ridge ($p < .001$):

1. 1A vs. 1B: the mean difference in tissue displacement between 1A and 1B was 0.109615. 1A showed a significantly higher tissue displacement compared to 1B.
2. 1A vs. 1C: the mean difference in tissue displacement between 1A and 1C was 0.190077. 1A showed a significantly higher tissue displacement compared to 1C.
3. 1B vs. 1C: the mean difference in tissue displacement between 1B and 1C was 0.080462. 1B showed a significantly higher tissue displacement compared to 1C.

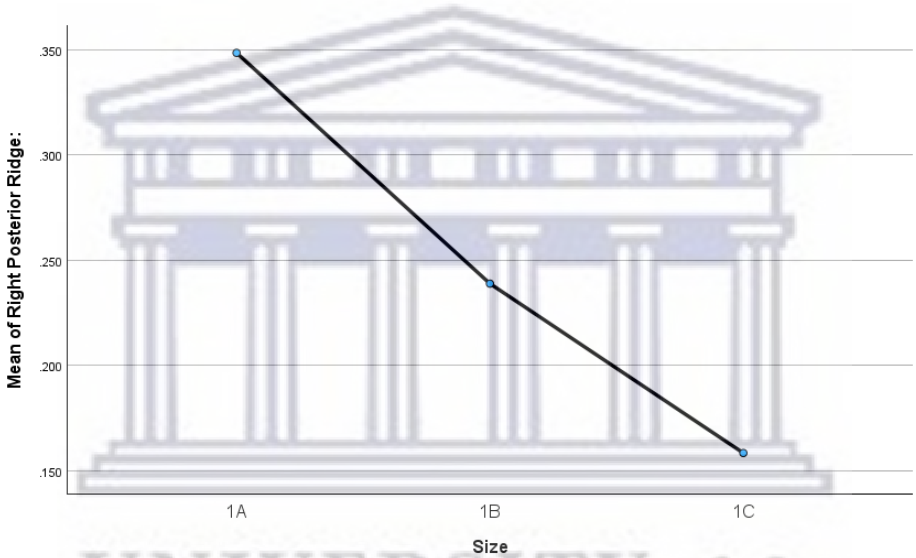

Figure 31: Mean plot for right posterior ridge 1A/1B/1C.

5.2.2 One-way analysis of variance performed for tray designs 2A/2B/2C:

Variable	Tray design 2A		Tray design 2B		Tray design 2C				
	M	*SD*	*M*	*SD*	*M*	*SD*	*F(2, 36)*	*η2*	*P*
Anterior ridge	.336	.004	.242	.001	.143	.001	516250.29***	.999	.001
Palate	.331	.002	.237	.001	.138	.001	32213.142***	.999	.001
Left posterior ridge	.324	.002	.237	.001	.138	.001	30863.307***	.999	.001
Right posterior ridge	.333	.002	.237	.001	.138	.001	35270.261***	.999	.001

Table 9: Mean differences of 2A/2B/2C at the four reference points.

Table 9 displays the ANOVA performed to evaluate the association between tissue displacement (the dependent variable) and tray designs 2A/2B/2C (the factor variable). For each of the reference points examined, the ANOVA results revealed significant differences in tissue displacement across tray designs 2A/2B/2C: anterior ridge $F(2, 36) = 16250.293$, $p < .001$, palate $F(2, 36) = 32213.142$, $p < .001$, left posterior ridge $F(2, 36) = 30863.307$, $p < .001$, and right posterior ridge $F(2, 36) = 35270.261$, $p < .001$.

5.2.2.1 Post hoc comparison for tray designs 2A/2B/2C:

Post hoc tests with the Bonferroni correction were performed to further analyze the variations in tissue displacement among tray designs 2A/2B/2C.

Anterior ridge 2A/2B/2C:

There were significant differences in tissue displacement among the tray designs 2A/2B/2C in the anterior ridge ($p < .001$):

1. 2A vs. 2B: the mean difference in tissue displacement between 2A and 2B was 0.094846. 2A showed significantly higher tissue displacement compared to 2B.
2. 2A vs. 2C: the mean difference in tissue displacement between 2A and 2C was 0.193692. 2A showed significantly higher tissue displacement compared to 2C.
3. 2B vs. 2C: the mean difference in tissue displacement between 2B and 2C was 0.098846. 2B showed significantly higher tissue displacement compared to 2C.

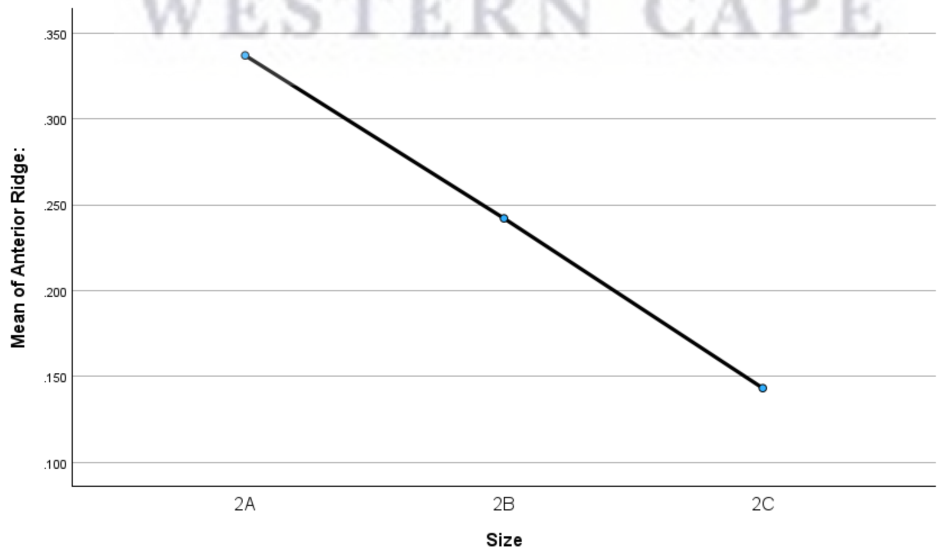

Figure 32: Mean plot for anterior ridge 2A/2B/2C.

Palate 2A/2B/2C:

There were significant differences in tissue displacement among the tray designs 2A/2B/2C in the palate (p < .001):

1. 2A vs. 2B: the mean difference in tissue displacement between 2A and 2B was 0.094000. 2A showed significantly higher tissue displacement compared to 2B.
2. 2A vs. 2C: the mean difference in tissue displacement between 2A and 2C was 0.193154. 2A showed significantly higher tissue displacement compared to 2C.
3. 2B vs. 2C: the mean difference in tissue displacement between 2B and 2C was 0.099154. 2B showed significantly higher tissue displacement compared to 2C.

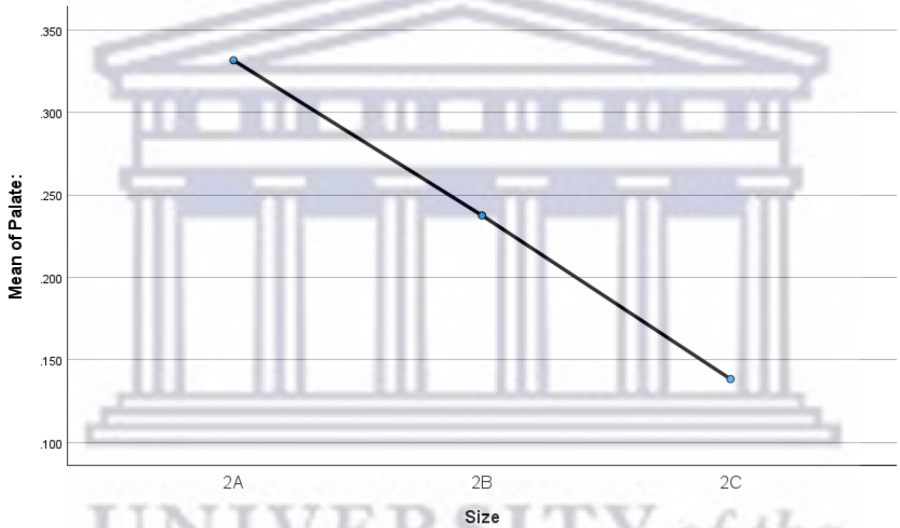

Figure 33: Mean plot for palate 2A/2B/2C.

Left posterior ridge 2A/2B/2C:

There were significant differences in tissue displacement among the tray designs 2A/2B/2C in the left posterior ridge (p < .001):

1. 2A vs. 2B: the mean difference in tissue displacement between 2A and 2B was 0.087692. 2A showed significantly higher tissue displacement compared to 2B.
2. 2A vs. 2C: the mean difference in tissue displacement between 2A and 2C was 0.186385. 2A showed significantly higher tissue displacement compared to 2C.
3. 2B vs. 2C: the mean difference in tissue displacement between 2B and 2C was 0.098692. 2B showed significantly higher tissue displacement compared to 2C.

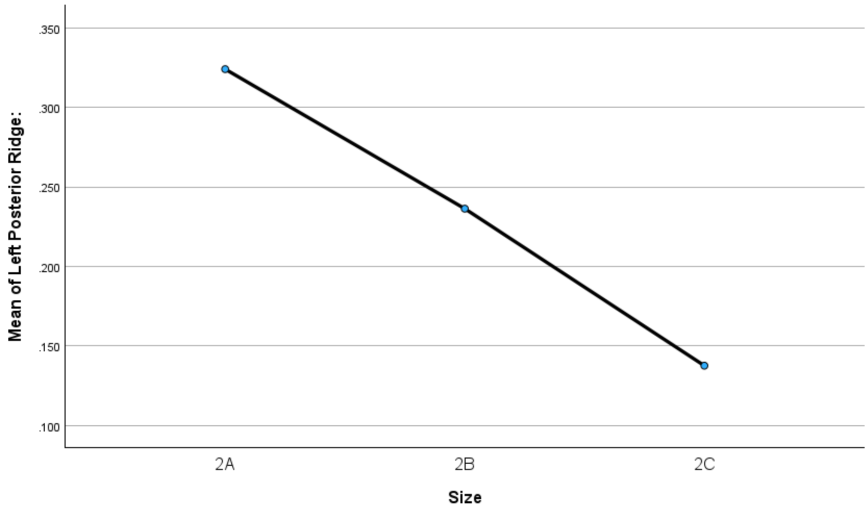

Figure 34: Mean plot for left posterior ridge 2A/2B/2C.

Right posterior ridge 2A/2B/2C:

There were significant differences in tissue displacement among the tray designs 2A/2B/2C in the right posterior ridge ($p < .001$):

1. 2A vs. 2B: the mean difference in tissue displacement between 2A and 2B was 0.095615. 2A showed significantly higher tissue displacement compared to 2B.
2. 2A vs. 2C: the mean difference in tissue displacement between 2A and 2C was 0.195000. 2A showed significantly higher tissue displacement compared to 2C.
3. 2B vs. 2C: the mean difference in tissue displacement between 2B and 2C was 0.099385. 2B showed significantly higher tissue displacement compared to 2C.

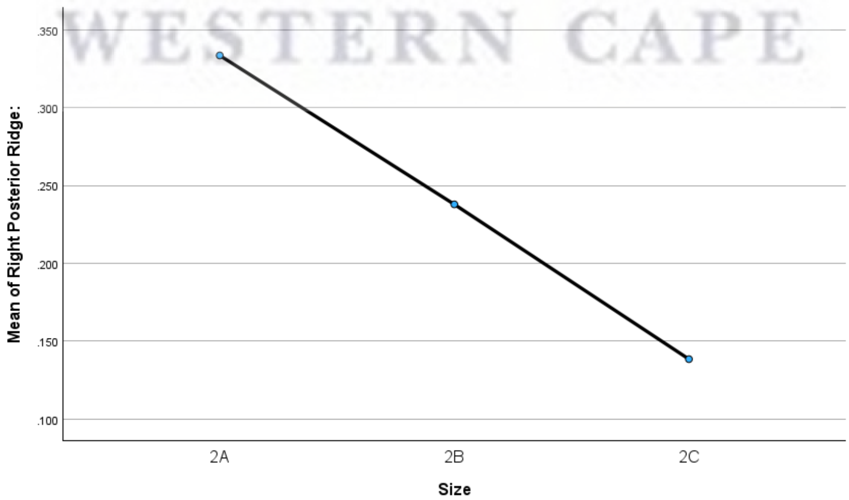

Figure 35: Mean plot for right posterior ridge 2A/2B/2C.

5.2.3 One-way analysis of variance performed for tray designs 3A/3B/3C:

Variable	Tray design 3A		Tray design 3B		Tray design 3C				
	M	*SD*	*M*	*SD*	*M*	*SD*	*F(2, 36)*	*η2*	*P*
Anterior ridge	.323	.001	.234	.001	.129	.001	42764.71***	1.0	.001
Palate	.318	.0009	.230	.001	.125	.001	108950.50***	1.0	.001
Left posterior ridge	.316	.002	.228	.0008	.119	.001	94733.42***	1.0	.001
Right posterior ridge	.318	.0008	.229	.001	.123	.001	72757.647***	1.0	.001

Table 10: Mean differences of 3A/3B/3C at the four reference points.

Table 10 displays the ANOVA performed to evaluate the association between tissue displacement (the dependent variable) and tray designs 3A/3B/3C (the factor variable). For each of the reference points examined, the ANOVA results revealed significant differences in tissue displacement across tray designs 3A/3B/3C: anterior ridge $F(2, 36) = 42764.712$, $p < .001$, palate $F(2, 36) = 108950.506$, $p < .001$, left posterior ridge $F(2, 36) = 94733.425$, $p < .001$, and right posterior ridge $F(2, 36) = 72757.647$, $p < .001$.

5.2.3.1 Post hoc comparison for tray designs 3A/3B/3C:

Post hoc tests with the Bonferroni correction were performed to further analyze the variations in tissue displacement among tray designs 3A/3B/3C.

Anterior ridge 3A/3B/3C:

There were significant differences in tissue displacement among the tray designs 3A/3B/3C in the anterior ridge ($p < .001$):

1. 3A vs. 3B: the mean difference in tissue displacement between 3A and 3B was 0.088769. 3A showed significantly higher tissue displacement compared to 3B.
2. 3A vs. 3C: the mean difference in tissue displacement between 3A and 3C was 0.193308. 3A showed significantly higher tissue displacement compared to 3C.
3. 3B vs. 3C: the mean difference in tissue displacement between 3B and 3C was 0.104538. 3B showed significantly higher tissue displacement compared to 3C.

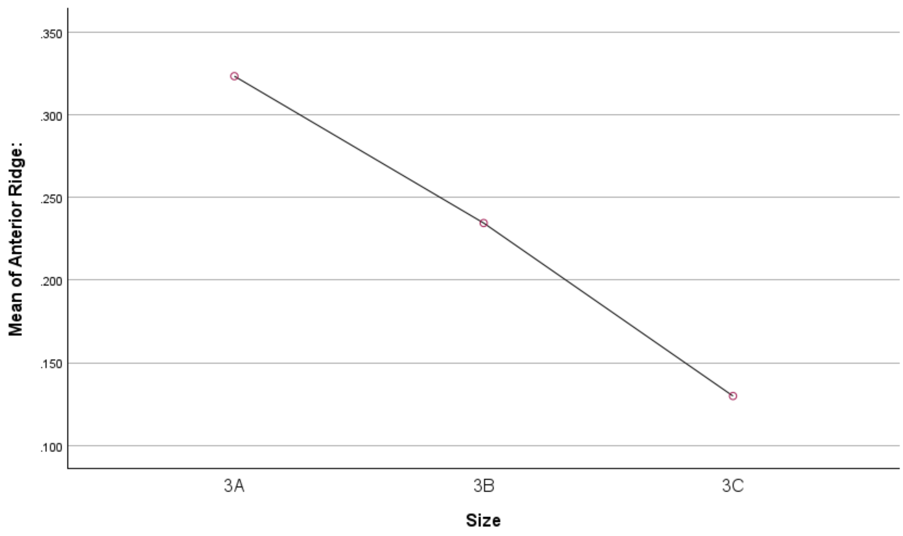

Figure 36: Mean plot for anterior ridge 3A/3B/3C.

Palate 3A/3B/3C:

There were significant differences in tissue displacement among the tray designs 3A/3B/3C in the palate ($p < .001$):

1. 3A vs. 3B: the mean difference in tissue displacement between 3A and 3B was 0.088692. 3A showed significantly higher tissue displacement compared to 3B.
2. 3A vs. 3C: the mean difference in tissue displacement between 3A and 3C was 0.193154. 3A showed significantly higher tissue displacement compared to 3C.
3. 3B vs. 3C: the mean difference in tissue displacement between 3B and 3C was 0.104462. 3B showed significantly higher tissue displacement compared to 3C.

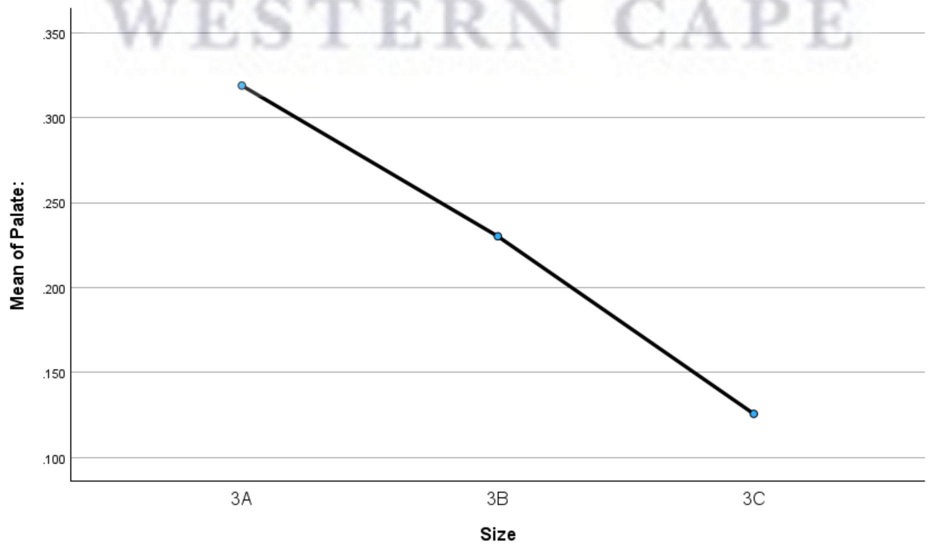

Figure 37: Mean plot for palate 3A/3B/3C.

Left posterior ridge 3A/3B/3C:

There were significant differences in tissue displacement among the tray designs 3A/3B/3C in the left posterior ridge ($p < .001$):

1. 3A vs. 3B: the mean difference in tissue displacement between 3A and 3B was 0.087923. 3A showed significantly higher tissue displacement compared to 3B.
2. 3A vs. 3C: the mean difference in tissue displacement between 3A and 3C was 0.197077. 3A showed significantly higher tissue displacement compared to 3C.
3. 3B vs. 3C: the mean difference in tissue displacement between 3B and 3C was 0.109154. 3B showed significantly higher tissue displacement compared to 3C.

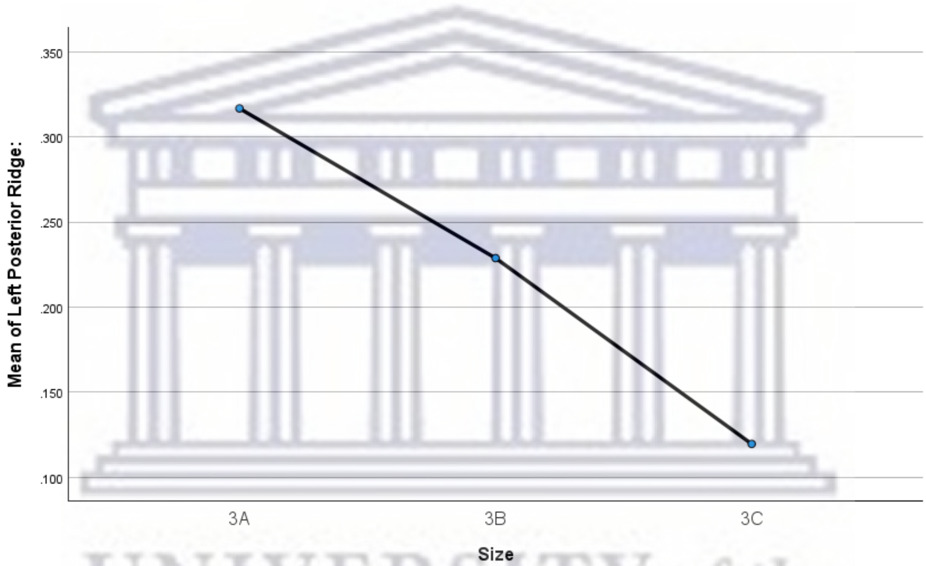

Figure 38: Mean plot for left posterior ridge 3A/3B/3C.

Right posterior ridge 3A/3B/3C:

There were significant differences in tissue displacement among the tray designs 3A/3B/3C in the right posterior ridge ($p < .001$):

1. 3A vs. 3B: the mean difference in tissue displacement between 3A and 3B was 0.088385. 3A showed significantly higher tissue displacement compared to 3B.
2. 3A vs. 3C: the mean difference in tissue displacement between 3A and 3C was 0.194615. 3A showed significantly higher tissue displacement compared to 3C.
3. 3B vs. 3C: the mean difference in tissue displacement between 3B and 3C was 0.106231. 3B showed significantly higher tissue displacement compared to 3C.

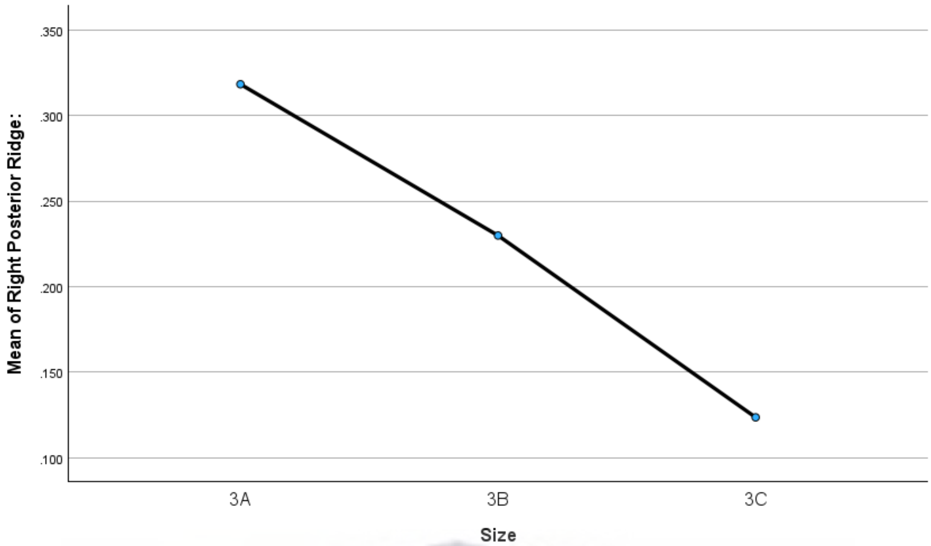

Figure 39: Mean plot for right posterior ridge 3A/3B/3C.

5.2.4 One-way analysis of variance performed for tray designs 1A/2A/3A:

Variable	Tray design 1A		Tray design 2A		Tray design 3A				
	M	*SD*	*M*	*SD*	*M*	*SD*	*F(2, 36)*	*η2*	*P*
Anterior ridge	.349	.001	.336	.004	.323	.001	279.315***	.939	.001
Palate	.347	.001	.331	.002	.328	.001	749.550***	.977	.001
Left posterior ridge	.348	.001	.324	.002	.316	.001	1223.700***	.986	.001
Right posterior ridge	.348	.001	.333	.002	.318	.001	843.488***	.979	.001

Table 11: Mean differences of 1A/2A/3A at the four reference points.

Table 11 displays the ANOVA performed to evaluate the association between tissue displacement (the dependent variable) and tray designs 1A/2A/3A (the factor variable). For each of the reference points examined, the ANOVA results revealed significant differences in tissue displacement across tray designs 1A/2A/3A: anterior ridge $F(2, 36) = 279.315$, $p < .001$, palate $F(2, 36) = 749.550$, $p < .001$, left posterior ridge $F(2, 36) = 1223.700$, $p < .001$, and right posterior ridge $F(2, 36) = 843.488$, $p < .001$.

5.2.4.1 Post hoc comparison for tray designs 1A/2A/3A:

Post hoc tests with the Bonferroni correction were performed to further analyze the variations in tissue displacement among tray designs 1A/2A/3A.

Anterior ridge 1A/2A/3A:

There were significant differences in tissue displacement among the tray designs 1A/2A/3A in the anterior ridge ($p < .001$):

1. 1A vs. 2A: the mean difference in tissue displacement between 1A and 2A was 0.012154. 1A showed significantly higher tissue displacement compared to 2A.
2. 1A vs. 3A: the mean difference in tissue displacement between 1A and 3A was 0.025846. 1A showed significantly higher tissue displacement compared to 3A.
3. 2A vs. 3A: the mean difference in tissue displacement between 2A and 3A was 0.013692. 2A showed significantly higher tissue displacement compared to 3A.

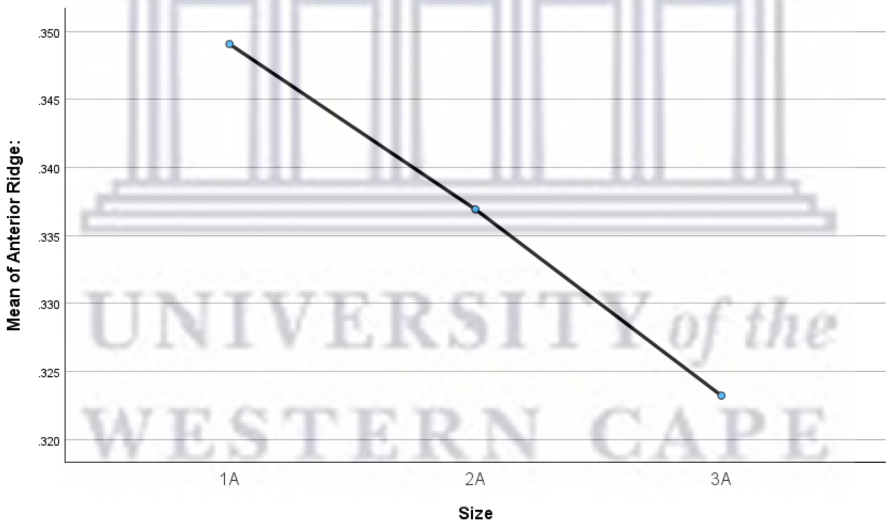

Figure 40: Mean plot for anterior ridge 1A/2A/3A.

Palate 1A/2A/3A:

There were significant differences in tissue displacement among the tray designs 1A/2A/3A in the palate ($p < .001$):

1. 1A vs. 2A: the mean difference in tissue displacement between 1A and 2A was 0.016231. 1A showed significantly higher tissue displacement compared to 2A.

2. 1A vs. 3A: the mean difference in tissue displacement between 1A and 3A was 0.028923. 1A showed significantly higher tissue displacement compared to 3A.
3. 2A vs. 3A: the mean difference in tissue displacement between 2A and 3A was 0.012692. 2A showed significantly higher tissue displacement compared to 3A.

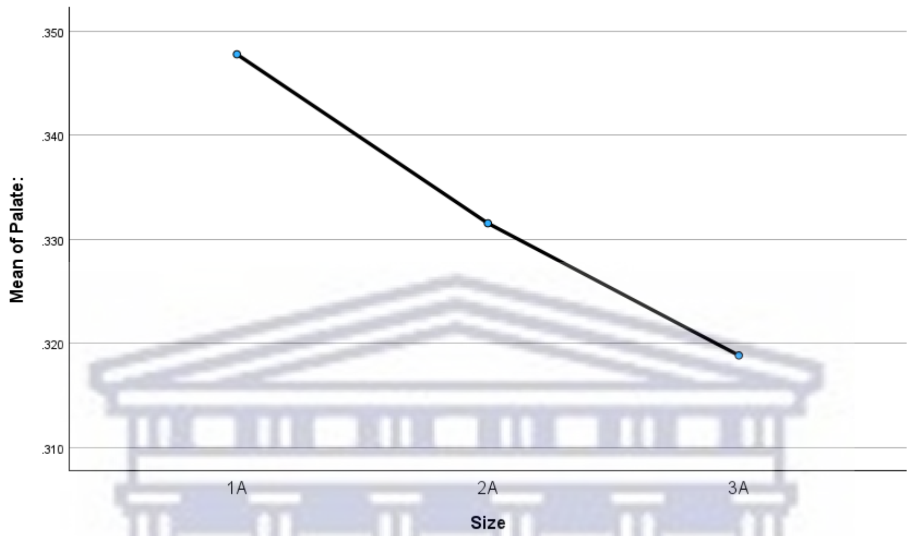

Figure 41: Mean plot for palate 1A/2A/3A.

Left posterior ridge 1A/2A/3A:

There were significant differences in tissue displacement among the tray designs 1A/2A/3A in the left posterior ridge ($p < .001$):

1. 1A vs. 2A: the mean difference in tissue displacement between 1A and 2A was 0.024692. 1A showed significantly higher tissue displacement compared to 2A.
2. 1A vs. 3A: the mean difference in tissue displacement between 1A and 3A was 0.032000. 1A showed significantly higher tissue displacement compared to 3A.
3. 2A vs. 3A: the mean difference in tissue displacement between 2A and 3A was 0.007308. 2A showed significantly higher tissue displacement compared to 3A.

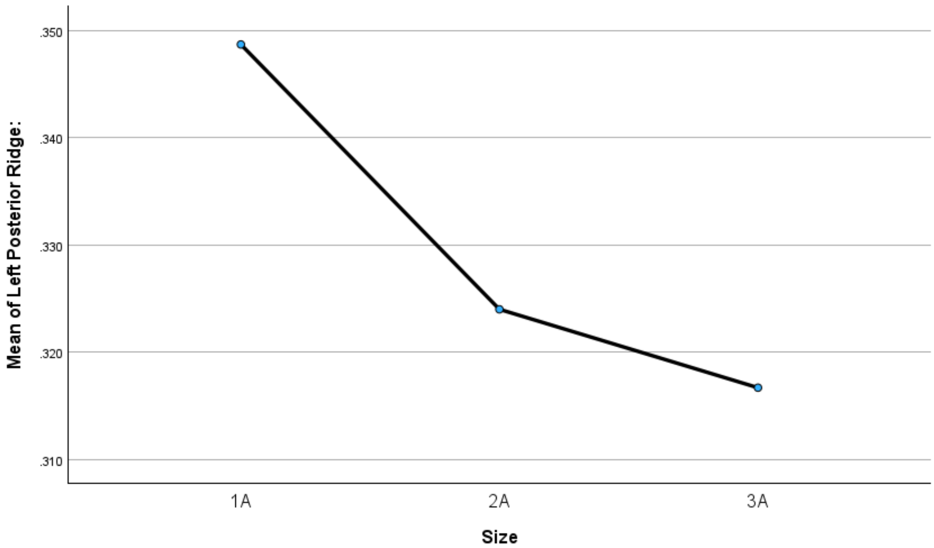

Figure 42: Mean plot for left posterior ridge 1A/2A/3A.

Right posterior ridge 1A/2A/3A:

There were significant differences in tissue displacement among the tray designs 1A/2A/3A in the right posterior ridge ($p < .001$):

1. 1A vs. 2A: the mean difference in tissue displacement between 1A and 2A was 0.015000. 1A showed significantly higher tissue displacement compared to 2A.
2. 1A vs. 3A: the mean difference in tissue displacement between 1A and 3A was 0.030231. 1A showed significantly higher tissue displacement compared to 3A.
3. 2A vs. 3A: the mean difference in tissue displacement between 2A and 3A was 0.015231. 2A showed significantly higher tissue displacement compared to 3A.

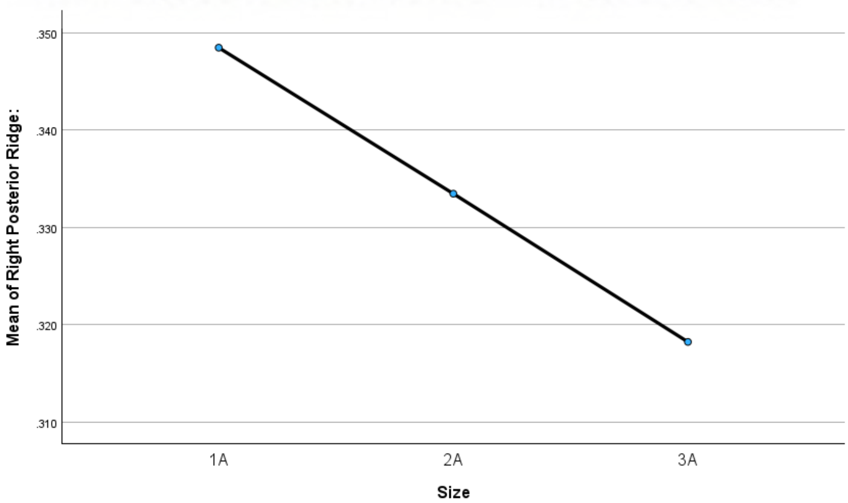

Figure 43: Mean plot for right posterior ridge 1A/2A/3A.

5.2.5 One-way analysis of variance performed for tray designs 1B/2B/3B:

Variable	Tray design 1B		Tray design 2B		Tray design 3B				
	M	*SD*	*M*	*SD*	*M*	*SD*	*F(2, 36)*	*η2*	*P*
Anterior ridge	.239	.0009	.232	.001	.234	.001	73.358***	.803	.001
Palate	.239	.001	.237	.001	.230	.001	206.665***	.856	.001
Left posterior ridge	.337	.0004	.236	.001	.228	.0008	255.915***	.881	.001
Right posterior ridge	.238	.0008	.337	.001	.229	.001	264.364***	.885	.001

Table 12: Mean differences of 1B/2B/3B at the four reference points.

Table 12 displays the ANOVA performed to evaluate the association between tissue displacement (the dependent variable) and tray designs 1B/2B/3B (the factor variable). For each of the reference points examined, the ANOVA results revealed significant differences in tissue displacement across tray designs 1B/2B/3B: anterior ridge $F(2, 36) = 73.358$, $p < .001$, palate $F(2, 36) = 206.665$, $p < .001$, left posterior ridge $F(2, 36) = 255.915$, $p < .001$, and right posterior ridge $F(2, 36) = 264.364$, $p < .001$.

5.2.5.1 Post hoc comparison of tray designs 1B/2B/3B:

Post hoc tests with the Bonferroni correction were performed to further analyze the variations in tissue displacement among tray designs 1B/2B/3B.

Anterior ridge 1B/2B/3B:

There were significant differences in tissue displacement among the tray designs 1B/2B/3B in the anterior ridge ($p < .001$):

1. 1B vs. 2B: the mean difference in tissue displacement between 1B and 2B was 0.002846. 1B showed significantly lower tissue displacement compared to 2B.
2. 1B vs. 3B: the mean difference in tissue displacement between 1B and 3B was 0.004769. 1B showed significantly higher tissue displacement compared to 3B.
3. 2B vs. 3B: the mean difference in tissue displacement between 2B and 3B was 0.007615. 2B showed significantly higher tissue displacement compared to 3B.

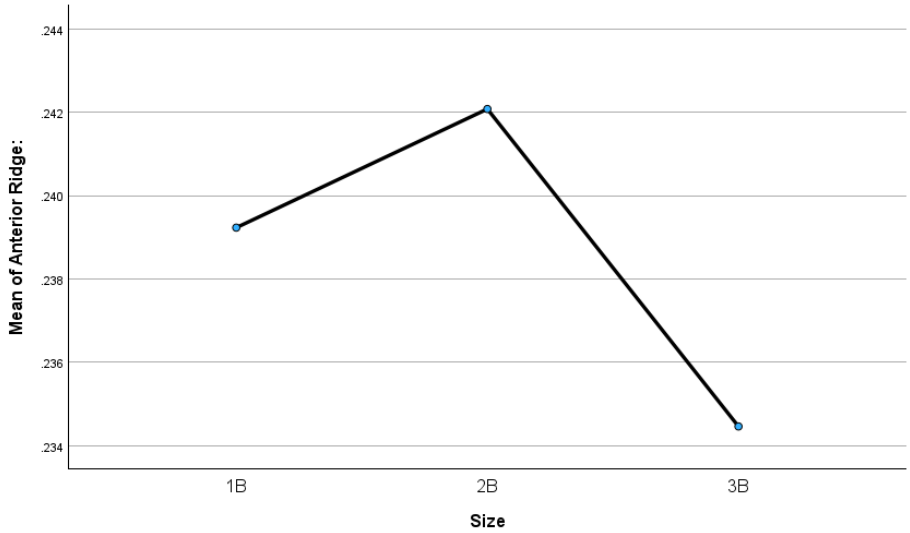

Figure 44: Mean plot for anterior ridge 1B/2B/3B.

Palate 1B/2B/3B:

There were significant differences in tissue displacement among the tray designs 1B/2B/3B in the palate ($p < .001$):

1. 1B vs. 2B: the mean difference in tissue displacement between 1B and 2B was 0.001462. 1B showed slightly higher tissue displacement compared to 2B.
2. 1B vs. 3B: the mean difference in tissue displacement between 1B and 3B was 0.008846. 1B showed significantly higher tissue displacement compared to 3B.
3. 2B vs. 3B: the mean difference in tissue displacement between 2B and 3B was 0.007385. 2B showed significantly higher tissue displacement compared to 3B.

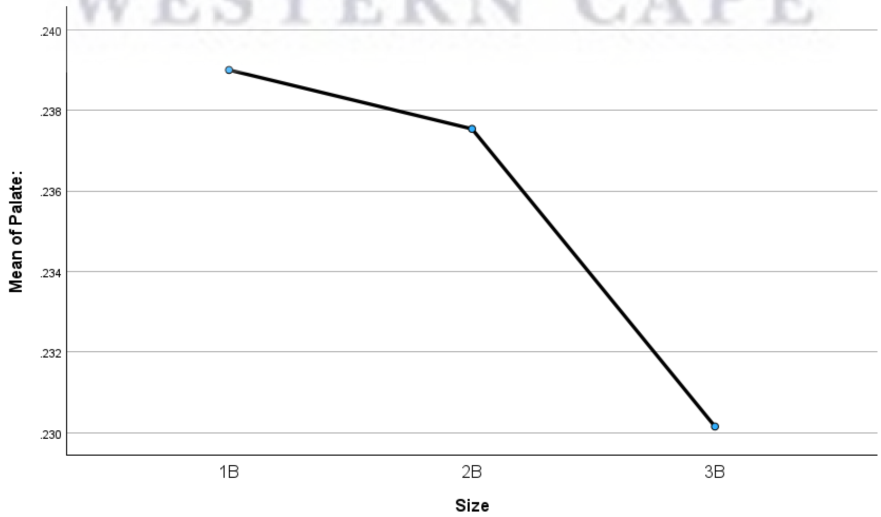

Figure 45: Mean plot for palate 1B/2B/3B.

Left posterior ridge 1B/2B/3B:

There were significant differences in tissue displacement among the tray designs 1B/2B/3B in the left posterior ridge ($p < .001$):

1. 1B vs. 2B: the mean difference in tissue displacement between 1B and 2B was 0.001000. 1B showed slightly higher tissue displacement compared to 2B, but this difference was not statistically significant.
2. Size 1B vs. Size 3B: the mean difference in tissue displacement between 1B and 3B was 0.008538. 1B showed significantly higher tissue displacement compared to 3B.
3. 2B vs. 3B: the mean difference in tissue displacement between 2B and 3B was 0.007538. 2B showed significantly higher tissue displacement compared to 3B.

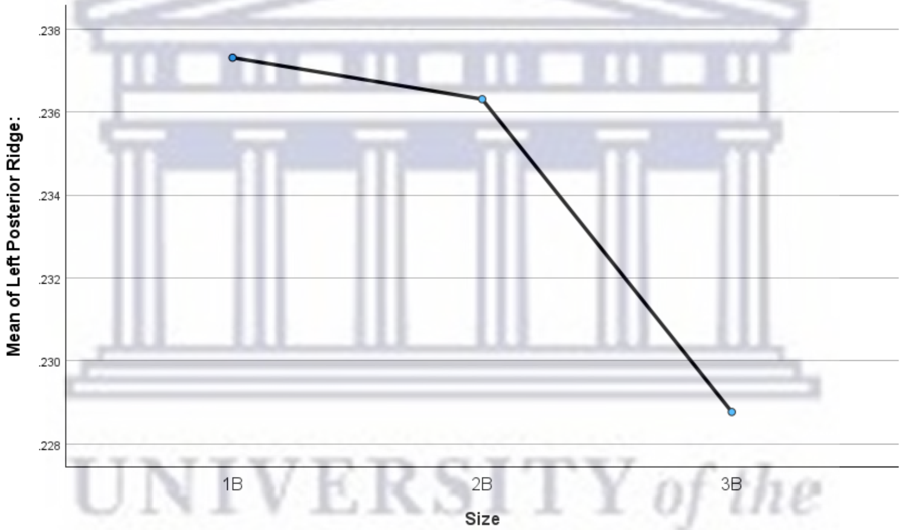

Figure 46: Mean plot for left posterior ridge 1B/2B/3B.

Right posterior ridge 1B/2B/3B:

There were significant differences in tissue displacement among the tray designs 1B/2B/3B in the right posterior ridge ($p < .001$):

1. 1B vs. 2B: the mean difference in tissue displacement between 1B and 2B was 0.001000. 1B showed slightly higher tissue displacement compared to 2B, but this difference was not statistically significant.
2. 1B vs. 3B: the mean difference in tissue displacement between 1B and 3B was 0.009000. 1B showed significantly higher tissue displacement compared to 3B.

3. 2B vs. 3B: the mean difference in tissue displacement between 2B and 3B was 0.008000. 2B demonstrated significantly higher tissue displacement compared to 3B.

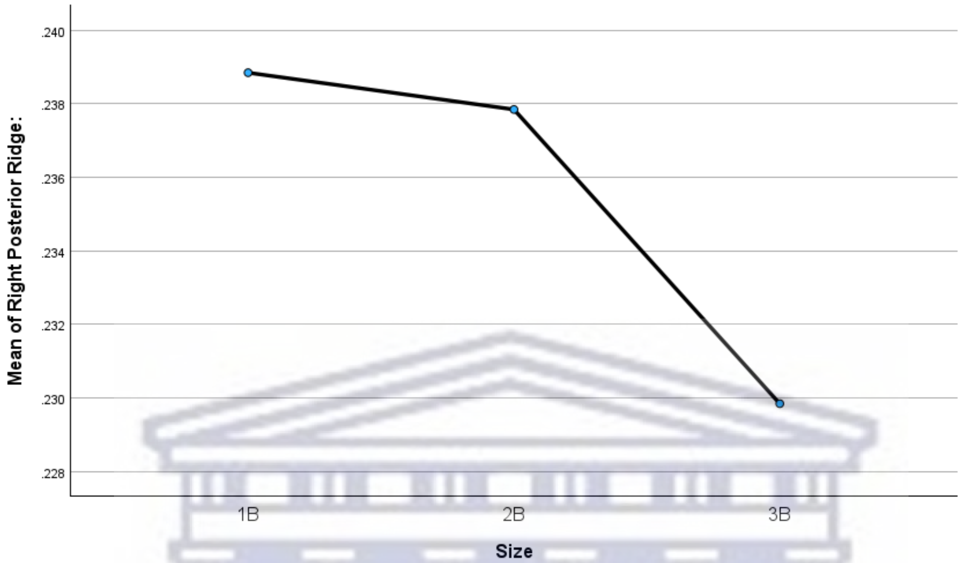

Figure 47: Mean plot for right posterior ridge 1B/2B/3B.

5.2.6 One-way analysis of variance performed for tray designs 1C/2C/3C:

Variable	Tray design 1C		Tray design 2C		Tray design 3C				
	M	*SD*	*M*	*SD*	*M*	*SD*	*F(2, 36)*	*η2*	*P*
Anterior ridge	.160	.001	.143	.001	.129	.001	1481.156***	.998	.001
Palate	.158	.001	.138	.001	.125	.001	1722.246***	.990	.001
Left posterior ridge	.158	.001	.137	.001	.119	.001	1945.658***	.991	.001
Right posterior ridge	.158	.0009	.138	.001	.123	.001	2052.998***	.991	.001

Table 13: Mean differences of 1C/2C/3C at the four reference points.

Table 13 displays the ANOVA performed to evaluate the association between tissue displacement (the dependent variable) and tray designs 1C/2C/3C (the factor variable). For each of the reference points examined, the ANOVA results revealed significant differences in tissue displacement across tray designs 1C/2C/3C: anterior ridge $F(2, 36) = 1481.156$, $p < .001$, palate $F(2, 36) = 1722.246$, $p < .001$, left posterior ridge $F(2, 36) = 1945.658$, $p < .001$, and right posterior ridge $F(2, 36) = 2052.998$, $p < .001$.

5.2.6.1 Post hoc comparison for tray designs 1C/2C/3C:

Post hoc tests with the Bonferroni correction were performed to further analyze the variations in tissue displacement among tray designs 1C/2C/3C.

Anterior ridge 1C/2C/3C:

There were significant differences in tissue displacement among the tray designs 1C/2C/3C in the anterior ridge ($p < .001$):

1. 1C vs. 2C: the mean difference in tissue displacement between 1C and 2C was 0.016846. 1C showed significantly higher tissue displacement compared to 2C.
2. 1C vs. 3C: the mean difference in tissue displacement between 1C and 3C was 0.030154. 1C showed significantly higher tissue displacement compared to 3C.
3. 2C vs. 3C: the mean difference in tissue displacement between 2C and 3C was 0.013308. 2C showed significantly higher tissue displacement compared to 3C.

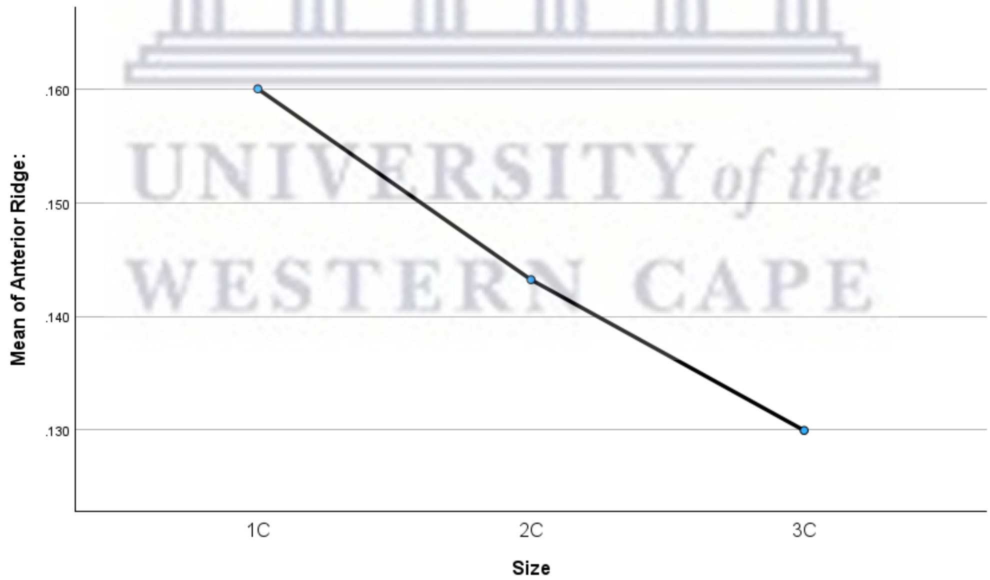

Figure 48: Mean plot for anterior ridge 1C/2C/3C.

Palate 1C/2C/3C:

There were significant differences in tissue displacement among the tray designs 1C/2C/3C in the palate ($p < .001$):

1. 1C vs. 2C: the mean difference in tissue displacement between 1C and 2C was 0.020231. 1C showed significantly higher tissue displacement compared to 2C.
2. 1C vs. 3C: the mean difference in tissue displacement between 1C and 3C was 0.032923. 1C showed significantly higher tissue displacement compared to 3C.
3. 2C vs. 3C: The mean difference in tissue displacement between 2C and 3C was 0.012692. 2C showed significantly higher tissue displacement compared to 3C.

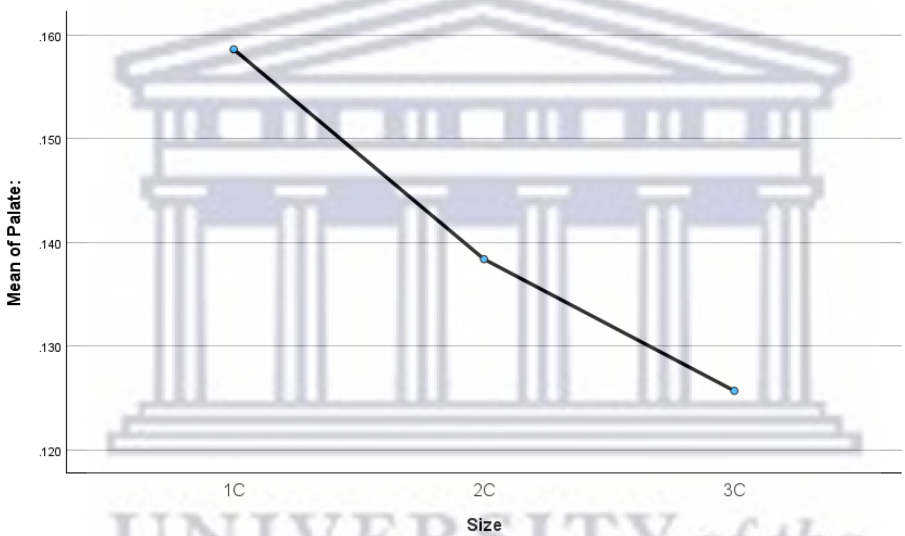

Figure 49: Mean plot for palate 1C/2C/3C.

Left posterior ridge 1C/2C/3C:

There were significant differences in tissue displacement among the tray designs 1C/2C/3C in the left posterior ridge ($p < .001$):

1. 1C vs. 2C: the mean difference in tissue displacement between 1C and 2C was 0.020462. 1C showed significantly higher tissue displacement compared to 2C.
2. 1C vs. 3C: the mean difference in tissue displacement between 1C and 3C was 0.038462. 1C showed significantly higher tissue displacement compared to 3C.
3. 2C vs. 3C: the mean difference in tissue displacement between 2C and 3C was 0.018000. 2C showed significantly higher tissue displacement compared to 3C.

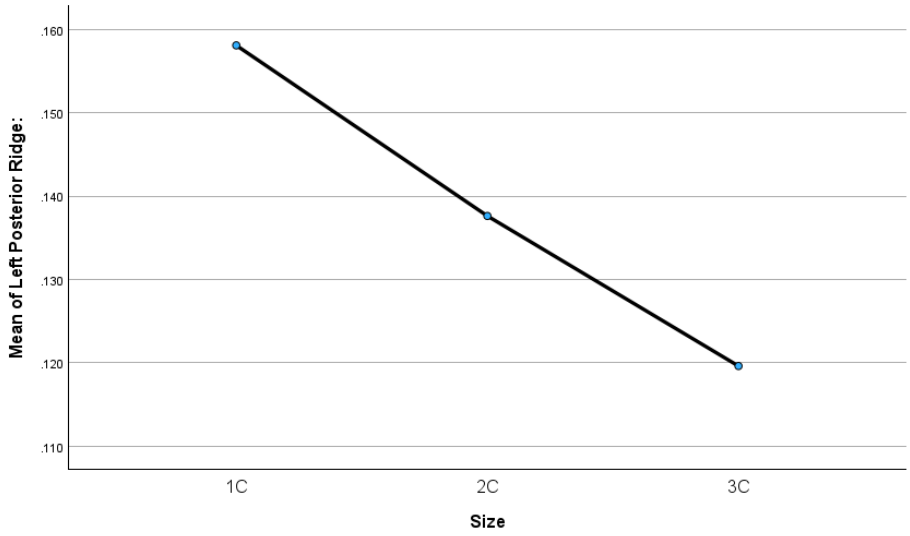

Figure 50: Mean plot for left posterior ridge 1C/2C/3C.

Right posterior ridge 1C/2C/3C:

There were significant differences in tissue displacement among the tray designs 1C/2C/3C in the right posterior ridge ($p < .001$):

1. 1C vs. 2C: The mean difference in tissue displacement between 1C and 2C was 0.019923. 1C showed significantly higher tissue displacement compared to 2C.
2. 1C vs. 3C: The mean difference in tissue displacement between 1C and 3C was 0.034769. 1C showed significantly higher tissue displacement compared to 3C.
3. 2C vs. 3C: The mean difference in tissue displacement between 2C and 3C was 0.014846. 2C showed significantly higher tissue displacement compared to 3C.

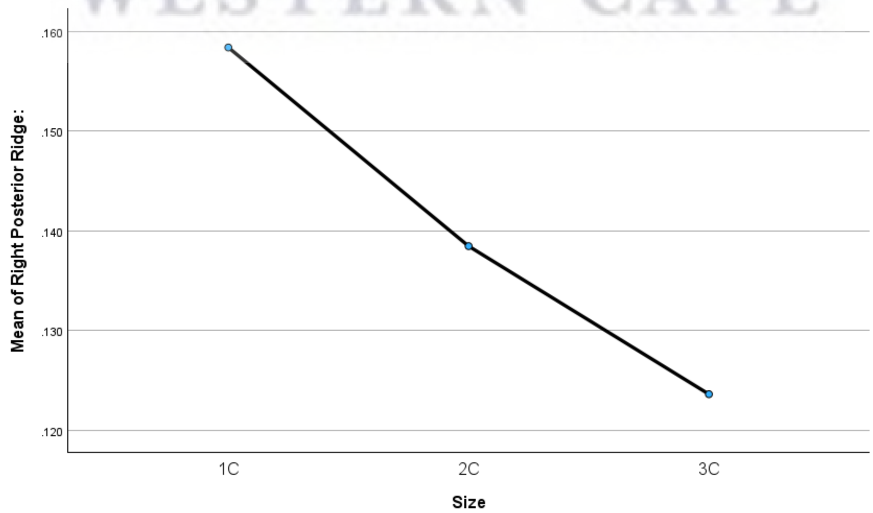

Figure 51: Mean plot for right posterior ridge 1C/2C/3C.

5.3 Intra examiner reliability – main researcher:

Category	Anterior ridge	Palate	Combined posterior	Intra class correlation	Cohen's Kappa
1A	0.350	0.349	0.351	0.798	0.958
1A	0.348	0.347	0.348		
1A	0.350	0.346	0.348		
1B	0.240	0.237	0.238	0.996	0.976
1B	0.239	0.240	0.238		
1B	0.238	0.239	0.239		
1C	0.163	0.160	0.157	0.861	0.907
1C	0.160	0.159	0.159		
2A	0.330	0.326	0.331	0.682	0.875
2A	0.343	0.332	0.326		
2B	0.240	0.235	0.235	0.957	0.964
2B	0.243	0.238	0.237		
2C	0.144	0.136	0.137	0.861	0.950
2C	0.141	0.136	0.136		
3A	0.324	0.318	0.316	0.995	0.957
3A	0.325	0.318	0.317		
3B	0.235	0.230	0.228	0.998	0.970
3B	0.233	0.229	0.228		
3C	0.131	0.126	0.120	0.943	0.930
3C	0.130	0.126	0.122		

Table 14: Intra examiner reliability showing Cohen's Kappa coefficient and intra class correlation values.

The ICC values range from 0.682 to 0.998, demonstrating moderate to nearly perfect agreement between the main researcher's repeated assessments. The highest ICC is found in Category 3B, while the lowest is found in Category 2A. Cohen's kappa coefficients range from 0.875 to 0.976, suggesting significant to nearly perfect agreement between the main researcher's repeated measurements. The Category 2B has the highest kappa coefficient, while the Category 3C has the lowest. Overall, the results indicate good intra examiner reliability and agreement between repeated measurements made by the main researcher, with varying levels of agreement observed across different measurement categories.

5.4 Inter examiner reliability between main researcher and supervisor:

Category	Anterior ridge	Cohen's Kappa	Palate	Cohen's Kappa	Combined posterior (right & left)	Cohen's Kappa	Intra class correlation
1A	0.350	0.737	0.349	0.737	0.349	0.737	0.737
1B	0.239	0.990	0.238	0.990	0.238	0.990	0.990
1C	0.161	0.832	0.157	0.832	0.157	0.832	0.832
2A	0.336	0.674	0.328	0.674	0.328	0.674	0.674
2B	0.241	0.957	0.237	0.957	0.236	0.957	0.957
2C	0.142	0.828	0.136	0.828	0.136	0.828	0.828
3A	0.324	0.992	0.317	0.992	0.316	0.992	0.992
3B	0.234	0.996	0.229	0.996	0.228	0.996	0.996
3C	0.130	0.951	0.125	0.951	0.121	0.951	0.951

Table 15: Inter examiner reliability showing Cohen's Kappa coefficient and intra class correlation values.

5.4.1 Anterior ridge:

The inter-examiner reliability for anterior ridge measures is high, with a Cohen's Kappa coefficient of 0.828. This indicates that the two examiners had a high level of agreement on the anterior ridge.

5.4.2 Palate:

With a Cohen's Kappa coefficient of 0.951, the inter examiner reliability for the palate measurements is nearly flawless. This indicates that the two examiners had a high level of agreement in their assessments of the palate.

5.4.3 Combined posterior:

The inter-examiner reliability for the combined posterior measures is nearly perfect, with a Cohen's Kappa coefficient of 0.951. This indicates that the two examiners had a very high level of agreement in their assessments of the combined posterior region.

Overall, inter-examiner reliability is excellent across all categories, with ICC values ranging from 0.674 to 0.992. This implies a high level of agreement between the two examiners. Furthermore, the Cohen's Kappa coefficients vary from 0.828 to 0.996, demonstrating moderate to near-perfect agreement between the two examiners. These findings indicate that the two examiners had consistent and reliable measurements in the evaluated categories, showing a high level of agreement in their evaluations.

Chapter 6: Discussion

This chapter expands on the findings provided in the preceding chapter.

The primary purpose of this *in vitro* study was to determine how the diameter and number of relief holes in custom trays affected simulated fibrous tissue displacement. As a result, the most appropriate relief hole diameter and amount to add into a custom tray for making impressions of fibrous tissues with a one stage impression technique were investigated. The amount of vertical tissue displacement was measured in coronal sections at specific reference points (midpalate, anterior ridge, posterior ridge left and right) by superimposing 3D digital control and test models. Because some characteristics may be controlled and larger sample numbers are possible, this experimental *in vitro* study provides for more consistent impressions.

The null hypothesis was rejected based on the statistical analyses performed in the current *in vitro* study because there was a significant difference in the degree of simulated maxillary fibrous tissue displacement when relief holes were strategically introduced within custom impression trays based on increases in size and quantity during a one-step impression technique.

According to the authors' best knowledge, no study has evaluated the degree of simulated fibrous tissue displacement of the edentulous maxillary alveolar ridge when comparing 3D printed custom tray configurations specifically based on the size and number of relief holes. The majority of the *in vitro* research evaluated used edentulous maxillary stone casts with or without simulated alveolar tissue and focused on the pressure created during impression making rather than the degree of tissue displacement.

When an impression is made, the pressure produced on fibrous tissue has a major effect on the displacement of these tissues (Klein and Broner, 1985). The findings of this *in vitro* study show that when pressure builds up, the displacement of the simulated fibrous tissue increases, which is consistent with Klein and Broner (1985). The changes in pressure management between custom tray designs are assumed to be attributable to differences in relief space thickness and the placement of additional escape holes. Previous *in vitro* studies evaluated pressure build-up on edentulous denture bearing tissues in custom impression trays with varying relief space thickness, the insertion of relief holes, and impression materials (Woelfel, 1962; Frank, 1969;

Masri *et al.*, 2002; Nishigawa *et al.,* 2003; Komiyama *et al*., 2004; Reddy *et al*., 2012; Chopra *et al*., 2016; Fouladi *et al.,* 2016).

Pressures applied were found to be significantly reduced as relief hole diameter and spacer thickness increased, however, the Masri *et al.* (2002) study was the only *in vitro* study that found the presence of relief holes with or without relief spacers had no effect on the extent of pressure applied to the denture bearing mucosa during impression making. The findings of this *in vitro* study show that larger relief holes of 3mm , as well as increased numbers of relief holes of 21, result in less pressure onto the simulated fibrous tissue, resulting in reduced tissue displacement of these tissues which contradicts Masri *et al.* (2002).

In studies that assessed tissue displacement, Shin *et al.* (2016) found that large relief spaces in custom impression trays reduce more effectively than a localised escape hole. Shin *et al.* (2019) discovered that the combination of impression materials with low viscosity and spaced custom impression trays reduced displacement on the simulated maxillary tissues. Although no relief spacers were included in the custom tray designs for this *in vitro* study, the results agree with Shin *et al.* (2019), who found that relief over mobile fibrous tissue combined with a low viscosity impression material reduces displacement of these tissues. Shin *et al.* (2016) concluded that using a localised escape hole does not effectively reduce simulated maxillary fibrous tissue displacement, contradicting the findings of this *in vitro* study, which show that larger relief holes of 3mm result in reduced simulated fibrous tissue displacement.

Based on the findings of the one-way analysis of variance (ANOVA) performed to investigate the association between the mean difference in tissue displacement and the number and diameter of relief holes, it can be stated that the width of the relief hole and the number of relief holes placed within each tray design group (1A/1B/1C, 2A/2B/2C, 3A/3B/3C) have a significant effect on tissue displacement. Overall, the results support the notion that the size of the relief hole, as well as the number of relief holes, have a significant impact on tissue displacement. Understanding these findings in the broader context of existing literature will contribute to a deeper understanding of tissue displacement in these regions and its relevance in clinical or scientific research. The post hoc comparison among the different tray design groups (1A/1B/1C, 2A/2B/2C, 3A/3B/3C, 1A/2A/3A, 1B/2B/3B, 1C/2C/3C) further elucidates the influence of the diameter and number of relief holes on tissue displacement.

The post-hoc comparison test for tray designs 1A/1B/1C, 2A/2B/2C, and 3A/3B/3C revealed that increasing the diameter of the relief hole to 3mm leads to significant lower tissue displacement at the four reference points measured.

The post-hoc comparison test for tray designs 1B and 2B at the anterior ridge revealed that 1B showed significantly lower tissue displacement than 2B. This finding may be attributed to the relief hole's different location between tray design 1B and 2B, specifically in the anterior segment of the custom tray. However, the post-hoc comparison test for tray designs 1A/2A/3A, 1B/2B/3B, and 1C/2C/3C revealed that increasing the number of relief holes to 21 leads to significantly lower tissue displacement at the four reference points measured.

Despite the fact that earlier research analyzed the change of the diameter rather than the number of relief holes, it was proposed that a relief hole of 1mm or bigger in diameter can minimize the pressure exerted to the denture bearing mucosal tissues in the area of relief. As a result, increasing the width of the relief hole significantly reduces the applied pressures. This *in vitro* study's findings are consistent with previous studies in that the degree of simulated fibrous tissue displacement was significantly lower with a custom tray consisting of relief holes with a 3mm diameter.

It is important to highlight that the statistical significance of the results obtained from this *in vitro* study implies that the observed differences in tissue displacement between the nine tray designs are unlikely to have occurred by chance. This validates the findings and emphasizes the clinical relevance when considering both relief hole diameter and the number of relief holes when constructing custom trays for tissue displacement in relevant applications. The reduced amount of fibrous tissue displacement when making a definitive impression can clinically improve complete denture retention and stability.

The findings of this *in vitro* study may contribute to the development of improved custom tray designs with larger diameters of 3mm and increased number of 21 relief holes in the fibrous tissue region, as well as improve understanding in the field of fibrous tissue displacement, particularly when incorporating the one-step impression technique.

Chapter 7: Conclusion, limitations and recommendation

7.1 Conclusion:

The manner in which mobile fibrous tissues are recorded during the impression-making process is critical to the complete denture's retention and stability. Increased displacement of fibrous tissue will result in poorly fitting dentures that are unstable and unretentive, producing discomfort while functioning. The purpose of relief holes in custom trays is to allow the impression material to escape while also relieving pressure on the underlying tissues below the perforation. The results of this *in vitro* study reveal that larger relief holes of 3mm, as well as an increase in the number of relief holes to 21, result in less pressure on the simulated fibrous tissue, minimising tissue displacement. As a result, strategically positioned relief holes within custom impression trays considerably reduced fibrous tissue displacement when used during the one-step impression technique, demonstrating an effective and promising approach for managing patients with "flabby ridges".

Based on the findings of this *in vitro* study, the following conclusion can be drawn:

1. The larger the diameter of the relief holes in the custom impression tray, the less displacement of maxillary fibrous tissue during a one-step secondary impression.

2. The greater the number of relief holes in the custom impression tray, the less displacement of maxillary fibrous tissue during a one-step secondary impression.

7.2 Limitations:

This study design has the limitation of the simulated tissues not being identical to the intra-oral alveolar tissues, particularly the mobile fibrous tissue. The thickness of the simulated fibrous tissue in this *in vitro* study was 3mm in the anterior ridge, 2mm in the posterior ridge, and 1mm in the palate. Because natural fibrous tissue may be associated with intra-oral undercuts and have different thicknesses, densities, and orientations of connective tissue fibres, the extent of fibrous tissue in the mouth may be overstated when compared to simulated fibrous tissue. The 3D analysis of the displacement distribution was primarily quantitative, therefore future research could add qualitative analysis. This study did not compare or evaluate the different relief spacer thicknesses utilised in 3D printed custom impression trays or other impression materials. Pressure production was not measured during the secondary impression procedure.

7.3 Recommendation:

Within the limitations of this *in vitro* study, it is recommended that the number of relief holes in a custom tray be increased from 7 to 21, and the diameter of the relief holes be increased from 1mm to 3mm when placed directly over fibrous tissue, to reduce the displacement of compromised mobile tissue during a one-step impression technique.

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Chapter 9: Appendices:

Appendix 1: Ethics approval

UNIVERSITY *of the* WESTERN CAPE

60 YEARS *of hope, action & knowledge*

15 December 2020

Dr L Brown-Steenkamp and Dr W Asia-Michaels
Prosthodontics
Faculty of Dentistry

Ethics Reference Number: BM20/10/2

Project Title: The effect of impression tray relief holes on tissue displacement: An in vitro simulation.

Approval Period: 20 November 2020 – 19 November 2023

I hereby certify that the Biomedical Science Research Ethics Committee of the University of the Western Cape approved the scientific methodology and ethics of the above mentioned research project.

Any amendments, extension or other modifications to the protocol must be submitted to the Ethics Committee for approval.

Please remember to submit a progress report annually by 30 November for the duration of the project.

Permission to conduct the study must be submitted to BMREC for record-keeping.

The Committee must be informed of any serious adverse event and/or termination of the study.

Ms Patricia Josias
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NHREC Registration Number: BMREC-130416-050

Appendix 2: Turnitin report