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ANALYSIS OF STRESS DISTRIBUTION AND COMPLETE DENTURE DISPLACEMENT ON FLABBY RIDGE WITH VARIOUS IMPRESSION TECHNIQUES AND MASTICATION LOAD DIRECTION USING FINITE ELEMENT ANALYSIS

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Abstract

Fully edentulous patient with flabby ridge are a common case in clinic, but it is still challenging for the dentist to fabricate the denture. Flabby ridge is a fibrous tissue with soft consistency that can deform under large force and result in the patient's denture unstable. In cases of flabby ridge, the window, one step double spacer, and dual tray impression techniques are advised since they affect stress distribution and denture displacement. Dentist should pay close attention to impression technique in cases of flabby ridge because they have a significant impact on the fabrication of complete denture for effective stabilization. This study aimed to analyse the stress distribution and displacement in complete denture's patient with flabby ridge used several impression techniques and applied mastication forces using Finite Element Analysis. Fabrication of three maxillary complete dentures from one fully edentulous patient with flabby ridges used three different impression techniques: window, one step double spacer and dual tray. Then, complete denture was scanned and replicated in software. Loads of 100 N axially and 119 N obliquely were then applied to simulate fully edentulous patient's maximum bite force. Von Mises stress value on alveolar ridge mucosa and denture displacement were observed in complete dentures. The lowest von mises stress and displacement values were observed in complete denture with window impression technique followed by dual tray impression technique and one step double spacer technique so the window impression technique is the most ideal impression method to fabricate denture for patient with flabby ridge.

***Keywords**: Complete Denture, Denture Displacement, Finite Element Analysis, Flabby, Stress Distribution.*

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INTRODUCTION

Full edentulous refers to the absence of any natural teeth in the mouth. In patients who are completely edentulous, oral rehabilitation using complete dentures is required to enhance mastication. According to Glossary Prosthodontics Terms, complete dentures are defined as removable dentures that may be attached to and removed by the patient and replace both the maxilla and mandible's natural teeth and associated structure [1]. Patients who are fully edentulous can resume regular social interaction with the aid of complete dentures, which help to restore mastication, phonetic, and aesthetic functions [2].

In patients who have lost their teeth for a long time, ridge resorption will occur and cause the ridges to become flat or the surrounding soft tissue becomes flabby, this condition becomes a problem of wearing complete dentures in the form of reduced retention and stability of the complete dentures. Flat ridges make the retention of denture decrease while flabby ridge cause denture stability decreased. Flabby ridges are movable soft tissues that can be found on the superficial aspects of the alveolar ridges. The masticatory load distributed on the flabby ridge causes a large stress distribution on the region, causing displacement of the denture and resulting in denture instability during functional and parafunctional movements. Large loads that occur continuously can cause damage to the mucosa and alveolar bone underneath, so that the denture base design needs to be made appropriately and the masticatory load can be distributed evenly [3].

Fully edentulous patient with flabby ridges is one of the most common encountered case in clinic, but it is still challenging for dentists in fabricating complete dentures with this condition. In order to manage these case, prosthodontic treatment might be used to minimize pressure on the flabby region [3, 4]. Therefore, it is necessary to have the proper impression technique on the flabby ridges for complete denture fabrication. Several impression techniques that can be used to overcome flabby ridges such as window, one step double spacer and dual tray impression techniques [5, 6]. These three techniques modify the impression tray to take physiological impression. The window impression technique is used to make impression on flabby region by making holes or window and using a low viscosity impression material so that it does not exert pressure while taking impression [6, 7]. One step double spacer impression technique with uses two layers of spacer in the flabby region and is done in one impression using a polyvinyl siloxane (PVS) medium body. The advantages of this technique are minimizing pressure on the flabby region and time efficiency [6]. The dual tray impression technique uses two impression trays. The first tray is made above the spacer using self-cured or light cured acrylic without covering the flabby ridge, then the second tray is made above the first tray using a thermoplastic vacuum form. The combination of the first and second impression trays is a dual tray. In this technique, impression is taking two times. The first impression is done using the first impression tray with medium body polyvinyl siloxane (PVS) material and the second impression uses a combination of the first and second impression trays and is applied through the hole of the second impression tray. The advantage of this technique is that it minimizes pressure on the flabby ridges and can control the application of the light body polyvinyl siloxane (PVS) impression material while taking impression [8].

Masticatory function will be adequately obtained with the appropriate impression technique. Measuring masticatory performance allows for an objective evaluation of masticatory function in patients wearing complete dentures. Masticatory performance, which measures food distribution under standardised test conditions, is an indicator of the all-encompassing skill needed for mastication [9, 10]. In previous studies, traditional techniques such as sieving and mixing ability method were used to evaluate masticatory performance. The use of numerous samples is required by conventional methods for evaluating mastication performance, but these methods are unable to measure the stress distribution and denture displacement, both of which have an impact on patients'

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use of dentures [11]. Therefore, other methods are used, such as finite element analysis (FEA), which is a numerical method to obtain a solution to a problem accurately by means of modeling simulation then be analyzed mathematically.

FEA has been used in many studies because of its accuracy, time efficiency, non-invasiveness, and minimizing the amount of research done directly on animals or humans. FEA can analyze stress and strain as a result of external pressure, temperature changes and other factors [3, 12]. Therefore, this study aimed to analyze the stress distribution and displacement in complete dentures against the masticatory load on flabby ridge in the oral cavity of full edentulous patients using FEA to determine the most ideal impression technique to manage cases of flabby ridges in fully edentulous patient.

MATERIALS AND METHODS

The process of model construction and FEA simulation study were carried out at the Mechanical Engineering Computational and Experimental Mechanical Systems Research Center, Universitas Sumatra Utara, using the ANSYS (ANSYS Inc, Canonsburg, PA, USA) and Space Claim software program. Research began with fabricating three maxillary complete denture in one fully edentulous patient with flabby ridges on the anterior region with window, one step double spacer and dual tray impression technique then scanning using an intraoral scanner on the denture (Figure 1) and maxillary ridge mucosa (Figure 2). Furthermore, three virtual models of complete dentures from three impression techniques were made and accompanied by a virtual model of the maxillary ridge mucosa where the virtual denture model was placed right above the maxillary ridge model using Space Claim software. (Figure 3 and 4).

Figure 1: 3D model of maxillary complete denture

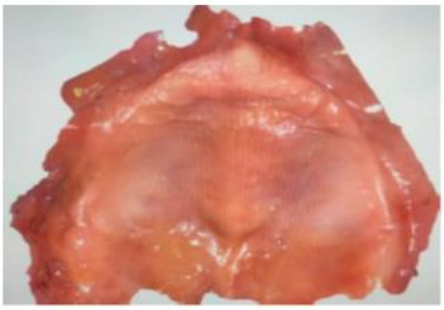

Figure 2: 3D model of maxillary alveolar ridge

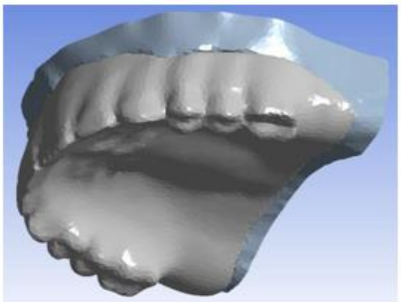

Figure 3: Model design on SpaceClaim

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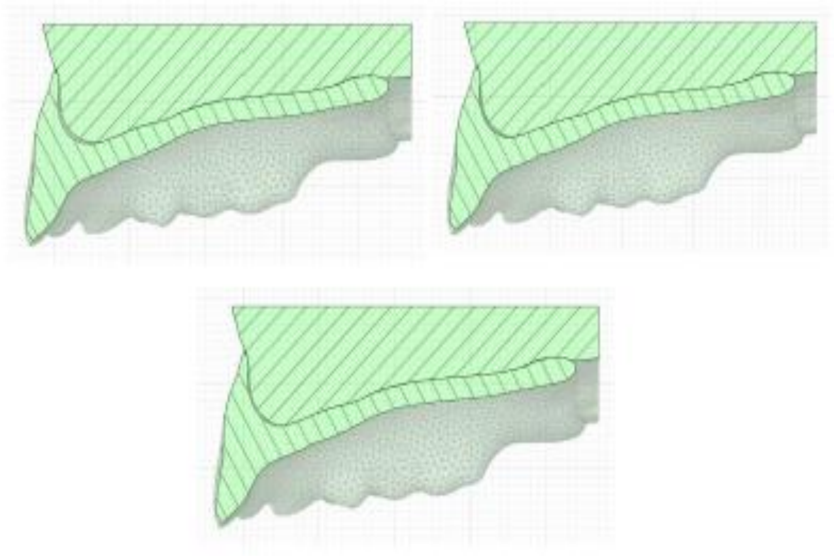

Figure 4: Intaglio surfaces of complete denture with alveolar ridge mucosa from cross sectional view (a) window (b) one step double spacer (c) dual tray on SpaceClaim

The FEA study was conducted in two phases. The first phase is the complete denture and maxillary alveolar ridge mucosa model design with Space Claim software. The second phase is simulation and data analysis with Ansys software. Additionally, complete denture and maxillary alveolar ridge 3D model designs were imported into Ansys simulation software for analysis. The stages of simulation and data analysis in Ansys consist of data engineering, geometry, model, setup, solution. Engineering data is the stage of inputting the mechanical properties of the denture and alveolar mucosa. The mechanical properties of the denture and alveolar ridge mucosa were input. The mechanical properties are denture's young modulus (E) (heat cured acrylic) = 1.960 MPa, denture's poisson ratio (v) = 0.3; alveolar ridge mucosa's young modulus (E) = 0.021, alveolar ridge mucosa's poisson ratio (v) = 0.37; alveolar ridge mucosa's thickness = 1.5 mm, flabby ridge thickness = 2.5 mm and the coefficient of friction between the ridge mucosa and denture = 0.16. Determination of the boundary condition is under the alveolar ridge mucosa (Figure 5).

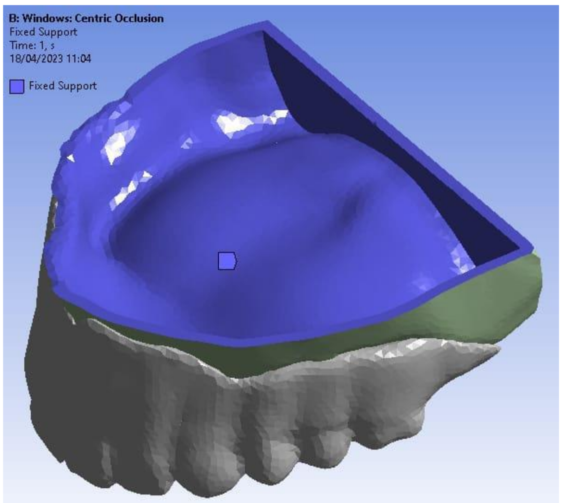

Figure 5: Boundary condition

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Geometry is the stage of inputting the model to be analyzed. Modeling is the stage of creating a mesh in the model by determining the number of elements and nodes which can be done automatically in the Ansys software. The fabrication of the mesh which includes alveolar ridge mucosa and denture were divided into 491.218 elements and 762.727 nodes (Figure 6). Maximum and minimum stress values are evaluated via colorimeter graphs.

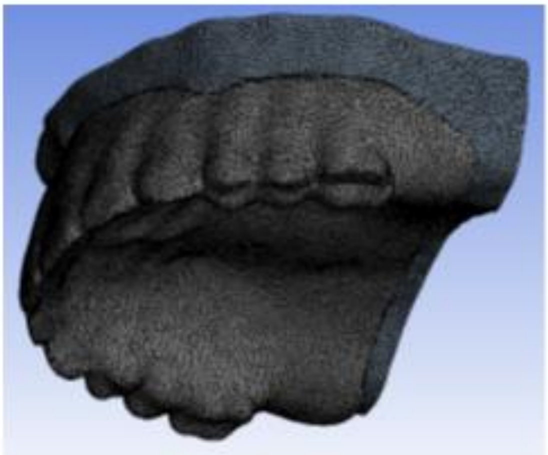

Figure 6: 3D model of complete denture meshing

Then proceed with the setup stage, namely inputting the load parameters on the model. At the setup stage, each model is assumed to be uniform, homogeneous and elastic under the applied load. The support is assumed to be elastic and the load is given to the first premolar, second premolar and first molar from the 3D denture model with a load of 100 N axial (0° angle/vertical load) to represent the masticatory load during centric occlusion (Figure 7) and 119 N obliquely (33° angle / lateral load) to represent the masticatory load during lateral movement so that the simulation is close to the real situation in the oral cavity (Figure 8). In the results stage, the results obtained are in the form of von Mises color contour plots on the surface of the 3D model after application.

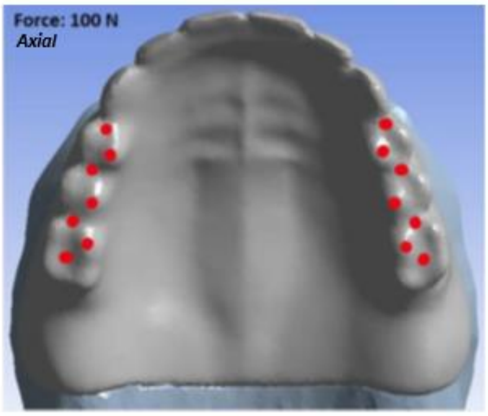

Figure 7: Load point on axial direction

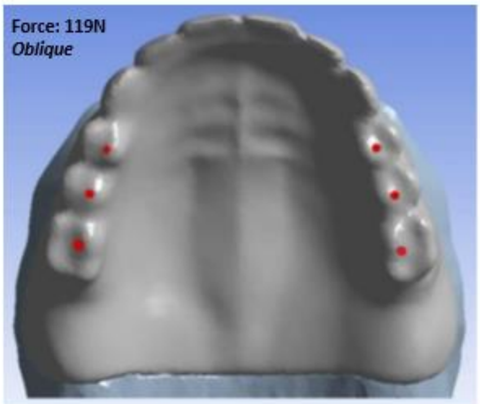

Figure 8: Load point on oblique direction

Three dimensional models of complete dentures and maxillary alveolar ridge mucosa were designed with software to optimize the design. After the numerical input was made and the load was simulated, the stress distribution and denture displacement were assessed. The post processing equivalent (von Misses) stress results were observed based on the color pattern. The stress distribution in the FEA can be seen more clearly than in vivo study. The Ansys software makes it

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possible to analyze stress distribution and deformation based on the discrete principle when the model is loaded in a static state. The advantage of this FEA is that the sample is minimal, time efficient and can be replicated of the same size and shape by other researchers.

RESULT

Von Mises contour plot colour distribution, a parameter that depicts the distribution of stress and displacement, were used to determine the stress distribution and displacement of the denture. The color contour plots that appear were red, orange, yellow, green and blue. The color determines the level of force and the displacement that occured, where the red color represents as the maximum value while the blue color indicate the minimum value.

The stress concentration in the maxillary alveolar ridge mucosa with the axial direction on the alveolar ridge mucosa from the window, one step double spacer and dual tray impression technique was seen more clearly in the premolar region and the largest stress value on the flabby region was found in the canine region (Figure 9). The maximum force value was shown in table 1.

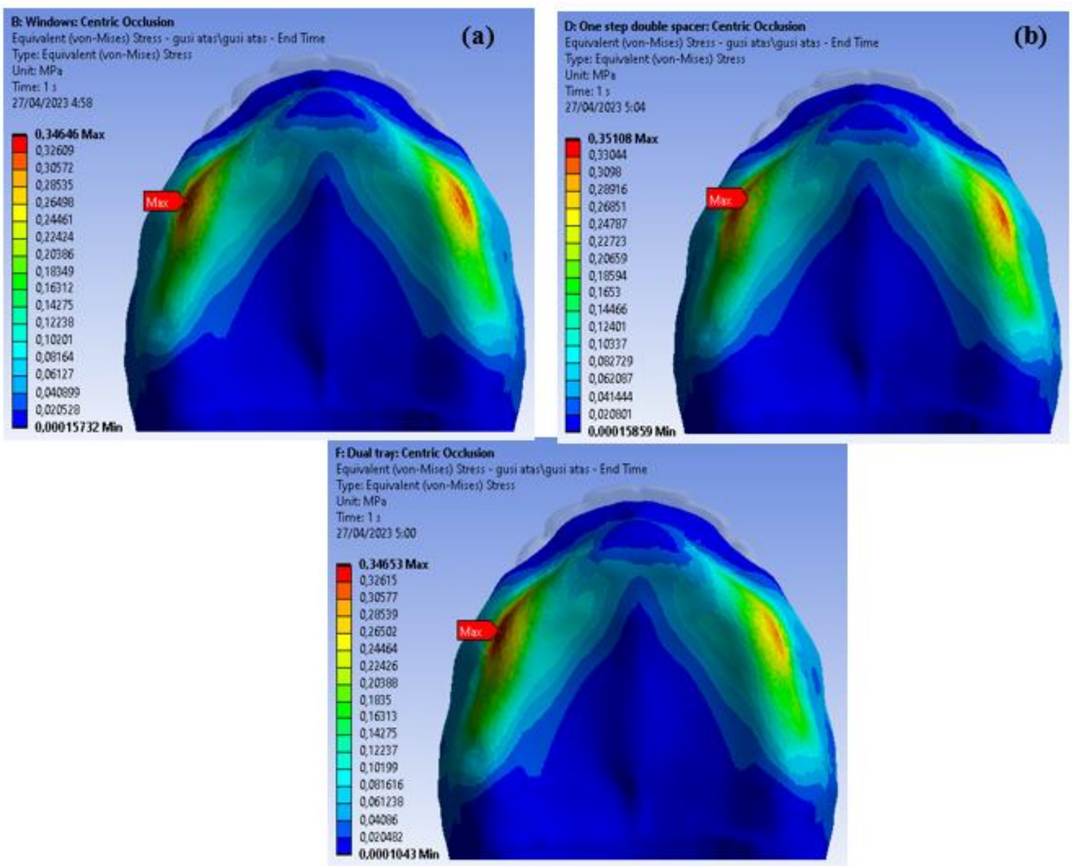

Figure 9: Stress distribution on maxillary alveolar ridge mucosa while load given from axial direction with (a) window (b) one step double spacer (c) dual tray impression technique

Table 1: Maximum force value on maxillary alveolar ridge mucosa while load given from axial direction

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Impression technique	Maximum force value on maxillary alveolar ridge mucosa (kPa)	Maximum force value on flabby ridge (kPa)
Window	346.46 (premolar region)	183.49 (caninus region)
One step double spacer	351.08 (premolar region)	185.94 (caninus region)
Dual tray	346.53 (premolar region)	183.5 (caninus region)

Stress concentration on the maxillary ridge mucosa with the oblique direction on the alveolar ridge mucosa from the window, one step double spacer and dual tray impression technique was seen more clearly in the premolar region and the highest stress value in the flabby region is found in the canine region. The maximum force value is shown in table 2.

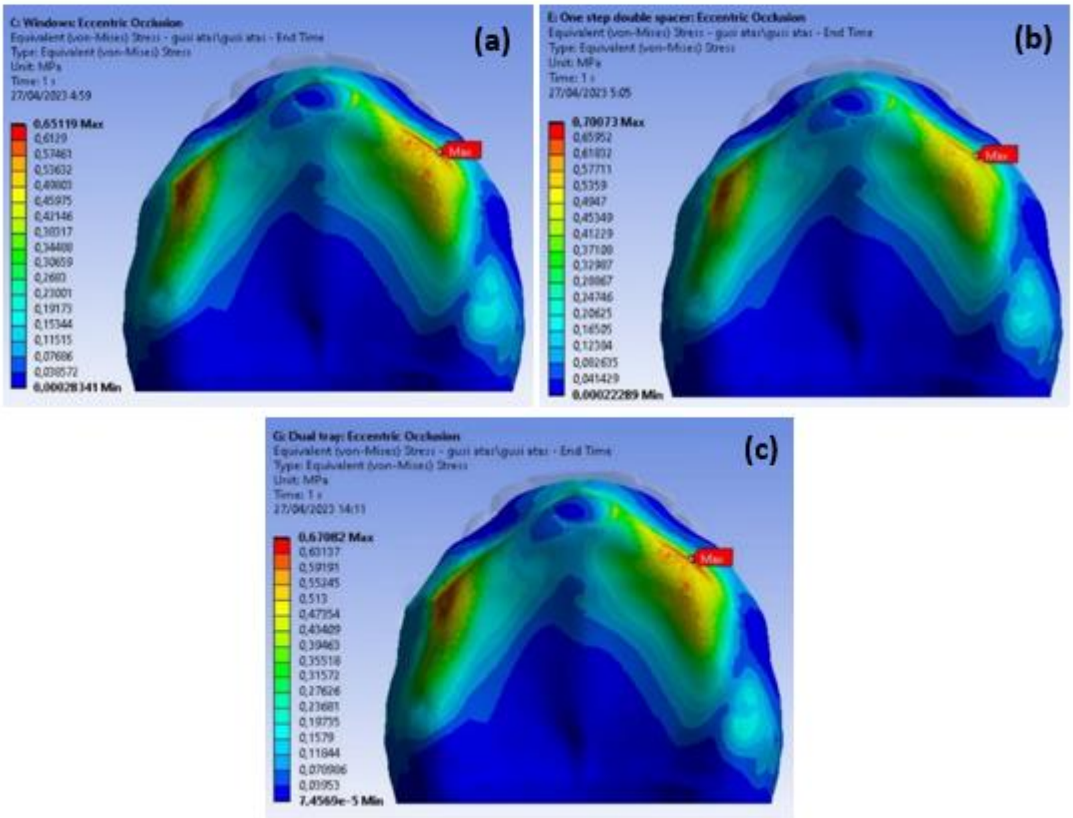

Figure 10: Stress distribution on maxillary alveolar ridge mucosa while load given from oblique direction with a) window (b) one step double spacer (c) dual tray impression technique

Table 2: Maximum force value on maxillary alveolar ridge mucosa while load given from oblique direction

Impression technique	Maximum force value on maxillary alveolar ridge mucosa (kPa)	Maximum force value on flabby ridge (kPa)
Window	651.19 (premolar region)	344.88 (caninus region)
One step double spacer	700.73 (premolar region)	371 (caninus region
Dual tray	670.82 (premolar region)	355.18 (caninus region)

Mucosa deformation below the denture from the results of window, one step double spacer and dual tray impression when given an axial load of 100 N on the alveolar ridge mucosa under the maxillary

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denture followed by analysis using Ansys software where the value on the mucosa shows a large displacement of the denture (Figure 10). The maximum displacement value of the denture is in the crest ridge of the central incisor region (Table 3).

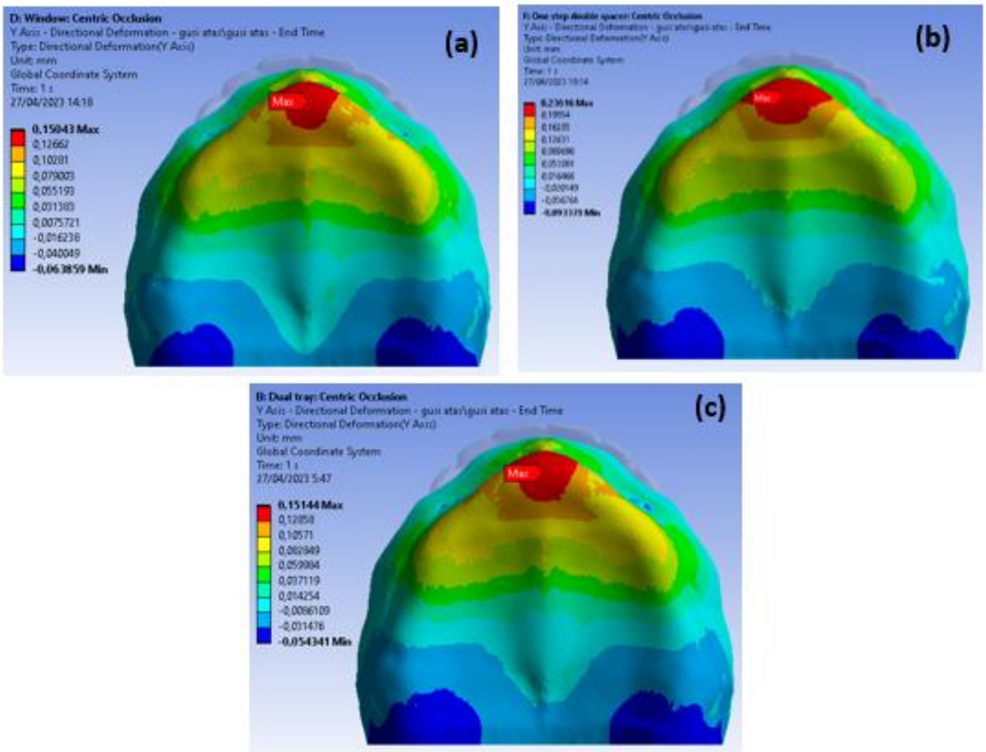

Figure 10: Deformation on maxillary alveolar ridge mucosa when given load from axial direction with (a) window (b) one step double spacer (c) dual tray impression technique

Table 3: Maximum displacement value of denture while given axial load

Impression technique	Maximum value (mm)
Window	0.15043
One step double spacer	0.23616
Dual tray	0.15144

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Description of the deformation of the mucosa under the denture from the results of window impression, one step double spacer and dual tray when given an oblique load of 119 N on the ridge mucosa under the maxillary denture followed by analysis using Ansys software where the deformation value on the mucosa shows a large displacement of dentures. The maximum deformation value in the maxillary ridge mucosa is on the left lateral incisor crest ridge. On the ridge mucosa from the window impression technique, the maximum deformation value is 0.15425 mm. On the ridge mucosa from the one step double spacer impression technique, the maximum deformation value is 0.29802 mm (Figure 11). On the ridge mucosa from the window impression technique, the maximum deformation value is 0.15785 mm (Table 4).

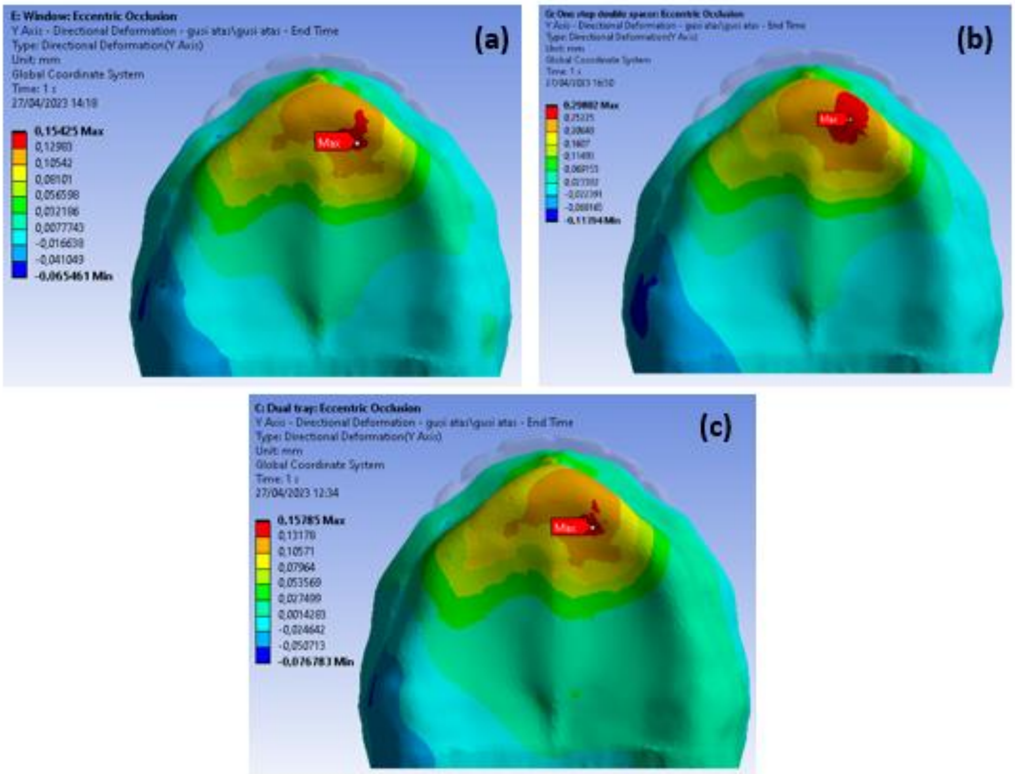

Figure 11: Deformation on maxillary alveolar ridge mucosa when given load from axial direction with (a) window (b) one step double spacer (c) dual tray impression technique

Table 4: Maximum displacement value of denture while given axial load

Impression Technique	Maximum value (mm)
Window	0.15425
One step double spacer	0.29802
Dual tray	0.15785

Figure 12 shows the difference in the stress distribution of the ridge mucosa under the denture from window, one step double spacer and dual tray impression. The maximum stress distribution value is found on the alveolar ridge mucosa under the denture from of one step double spacer impression followed by dual tray impression and window impression.

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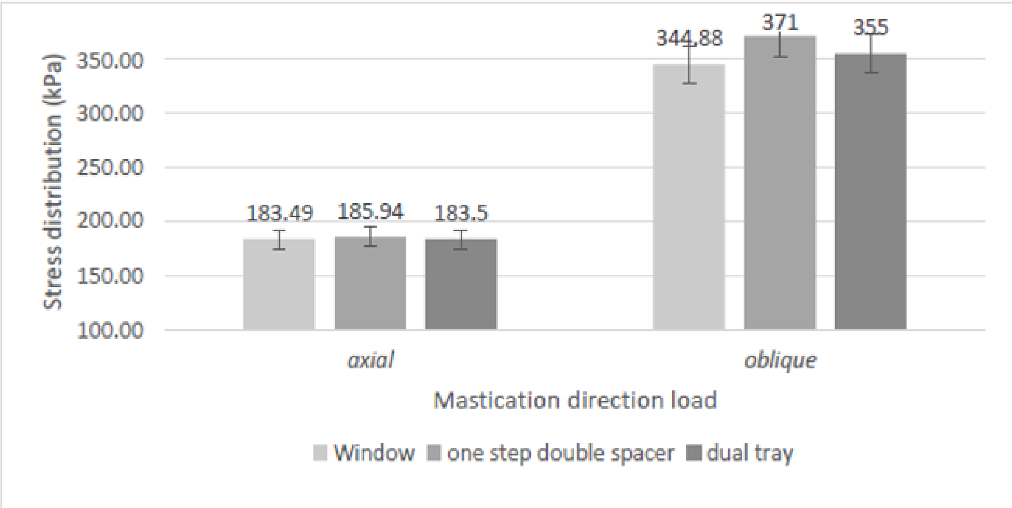

Figure 12: Maximum force value on alveolar ridge mucosa below denture with different direction load and impression technique

Figure 13 shows the difference denture displacement on denture from window, one step double spacer and dual tray impression

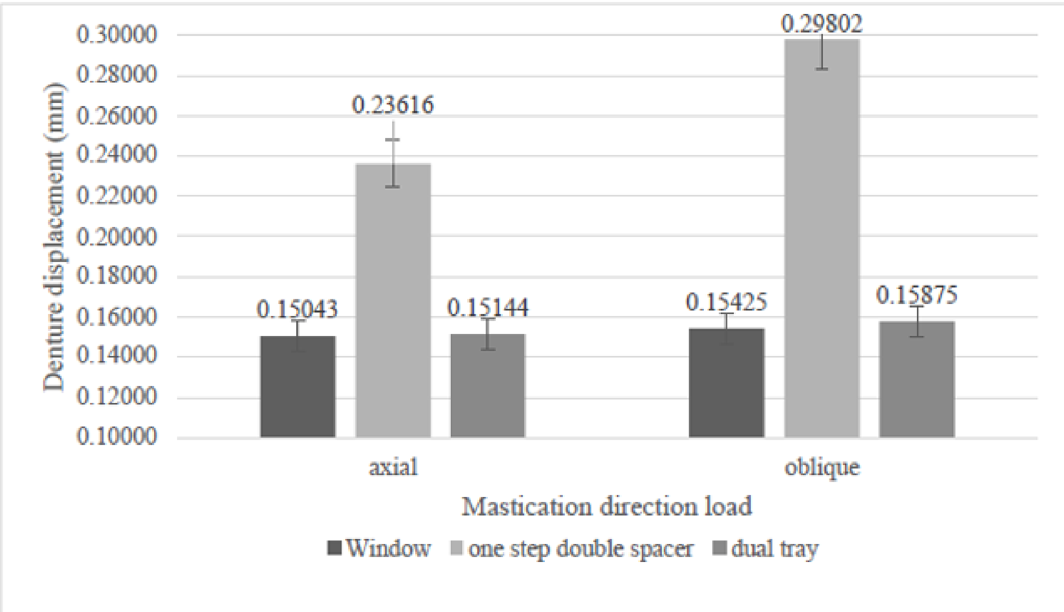

Figure 13: Denture displacement value on alveolar ridge mucosa below denture with different direction load and impression technique

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DISCUSSION

An in silico study with simulations using FEA has been widely used in the field of dentistry to analyze stress distribution on the mucosa and denture, to observe response generated from the mucosa and the fracture resistance of natural teeth and dentures when given a certain amount of masticatory load [5,12,13,14]. This simulation represents a simplification of clinical experimental trials. In this study, a maxillary complete denture model from a fully edentulous patient with a flabby ridge on the anterior region was used and the design of the 3D denture model and maxillary alveolar ridge mucosa were made to replicate the denture and maxillary alveolar ridge mucosa by inputting the mechanical properties of modulus of elasticity, poisson ratio, thickness of the mucosa, and coefficient of friction so that the simulation replicate the real situation in the oral cavity. This study assumed that the artificial teeth and denture base have the same mechanical properties and there are no internal defects in the denture. In this study, a masticatory load of 100 N was applied in the axial direction as maximum force of fully denture patient and 119 N was applied in the oblique direction because this value is the resultant load of 100 N at an angle of 33° which corresponds to the angle of the anatomical cusp on the artificial teeth.

Three designs of denture models and one model of maxillary ridge mucosa were made to simulate the stress distribution in region that receive force in the occlusal loading area: first premolar, second premolar and first molar. This was based on Mankani's study which stated a person performs centric and eccentric occlusion, the mastication load will be at that point [5]. Finite element analysis was used after being given a simulation of external pressure in the form of compressive forces that mimic masticatory load in the mouth to produce equivalent von mises stress and total deformation. Simulation of maxillary complete dentures when given a masticatory load of 100 N axially at the contact point of centric occlusion: the central fossa and the cusp tip of the first premolar, second premolar and first molar. The masticatory load was directed to artificial teeth of the denture and transfer to the denture base which has contact with the periodontal tissues [5,15].

The value of stress distribution was greatest in the posterior region of alveolar ridge, because the load was applied to the posterior region while determining the point of mastication. Stress distribution on flabby region was the lowest, because in the impression taking techniques the tray has been modified to minimize pressure on the flabby region. The value of the stress distribution was greater in the one step double spacer impression technique followed by the dual tray and window impression technique because selective pressure impression technique provides greater pressure [16]. At the time of taking impression, there was still pressure on the flabby region, according to the research of Shin, et al (2019) so that the dentures produced by the one step double spacer impression technique still have tight contact with the mucosa which results in a greater stress distribution in that area, larger than window and dual tray impression techniques [7].

The maximum displacement value of the denture in both the axial and oblique directions was found on the flabby region because when there was masticatory load on the flabby ridge, where the flabby ridge has a greater soft tissue thickness and can experience movement compared to the non-flabby ridge, the ridge in the flabby region will experience a bounce effect that can result in denture displacement and discomfort [17, 18]. The maximum displacement value of the denture was centered on the central incisor region because when a load is given in an axial direction or the denture is in a centric occlusion position, the displacement will be centered on the middle region of the flabby ridge [4, 6, 7]. The maximum displacement value with window impression was almost the same as the results of the research by Shin et al (2019), who examined the magnitude of the displacement of the flabby tissue when several impression techniques were carried out where the window impression technique using polivinysiloxane obtained a value of 0.1 mm whereas it was contrary to the results double spacer impression technique that is equal to 0.5 mm. This may be due

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to the large difference in impression pressure exerted by the operator while taking physiological impression [7].

Mucosa deformation value differences indicates the denture displacement, supported by the research of Gomaa, et al (2017), who conducted a study by comparing the displacement of the maxillary flabby ridges with different impression techniques. The study showed that selective pressure impression techniques such as the one step double spacer impression technique provides a greater displacement compared to mucostatic impression techniques such as windows and dual trays [19]. When the oblique load was applied, the displacement that occured in the flabby ridge mucosa occured more on the working side than balancing side so that the maximum displacement value of the denture was in the left lateral incisor region. This was accordance with Langevin's study (2021), which stated that when the same amount of pressure is applied to a soft and hard material, the soft material will have greater deformation than the hard material, where the flabby ridge is fibrous tissue with the same consistency [18].

Denture displacement in the direction of oblique masticatory load compared to the axial mastication load with the greatest displacement found in one step double spacer impression technique followed by dual tray and window. However, the displacement of the dentures in the window technique with the axial load direction being greater than the oblique load direction with a difference of only 0.00281 mm which has no clinical implications. The difference in denture displacement values on flabby tissue with the window impression technique, one step double spacer and dual tray is under 2 mm and only slightly different. Based on the research of Antoneli, et al (2019), a deformation value of the flabby ridge mucosa that is more than 2 mm is a value that indicates the flabby tissue was experiencing large movement and displacement so it was difficult to handle, while a deformation value that less than 2 mm was a value that was experiencing movement and displacements that are slight and still clinically acceptable [20]. This showed that the three impression techniques can still be used in manage flabby cases where each impression technique has its advantages and disadvantages. The window impression technique produces minimal deformation of the flabby ridge but has difficulty in controlling the impression material when taking impression due to the open part of the impression tray on the flabby ridge. The one step double spacer impression technique has advantages in time efficiency when impression and a more simple impression tray design. Dual tray impression technique has the advantage of minimal denture displacement on flabby tissue but more complicated in fabricate the impression tray [4, 6, 8].

Several different impression techniques have been recommended by researchers which aim to minimize the deformation of the flabby tissue during impression. Impression techniques that can be used to treat flabby cases are mucostatic impression and selective pressure techniques. The selective pressure impression technique used in this study is the one step double spacer impression technique and the mucostatic impression technique used in this study is the window and dual tray impression technique. In this study, the one step double spacer impression technique produce larger displacement than other impression techniques. However, this one step double spacer impression technique also has the advantage of time efficiency because impression is only done in one stage and the design of the impression tray is simpler [4, 21].

Denture displacement on flabby ridge conditions with window impression technique, one step double spacer and dual tray in the direction of oblique mastication load with 119 N load showed that the denture from one step double spacer impression experience greater displacement than the dual tray and window. This showed that the impression technique affects the displacement of the denture where the one step double spacer impression technique exerts greater pressure so that the alveolar ridge mucosa experiences greater deformation than the window and dual tray impression techniques. This was supported by the research of Shin et al., which stated that modifications of

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impression tray and the amount of impression pressure affect denture displacement. Study by shin, et al (2019) and Matoo, et al (2022) that comparing the size of the displacement on the flabby ridge after impression and it was found that the impression tray with an open design on the flabby ridge had a smaller displacement compared to the close design on the flabby ridge [7,22].

In this study, light body polyvinylsiloxane impression material was used in window and dual tray impression technique while medium body polyvinylsiloxane impression material was used in one step double spacer impression technique and a greater displacement value was obtained in the one step double spacer impression technique. Light body polyvinylsiloxane has a low viscosity and high flow ability while medium body polyvinylsiloxane has a higher viscosity and lower flow ability than the light body polyvinylsiloxane. Matoo, et al (2022) stated that the most ideal impression materials for impression flabby ridges were plaster of paris and light body polyvinylsiloxane because they have a consistency similar to water which is the only material that does not result in deformation while the polyvinylsiloxane medium body impression material can still cause deformation of the flabby ridge [22].

The limitation of this study was many intersect faces from the scanning results during the modeling process, so it takes a long time to remove the intersect parts using Space Claim software before proceeding to the simulation process using Ansys software. This occurred because repeated scanning process on the same region from different directions, which caused overlapping surfaces.

CONCLUSION

Based on this study, it could be concluded that the window impression technique was the most ideal technique for flabby ridges cases in fully edentulous patients due to its advantages in the design of impression tray where there is a hole in the flabby region so while taking impression, the impression material flowing in the flabby region does not provide compression, the shape of the flabby ridge does not deform and the impression material light body polyvinyl siloxane, has a consistency that cannot cause mucosa deformation.

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