Stress distribution evaluation of complete denture with soft denture liners in knife-edge alveolar ridge using finite element analysis

Tiroi Paulina, Ariyani, Ismet Danial Nasution
Specialist Program in Prosthodontics
Faculty of Dentistry, Universitas Sumatera Utara
Medan, Indonesia
Corresponding author: **Ismet Danial Nasution,** e-mail: **ismetdanial@yahoo.com**

ABSTRACT
Edentulous induces the function of the stomatognathic system particularly masticatory performance. The consequence that occurs in complete edentulous is the resorption of residual ridge and can alter the morphology of alveolar bone gradually from well-rounded to knife-edge ridge form. Excessive occlusal load absorbed by the knife-edge alveolar ridge when the denture is exposed to masticatory loads enhances ridge resorption and more complex treatments are needed in manufacturing complete dentures (CD). Soft denture liners (SDL) overcome CD problems with knife-edge ridges by utilizing the cushioning effect by distributing the load evenly to the alveolar ridge. The most popular method used today to evaluate the stress distribution at the alveolar ridge is *finite element analysis* (FEA) because it presents information in both qualitative and quantitative forms. This study is aimed to evaluate the differences in stress distribution received by knife-edge ridges in CD with SDL. Denture base applied with acrylic soft denture liner (ASDL) and silicone soft denture liner (SSDL). It is concluded that ASDL provides a better stress distribution than SSDL because of its viscoelasticity, while SSDL is superior in terms of durability.
Keywords: complete denture, knife-edge ridge, stress distribution, soft denture liner, finite element analysis

INTRODUCTION

Stomatognathism is a system consisting of dynamic structures (masticatory, supra and infrahyoid muscles and tongue, lips and cheek muscles) and static structures (mandible, maxilla, dental arches, TMJs and hyoid bone) that perform together to control stomatognathic functions especially mastication performance. The efficiency of mastication performance requires a balance between dynamic and static structures of stomatognathic system. Loss of teeth can cause changes in the structure of the stomatognathic system.[1]

An unavoidable consequences of tooth loss, affecting the morphology of ridge if occurs rapidly and continually.[2] Remodeling activity after tooth extraction occurs especially in the crestal residual ridge area, not only reducing bone height but also creating 3-D residual ridge form. Residual alveolar crest crest flattens if bone resorption is greater. When ridge resorption is particularly active at the buccal and or lingual areas, the residual alveolar bone may become a knife-edge shape.[3]

The most common treatment for edentulousness is still complete denture (CD).[4] CD treatment in knife-edge ridge is more complex.[5] In prosthetic area, bone is considered to be the base which provides support for dentures while in the physiological area, it is an area where forces created while biting and chewing foods are transmitted.[6] Discomfort is the most problem to denture patients with knife-edge ridge.[7]

Relining CD with SDL is treatment of choice for knife-edge ridge; SDL properties is cushion effect can minimizing denture bearing area's load by distributing the masticatory forces transmitted to the underlying tissue to prevent severed bone resorption.[7] Using the best SDL material still arouse some discussion. The commonly SDL used nowadays is plasticized acrylic and silicone [8] Acrylic soft denture liner (ASDL) demonstrate viscoelastic behaviour, distributing occlusal load transmitted to the underlying tissue, meanwhile silicone soft denture liner (SSDL) demonstrate elastic behaviour, preserve their shape despite the applied pressure upon them.[9] SDL is a material that can be used for residual ridge resorption cases.[8] Several methodologies have been used to help assess stress distribution in dentures wearers such as photoelastic models, analytical mathematical models, use of strain gauges and finite element analysis (FEA). First three methods provides only provide limited data while FEA is capable of providing detailed quantitative and qualitative data.[10]

The FEA provide noninvasive technology that provide qualitative and quantitative information of biomechanical characteristic of dental prosthesis and supporting structures for assessing occlusal load to the underlying tissue.[11,12] This method expected to evaluate stress distribution of CD with SDL in knife-edge ridge.

LITERATURE STUDIES

Edentulous

Full edentulous has a high prevalence globally and affects 0.1–14.5% of people under the age of 50 and 2.1–32.3% of the elderly worldwide.[13,14]

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Progressive residual alveolar ridge remodeling will occurs rapidly especially in the first year after tooth extraction on edentulous patient in the mandible than maxilla, with the mean rate of resorption varying depending on the individual.[5] If bone resorption is emphasized at the crest of the residual alveolar bone, it becomes flattened. When the resorption is more active at the buccal and/or lingual areas, the residual alveolar bone tends to become thin and sharp or known as a knife-edge ridge,[3] where the mucosa is squeezed between the sharp ridge and the denture resulting patient's pain and discomfort.[15]

The masticatory force of the edentulus is only ¼ of that normal mastication. The CD wearers will change in mastication associated with increased mastication cycles, longer mastication times and decreased mastication averages. To overcome this, the prosthetic treatment of choice for a long time has been CD with the aim of rehabilitating edentulous patients in order to improve comfort, aesthetics, occlusal and facial support, masticatory function and pronunciation.[13]

Knife-edge ridge

Knife-edge ridge is a localized phenomenon that occurs in the buccal or lingual area of residual alveolar bone due to continuous osteoclast activity.[3]

Classification of residual ridge resorption according to Atwood (Fig.1): order 1 is pre-extraction, order 2 is post extraction, order 3 is high, well-rounded, order 4 is knife-edged, order 5 is low, well rounded, and order 6 is depressed[16,17]

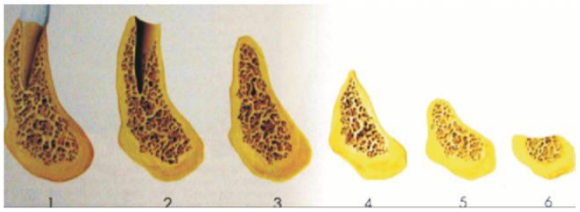

Figure 1 I (pre-extraction), II (post extraction), III (high, well-rounded), IV (knife-edged), V (low, well rounded), VI (depressed).[17]

Knife-edge ridges require surgical treatment but if the patient's condition is not possible, SDL can be applied to improved masticatory function of the denture.[14]

Soft denture liner

Soft denture liner (SDL) is a material that form a cushioning layer between the denture base and the underlying mucosa;[7] SDL is indicated in knife-edge ridges cases, large ridge resorption, severe bony undercuts, chronic soft tissue inflammation and relining immediate dentures.[9,18] The advantages of using SDL is its flexibility and resilience, provide a *cushion effect* that can absorb stress and function as a *shock absorber*[5,14] as well as provide *chewing-wing satisfaction*.[19]

Based on term usage, SDL is divided into short-term SDL and long-term SDL. Short-term SDL is known as tissue conditioner while long-term SDL is also called semi-permanent reline materials. Based on the composition, long-term SDL is divided into acrylic soft denture liner (ASDL) and silicon soft denture liner (SSDL) which are available in auto-polymerized and heat-polymerized forms. ASDL auto-polymerized include *Permasoft, Flexacryl* while heat-polymerized include *EverSoft, Super-Soft*. Auto-polymerized SSDL include *Mollosil Plus*, *Tokuyama Soft* while heat-polymerized include *Molloplast B, Permaflex Luci-Soft*.[12,20]

The ASDL has material properties of viscoelastic behavior while SSDL shows material properties of elastic behavior. Viscoelasticity is a material property that provides both viscous and elastic properties, in other words when the applied pressure is removed, there will be elastic deformation (back to its original shape) which will increase the contact surface with the denture so that the stress distribution is more even and if the pressure is not removed for a long time, there will be plastic deformation (changes in shape).[21,22] ASDL has good adhesion to the denture base but over time due to plasticizers (components that make acrylic softer) easily dissolve, SDL will harden and lose its *cushion effect* while SSDL will last for a longer time.[7] SDL thickness also plays an important role in stress distribution, especially in patients with thin mucosal conditions.[23]

Widely used method to evaluate the stress distribution is FEA because it can simulate the FE model as closely as possible to the original condition.[11] FEA is able to provide quantitative data on all area so it's needed in dentistry. The advantage of FEA is its ability to analyze various forms, loads, and supporting conditions so that it allows the application of forces or stresses at various points in various directions.[10]

Finite element analysis

Finite element analysis (FEA) is a non-invasive technology that produces qualitative and quantitative information on the biomechanical characteristics of dental prostheses and their supporting structures that can analyze masticatory loads under denture bases.[11,12]

Application of FEA by constructing a finite element (FE) model(s), by recording specific material properties, loads and special conditions to get an

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accurate simulation. With the development of digital imaging systems, FEA can be performed on the human body through the transfer of geometry data and bone properties in 3-D form from cone beam computerized tomography (CBCT) or magnetic resonance imaging (MRI) to the FE model so that the model is anatomically accurate and the simulation carried out can be conditioned as the original.[11]

DISCUSSION

The SDL is one of the solutions to overcome complaints about discomfort, instability and lack of retention on CD wearers. A recent study was conducted to compare the effect of using CD before and after the addition of SDL on mastication performance and the results showed a significant increase in mastication performance after the addition of SDL. SDL is effective in increasing stress distribution for CD wearers with knife-edge ridges.[5] Based on literature, the use of SDL can reduce the occlusal load received by the alveolar ridge so that will decrease the resorption due to the cushioning effect produced by the SDL.[15]

In 2016, Singh et al stated that the use of SDL on knife-edge ridges can balance the occlusal load received by the supporting tissues under the denture base.[24] In theory, ideally SDL should have elastic behavior to transmit the energy needed in the mastication system and have viscous properties to distribute the force, absorb energy and avoid pain during mastication, providing cushioning effect to prevent the transmission of load to the denture bearing area.[25] Kreve et al stated that viscoelastic properties played a role in stress distribution and absorption during clinical function.[26]

Shrivastava et al based on their research showed that ASDL have a higher average stress relaxation than SSDL. Clinically, almost all patients who were research subjects were satisfied with the use of ASDL rather than SSDL, possibly due to the viscoelastic behavior of ASDL.[27,28] The same thing was also stated by Salloum, quoted from Taguchi et al, in his research which stated that ASDL showed a higher average stress relaxation than SSDL and is related to the viscoelastic properties demonstrated by ASDL while SSDL shows more elastic properties.[29] That statement is also supported by Murata et al, who stated that the clinical success of an SDL material depends on its viscoelasticity and durability. Viscoelasticity greatly affects the *cushion ef-fect* of SDLwhich is owned by ASDL while SSDL is superior in terms of durability observed over a 3-year period.[28]

On the other hand, Husein stated that the use of SSDL showed a better stress distribution than ASDL and this was also confirmed by Radi et al who stated that the stress distribution analyzed using FEA showed a stress distribution decrease up to 73% when ASDL was replaced by SSDL.[30] A clinical study conducted by Abdelnabi et al in 2020 also concluded that the addition of SSDL to the CD base provided better masticatory performance than ASDL after 3 months of use, indicating that SSDL has better long-term results.[31]

Differences of opinion in some literature may be due to the *cushion effect* of SDL related to length of use, the short time period of the study and the material behavior of SDL.

It is concluded that the stress distribution of CD in knife-edge ridge with the addition of ASDL is better than SSDL when evaluated using FEA because of its greater viscoelasticity while SSDL is superior in terms of durability.

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