Biomechanical Aspects of the Oral Mucosa in Clinical Implications: Scoping Review

Winny Yohana[1]*, Julianisa Safira[1], Moch Rodian [1]

1. Department of Oral Biology, Faculty of Dentistry, Padjadjaran University, Indonesia.

Abstract

Biomechanics of oral mucosa is the changing shape and properties of the mucosal tissue when given a force or pressure. Clinical implications of oral mucosal biomechanics in removable denture treatment have clinical relevance with static, dynamic, volumetric, and interactive responses. These responses are related to clinical factors used as benchmarks in designing and planning removable dentures. This study aimed to analyze the biomechanical aspects of the oral mucosa in planning removable dentures.

Articles searches referred to Preferred Reporting Items for Systematic Reviews and Meta-analyses extension for Scoping Reviews (PRISMA-ScR), through PubMed, Science Direct, and Google scholar with the publication 2011-2021. Articles are filtered for eligibility, and screening by checking for duplication, reading titles, abstracts, and full text.

A total of 14 articles were included in this scoping review, consisting of experimental studies (n=8) and clinical studies (n=6). Based on the results of the review, the suggested biomechanical response values for denture planning are as follows, static response with elastic modulus parameter (2.5-54.8 MPa), dynamic response with viscoelasticity indicator (8.0 ± 3.0) × 10- 5 GPa, the Coefficient of Friction as an interactive response is 0.213 for the hydrated mucosa and 0.40 for the case of xerostomia mucosa, volumetric response with the Poisson ratio parameter is 0.402.

Considerate the biomechanics of oral mucosa used in selecting compatible denture materials by allowing for the values of elastic modulus, viscoelasticity, Poisson's ratio, and coefficient of friction.

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Introduction

Biomechanics of oral mucosa is the changing shape and properties of the mucosal tissue when given a force or pressure.[1] *Considerate* the biomechanics of the oral mucosa in prosthodontics is used in selecting removable denture base materials with biocompatible properties for mucosal tissues. It is also valuable for developing complementary denture materials to mucosal tissues.[2] Oral mucosal biomechanics can also help identify biological determinants influencing mucosal response in planning better prosthodontic treatment.[2,3] Thus, it can prevent trauma and arrange for instructions to patients regarding the time needed for tissue recovery.[4,5] This information is also used to identify areas of use for denture liners as a coating material that will protect the mucosal tissue.[2]

Corresponding author:
Winny Yohana,
Department of Oral Biology, Faculty of Dentistry,
Padjadjaran University, Indonesia.
E-Mail: winny.yohana@fkg.unpad.ac.id

Considerate oral mucosal biomechanics has clinical implications for interpreting, analyzing, and predicting various biomechanical aspects of mucosal response. Thus it is expected to optimize treatment results with minimal side effects for patients. [4] The clinical implications of oral mucosal biomechanics in the treatment of removable dentures were used as biological and mechanical considerations.[3,4] Biomechanical considerations of the oral mucosa on removable dentures are obtained from several responses that have clinical relevance; static response, dynamic response, volumetric response, and interactive response.[3–5,7] These four responses are assessment parameters in planning removable dentures and related to clinical factors used as benchmarks in designing and planning removable denture, specifically pressure-pain threshold and relaxation or mucosal tissue recovery time.[4]

Based on Global Burden of Disease data, the incidence of severe tooth loss in the global population in 2010 was 205 cases per 100,000 people/year.[8] The presentation of partial tooth loss or partial edentulism has increased. The American College of Prosthodontics estimates that in the next 15 years, the percentage of the population with partial edentulism will increase to 200 million people in the United States.[9] According to Riskesdas 2018, the prevalence of partial edentulism reaches 51.4%, and the majority of full edentulism comes to 1.3%, so it is predicted that the demand for removable denture care will also increase. Information regarding the biomechanics of the oral mucosa is needed as a consideration in planning removable dentures.[10] Based on a literature search conducted on the Pubmed, Science Direct, and Google Scholars databases, it is known that there are several articles discussing the biomechanics of oral mucosa in the form of literature reviews and research articles. However, so far, no reports have comprehensively addressed the oral mucosa's biomechanical aspects in clinical implications for removable denture treatment. So the authors interested in conducting a study on analyze the biomechanical aspects of the oral mucosa in terms of clinical implications, especially in the planning of removable dentures.

Materials and methods

This article is a scoping review prepared according to the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-analyses extension for Scoping Reviews) guidelines.[11–13] Searching in this scoping review article uses "Boolean Operators", which is an article search method by combining keywords with "OR" for word equations or with "AND" for word combinations.[11–13] The search strategy for this article uses a combination of keywords in advanced search PubMed, ScienceDirect, and Google Scholar, namely ((Biomechanics) OR (Mechanical Properties) AND (Oral Mucosa))". At the search stage, use filters: Full text, in the last ten years, English. A manual search was carried out for additional articles by searching the list of references in the selected articles to be reviewed to find other related studies.

The inclusion criteria used were articles that discussed oral mucosal biomechanics with research designs of experimental studies, clinical studies and laboratory studies, full-text accessible, and published with 2011-2022. The first article screening was carried out by identifying relevant titles, and the next stage was filtering articles based on abstracts. Articles with relevant abstracts are subjected to a third screening by reading the entire article text to determine relevance to the research. All articles that result from screening are subjected to a data extraction process. The data were analyzed using qualitative methods, which will then be mapped according to the research objectives.

Results

A total of 14 articles were identified through searches on the Pubmed database, Science Direct, Google scholars, and additional articles, which were identified manually from the selected article bibliography, and had gone through the screening stages of title, abstract and reading the manuscript as a whole. The following is in Figure 1-PRIMA flowchart.

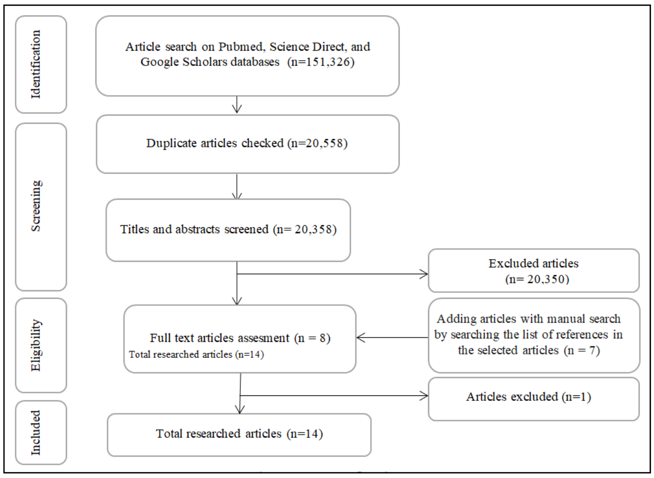

Figure 1. PRISMA flowchart.

Duplication cheks were carried out so that 20,558 articles were obtained. The screening is done by reading the title and abstract is then 20,358 articles. A total 8 Full text assessment, and adding 6 articles with manual searching the list of reference are obtained to review. The data are presented in several tables, which are differentiated based on clinical factors and the biomechanical response of the oral mucosa. Table 1 shows a general summary of research results from all articles. The reviewed articles have two study designs: clinical and experimental, and divided into in vivo, in-vitro, and in-silico studies. In-vivo is research directly on organisms, and In-vitro is research in a laboratory using samples from body parts of organisms. In-Silico is research with the support of a computer.[14] Tables 2, 3, 4 and 5 show the biomechanical responses of the oral mucosa, is a static response, a dynamic response, an interactive response and a volumetric response. Meanwhile, Table 6 shows the clinical aspect of the pressure-pain threshold of the oral mucosa.

Static Response

The static response is an instant or short-term response on the oral mucosa with the parameters of the assessment of elastic modulus and Young's modulus.[4] Elastic modulus describes an object's resistance to deformation or physical change proportionally when given a force. Contrary to Young's modulus measures an object's ability to horizontal deformation when applied tension or longitudinal compression.[25,26] These two parameters have different values in each part of the oral mucosa as the modulus value depends on the depth of the tissue.[3] Tsaira et al.,[17] explained that the elastic modulus value of the oral mucosa would increase from superficial to deep layers. An ex-vivo study by Choi et al.[3] using partially edentulous cadaveric mucosa samples obtained significantly different modulus of elasticity in three parts of the oral mucosa; attached gingiva of 37.4 ± 17.4 MPa, hard palate 18.1 ± 4 .5 MPa, and buccal mucosa 8.3 ± 5.8 MPa. An in-vivo study by Isobe Akio et al.,[19] conducted on dentate subjects, obtained a modulus of elasticity of the oral mucosa ranging from 0.91 to 5.93 MPa with details on the palatal median of 2.23 MPa, midpoint of 1.70 MPa, and lateral mucosa. The first molar is 3.74 MPa. The results of these two studies indicate that the difference in the value of the elastic modulus occurs due to individual condition factors based on dentate, edentulism, or partial edentulism. In dentate individuals, the modulus of elasticity of the oral mucosa is lower than that of individuals with partial edentulism. Other identification results regarding the elastic modulus and Young's modulus can be seen in Table 2.

Dynamic Response

The dynamic response is a long-term response influenced by the viscoelasticity and permeability of the fluid in the oral mucosa.[27] The viscoelasticity shows that the viscoelasticity of the oral mucosa deforms when stress is applied and recovers when the tension is removed.[4] The viscoelasticity of the oral mucosa will show the creep and recovery processes that occur in the mucosa, with tensile strength and contact pressure being benchmarks in the assessment.[20,22,23] In Table 3, Choi et al.,[3] showed that the tensile strength of the oral mucosa ranged from 1.5 ± 0.5 MPa to 3.8 ± 0.9 MPa. Goktas et al.,[2] also showed close results; 3, 94 ± 1.19 MPa. Based on Sawada et al.'s research, Mucosa under continuous load will experience creep or deformation of the mucosa in the superficial layer; this occurs due to the accumulation of continuous and repeated loads as a strain on the layer,[23] while the inner layer has a constant stretch without a picture creeps.[28] The process of recovering mucosal tissue is known from the study of Wakabayashi et al.,[23] on partial edentulism individual subjects with the application of 5N load to the mucosa for 10 seconds, the results showed mucosal recovery of 87.3% immediately after the load was removed; this event is referred to as instant recovery. 97.7% recovery is obtained in the next 20s, which is called delayed recovery.

Interactive Response

The response of friction on the surface between the mucosa and the denture is interactive. This considerate is necessary to prevent diseases of the oral mucosa due to denture friction, such as irritation, keratosis, cheilitis, traumatic ulcers and hyperplasia.[29] Prevention is required by determining the correct contact between the mucosa and denture, which is associated with considering the coefficient of friction. [4,5] Accordance Chen et al., the value coefficient of friction between the mucosa and the denture has 0.213, with the condition of the mucosa being hydrated. Whereas in the dehydrated mucosa is 0.4.

Volumetric Response

The volumetric response is the ability of the mucosa to tolerate volume changes when a changing shape occurs. This response is influenced by the Poisson ratio; known as compressibility or lateral response.[5,6] This response is also known as the negative ratio of transverse stretch to longitudinal stretch. The mucosa will tend to widen sideways along the direction perpendicular to the source of compression, whereas the mucosa will tend to shrink when under tension.[5] Table 5 shows the Poisson ratio mucosa results from experimental and clinical studies with a value range of 0.37-

0.45. [5,6,15,18]

Pressure-Pain Threshold

Pain response is one of the parameters indicating that the denture is not adaptive to the oral mucosa. [5] The high contact pressure of the denture on the oral mucosa, which refers to the load supported by the mucosa, is a factor causing pain.[5,30,31] Pressure pain threshold is a parameter in determining the lowest pressure value that causes pain. The pressure pain threshold relates an objective stimulus (pressure from dentures) with a subjective response to pain response. Based on the review results in Table 6, PPT on the oral mucosa has a reasonably extensive variation range, namely 0.02-2.26 MPa.[15,16,19,24]

Discussion

The oral mucosa is a surface layer that separates and protects the underlying tissues or organs from the oral cavity environment.[32–34] The oral mucosa shows adaptations in the epithelial layer and connective tissue to tolerate mechanical forces (compression, stretching, shearing) formed in functional mastication activities and prevent surface abrasion. Clinically, the oral mucosa becomes one of the supporting tissues in the treatment of removable dentures. The aspect that plays a role in this treatment is the biomechanical aspect of the oral mucosa, which is interpreted by specific responses.[4] The first response is the static response, which is a factor to consider in determining the type of material to be chosen for the denture base. The determining parameter used in selecting denture base materials is the elastic modulus value. The material's modulus of elasticity is directly proportional to the material's stiffness; the higher the modulus of elasticity, the higher the material's rigidity.[25] The material selected with criteria resembling the oral mucosa is a material that has an elastic modulus, that resembles the tissue modulus of elasticity to prevent tissue damage.[35] If the material's elastic modulus is higher than the tissue, it will cause injury to the tissue. However, if the material's modulus of elasticity is lower than that of the tissue, the material will experience fragility or fracture.[35] The size of the elastic modulus recommended in selecting denture materials suitable for partial edentulism is in the range of 2.5-54.8 MPa.[3]

The role of the mucosa as a self-defense factor from tissue damage or degradation is shown in the dynamic response. The dynamic response in removable denture care is related to the adhesive retention factor, which is a tug-of-war interaction between the mucosa and saliva under the denture. Adhesive retention serves as a defense so that the dentures remain in position in the oral cavity. The behavior of viscoelasticity and tissue permeability influences this. [23] Viscoelasticity is manifested by the process of deformation and recovery of the mucosa during application and load removal, as a removable dentures. [4] The viscoelasticity of the oral mucosa shows deformation in the form of creep, which is a time-dependent process.[21] *Creep* deformation occurs permanently due to constant and continuous stress or load. [22,23] Sustained loads produce increased strain on the mucosal surface and are constant on the deep layer, which shows that more deformation occurs in the superficial layer of the mucosa than in the deep layer. [22] The inner layer of the mucosa has better deformation resistance because it has a solid attachment to cortical bone. On the controrary, the superficial layer, which is not supported by cortical bone, only shows viscous behavior.[3,21] The increased stretch on the mucosal surface occurs due to the mastication cycle process, which produces stress on the compressed mucosa causing gradual distortion of the mucosal connective tissue.[23] The duration of loading is one of the factors essential causes of the increased strain.[18]

Dynamic response, in the form of fluid permeability, functions in eliminating stress concentrations on the mucosa, which is associated with the movement of fluids in the form of blood and interstitial fluids and tissues.[23] Fluid permeability assumes that the mucosal response consists of two phases: the response originating from a dense porous matrix such as collagen fibers and the fluid response (fluid). [4] When the mucosa is given pressure, the interstitial fluid will flow through the porosity to the unstressed part, besides changes in permeability in the form of increasing or decreasing fluid flow. [22,30,36] The dynamic response in removable denture treatment is closely related to adhesive retention. The dynamic response results can explain the mechanism and differences in pressure-pain threshold values in each part of the oral mucosa. The initial shear modulus and the proper relaxation time determine the viscoelasticity. Wakabayashi et al.,[20] showed an average oral mucosal initial shear modulus of 8.3 × 10−5 GPa and an average relaxation time of 503 seconds. Sawada et al.,[23] research showed the same range of values, namely the initial shear modulus (8.0 ± 3.0) × 10-5 GPa and the relaxation time (τ) was 494 ± 8 seconds; this means that the measure of viscoelasticity that the mucosa can still accept is (8.0 ± 3.0) × 10-5 GPa.[20,23]

The interactive response of friction on the surface between the denture and the oral mucosa is influenced by physiological conditions of the mucosa, such as xerostomia. [5] Normal oral mucosa with well-hydrated conditions has a lower friction coefficient than xerostomia. The coefficient of friction is also affected by denture material type and variations in the amount of saliva, so calculating the coefficient of friction requires physiological considerations for each individual and the type of denture material used. Determining the friction coefficient effectively avoids mucosal trauma due to friction under the dentures, such as irritation and keratosis. The proper friction coefficient for denture design with hydrated mucosal conditions is 0.213, while for the case of xerostomia mucosa, it is 0.40.[5]

Poisson's ratio is an indicator in determining the volumetric response of the mucosa to mechanical loads. The value of the Poisson ratio for each individual differs, which is influenced by mucosal thickness, location, morphology, age and duration of wearing dentures.[4] Removable denture-supporting tissues such as abutment teeth, mucosa and alveolar bone can move; this causes deformation on the denture so that there is a shift in the contact surface, which results in stress concentration on the oral mucosa below it.[15] Determination of the value of the Poisson ratio is essential for estimating the distribution of contact pressure and displacement of the oral mucosa under removable dentures to prevent tissue damage due to compressive and shearing.[2,19] The value of the Poisson ratio tested in experimental studies using the FEA computational model was confirmed by in-vivo contact pressure measurements is 0.402.[5]

Conclusions

Considerate the biomechanics of oral mucosa is used in selecting compatible denture materials by allowing for the values of modulus of elasticity, viscoelasticity, Poisson's ratio, and coefficient of friction. In further research, biomechanics of the oral mucosa needs to be deliberated in developing denture materials with complementary mucosal tissue.

Declaration of Interest

The authors report no conflict of interest.

Author	Design Study	Sample	Result
Ramakrishnan et al., (2021)[15]	Experimental Studies - Numerical/In silico	A geometric 3D model with jaw components, oral mucosa, and GTSL was developed from 3 CT-Scan data of jaw bones and removable partial dentures (RPD).	• Young's modulus of mucosa 8.33 MPa, Poisson Ratio 0.4 • Average maximum occlusal strength is in the range of 65-110 N • Maximum contact pressure on the oral mucosa is 0.131 MPa, (represents a lower value than the PPT of the oral mucosa) • PPT on the oral mucosa shows a pressure of 0.25 MPa in the buccal region of the mandible, 1 MPa in the palatal area • Poor slippage or retention criteria in removable denture has the potential to cause inconvenience to removable denture users
Choi et al., (2020)[3]	Experimental Study - ex vivo (Finite Element Analysis/FEA)	N = 30 mucosal samples from three different sites (buccal mucosa, hard palate and attached gingiva) were taken from two partially edentulous human cadavers preserved with the Thiel embalmed method (ages at death 69 and 81 years).	• Mucosal tissue from different intraoral areas has mechanical behavior • The highest average modulus of elasticity was in the attached gingiva (37.4 ± 17.4 MPa). Samples of the hard palate (18.1 ± 4.5 MPa) and buccal mucosa (8.3 ± 5.8 MPa). • The tensile strength of tissue samples ranges from 1.5 ± 0.5 MPa to 3.8 ± 0.9 MPa

Inamochi et al., (2019) [16]	Clinical Studies - In Vivo	N = 333 patients using removable dentures (mean age 71.2 years, male 33.3%). Midline oral mucosa around maxillary and mandibular central incisors.	• Mean PPT = 2.00 ± 0.26 for patients with oral dryness • PPT = 2.04 ± 0.22 for normal patients • This shows that there is a relationship between oral dryness and lower PPT values in patients with complete dentures but not in patients with removable partial dentures
Tsaira et al., (2016) [17]	Experiment al Study - In Vitro	N=8 block of keratinized oral mucosa and underlying bone with a block size of 12×8×8 mm (Specimens were taken from a corpse in the palatal area of the maxilla adjacent to the edentulous ridges)	• Mechanical properties depend on the location and direction of the applied force. • The modulus of elasticity varies depending on the depth of the tissue; the modulus of elasticity will increase from the superficial layers to the deep layers. • Young's modulus and Poisson's ratio change during different stages of cell development.
Chen et al., (2015) [5]	Experiment al Study - in vivo/in silico	A 66-year-old female with a removable partial denture (RPD) in the mandible.	• The total occlusal force over the entire dental arch is 438.7 N, whereas the full force over the denture is 84.6 N. • The pressure at the occlusal contact varies from 0.09 - 0.87 MPa, with the maximum pressure occurring at the lingual portion of the residual ridge crest and the minimum occurring at the mesial and distal ends of the buccal side • ν (Poisson ratio) and f c (friction coefficient) significantly affect the oral mucosa's response; this is indicated by changes in the distribution of contact pressure and their maximum value. • When the modeled mucosa is well lubricated (ν = 0.499: f c = 0.02), the maximum contact pressure can reach 1.8 MPa, 21 times that of the lowest Poisson's ratio case (ν = 0.30 f c = 0.02). • When (f c = 0.40) the predicted contact pressure reaches 2.69 MPa at ν =0.499 • ν has a more dominant effect on tissue displacement when pressure is applied • Poisson's ratio of the mucosa and the coefficient of friction between the denture and the oral mucosa, which has the minimum deviation value (1.57 kPa) and the value most agrees with previous studies, namely ν = 0.402 and f c = 0.213
Suenaga et al.(2014) [18]	Clinical Studies - in silico/finite element study	A 66-year-old woman who had a CT scan of the mandible and RPD	• Young mucosal modulus 1 MPa, Poisson Ratio 0.37 • Pressure on the residual ridge = 0.09-0.87 MPa with a maximum pressure of 0.87 MPa on the lingual side of the residual ridge
J. B. G. Lima et al., (2013) [6]	Experiment al Study - in silico/finite element study	~N=2 CT scans of patients with complete edentulous =5 3D models	• Young's modulus of mucosa 3 MPa, Poisson Ratio 0.45 • When a 60N force is applied to the occlusal denture, the maximum principal stress (MPS) value on the mucosal surface is 0.1462 MPa • The decrease in stress tends to occur as the thickness of the material increases • Comparison of mucosal thickness and maximum stress distribution, Mucosal thickness of 3 mm produces the least stress, while a thinner (1 mm) or thicker (5 mm) mucosa makes higher stress.
Isobe Akio et al., (2013) [19]	Clinical Studies - In vivo	Three sections of the palatal mucosa: median palate, lateral first molar and midpoint between the two sections were taken from N=17 dentate subjects (6 males and 11 females: mean age 29.5 years)	• Median palate: T : 0.95mm, E : 2.23 MPa, P : 0.29-0.97 MPa S : 0.13-0.50 mm • Midpoints: T : 3.59 mm, E : 1.70 MPa, P : 0.27-0.69

			MPa - S : 0.41-2.01 mm • Laterals M1: T : 2.67 mm, E : 3.74 MPa,,P : 0.34-1.72 MPa - S : 0.30-1.07 mm • Palatal Median T=Muscosal thickness; S is the decrease in the oral mucosa(mm); P = pain pressure threshold (MPa); C = compressibility (%); E = modulus of elasticity (MPa). • In this article, the modulus of elasticity values range from 0.91 to 5.93 MPa. • elastic modulus is calculated from the pressure pain threshold parameter; there is no significant relationship between T and E
Wakabayashi et al., (2013) [20]	Clinical Studies - In vivo	N=3 male patients lost maxillary molars on one side, postoperatively, and had no complaints of pain and tenderness (mean age = 58.3 years; range = 58-62 years)	• Constant load 5N, time maintained 10s, : • after the load has been removed. Recovery 87.3% • In the 20s after load removal, 97.7% recovery • Average G0 = 8.3 × 10−5Gpa . τ mean ± standard deviation = 503 ± 46 s • [G0: Initial elastic modulus, τ: Relaxation time]
Żmudzki et al., (2012) [21]	Experimental Study - in silico	Mandibular and denture models were designed with CAD (Autodesk InventorTM) software and exported to FEM software.	• The pressure under the denture decreased from 2.9 to 2.12 MPa. The decrease in contact pressure results from the increased contact area
Lacoste-Ferré et al., (2011) [22]	Experimental Study – in vitro	N=2 samples of porcine mandibular mucosa (hydrated and dehydrated samples), N=6 soft liners (2 acrylics, 4 silicone, and polyisoprene permanent soft liners)	• The compressive modulus value of the oral mucosa, adjusted for elderly patients under physiological conditions, is 3 MPa • When stress release occurs, 3.2% deformation of the oral mucosa, instant elastic strain 0.01 (1%) • When stress is applied: strain increases after 5 minutes with deformation of the mucosa three times = 9.6 % (creep strain) • Creep recovery of the oral mucosa is observed for 30 minutes: Residual stretch 0.25%
Sawada et al., (2011) [23]	Clinical Studies - In vivo	Individuals with missing posterior maxillary teeth on one side who experienced no aches and pains (N = 5; mean age, 64.2 years; range, 55–74 years)	• Mean mucosal thickness = 2.6 mm ± 0.6 mm • Average G0 = (8.0 ± 3.0) × 10-5 GPa ~ (0.08 ± 0.03) MPa • (τ) = 494 ± 8 seconds • [G0: Initial elastic modulus, τ: Relaxation time] • Maximum stretch under sustained load is increased in the superficial mucosa. However, the deep mucosa remained constant, suggesting that the superficial mucosa underwent tissue creep/deformation behavior • Sustained and repeated loads accumulate as tension on the mucosal surface, giving rise to creep.
Suzuki et al., (2011) [24]	Clinical Studies - In vivo	N=8 Partially edentulous patients after tooth extraction without complications (1 male and seven female, mean age 75 years)	• PPT 7 days after the extraction on Maxilla: 230-640 gf, Mandibula: 240-430 gf PPT • At 7 ; 30 ; 90 days after extraction is 358.5gf respectively; 662.5gf ; 978.1 gf.
Goktas et al., (2011) [2]	Experimental Study - In Vitro	N=25 pigs aged 6-9 months with normal oral tissue taken from the lower jaw area of the buccal attached gingiva, buccal alveolar mucosa, buccal mucosa, lingual attached gingiva, and lingual alveolar mucosa.	Keratinized gingiva has increased tensile strength (3.94 – 1.19 MPa) and stiffness (Young's modulus 19.75 – 6.20 MPa) in non-keratinized mucosal areas, densely packed elastin fibers contribute to the tissue with increased viscoelastic properties. Dynamic compression analysis showed instantaneous modulus (Eint), stable modulus (Es), and peak stress increased with loading frequency and strain amplitude, with the highest values found in the fixed buccal gingiva.

Table 1. General summary of the article reviewed.

Author	Design Study	Sample	Result
Ramakrishnan et al., (2021)[15]	Experimental Studies - Numerical/In silico	A geometric 3D model with jaw components, oral mucosa, and GTSL was developed from 3 CT-Scan data of jaw bones and removable partial dentures (RPD).	• Young's modulus of mucosa 8.33 MPa.
Choi et al., (2020)[3]	Experimental Study - ex vivo (Finite Element Analysis/FEA)	N = 30 mucosal samples from three different sites (buccal mucosa, hard palate and attached gingiva) were taken from two partially edentulous human cadavers preserved with the Thiel embalmed method (ages at death 69 and 81 years).	• The highest average modulus of elasticity was in the attached gingiva (37.4 ± 17.4 MPa) samples of the hard palate. (18.1 ± 4.5 MPa) and buccal mucosa (8.3 ± 5.8 MPa).
Tsaira et al., (2016)[17]	Experimental Study - In Vitro	N=8 block of keratinized oral mucosa and underlying bone with a block size of 12×8×8 mm (Specimens were taken from a corpse in the palatal area of the maxilla adjacent to the edentulous ridges)	• Mechanical properties depend on the location and direction of the applied force. • The modulus of elasticity varies depending on the depth of the tissue; the modulus of elasticity will increase from the superficial layers to the deep layers. • Young's modulus and Poisson's ratio change during different stages of cell development.
Suenaga et al., (2014)[18]	Clinical Studies - in silico/finite element study	A 66-year-old woman who had a CT scan of the mandible and RPD	• Young's modulus of mucosa 1 MPa,
J. B. G. Lima et al., (2013)[6]	Experimental Study - in silico/finite element study	~N=2 CT scans of patients with complete edentulous =5 3D models	• Young's modulus of the oral mucosa is 3 MPa.
Isobe Akio et al., (2013)[19]	Clinical Studies - In vivo	Three sections of the palatal mucosa: median palate, lateral first molar and midpoint between the two sections were taken from N=17 dentate subjects (6 males and 11 females: mean age 29.5 years)	• In this article, the modulus of elasticity of the oral mucosa ranges from 0.91 to 5.93 MPa. • Modulus of elasticity of the oral mucosa on the palatal median was 2.23 MPa, Midpoint was 1.70 MPa, and that of the mucosa on the lateral side of the first molars was 3.74 MPa.

Table 2. Oral mucosa static response with the parameters of modulus of elasticity and Young's modulus.

Author	Design Study	Sample	Result
Choi et al., (2020)[3]	Experimental Study - ex vivo (Finite Element Analysis/FEA)	N = 30 mucosal samples from three different sites (buccal mucosa, hard palate and attached gingiva) were taken from two partially edentulous human cadavers preserved with the Thiel embalmed method (ages at death 69 and 81 years).	• The tensile strength of tissue samples ranges from 1.5 ± 0.5 MPa to 3.8 ± 0.9 MPa.
Wakabayashi et al., (2013)[20]	Clinical Studies - In vivo	N=3 male patients lost maxillary molars on one side, postoperatively, and had no complaints of pain and tenderness (mean age = 58.3 years; range = 58-62 years)	• Constant load 5N, time maintained 10s, • after the load is removed. Recovery 87.3% • Constant load 5N, time maintained 20s, recovery 97.7% after load is removed • Average G0=8.3 × 10−5Gpa . τ mean ± standard deviation = 503 ± 46 s [G0:Initial shear modulus, τ: Relaxation time]
Żmudzki et al., (2012)[21]	Experimental Study - in silico	Mandibular and denture models were designed with CAD (Autodesk InventorTM) software and exported to FEM software.	The pressure under the denture decreased from 2.9 to 2.12 MPa. The decrease in contact pressure results from the increased contact area.

Goktas et al., (2011)[2]	Experimental Study - In Vitro	N=25 pigs aged 6-9 months with normal oral tissue taken from the lower jaw area of the buccal attached gingiva, buccal alveolar mucosa, buccal mucosa, lingual attached gingiva, and lingual alveolar mucosa.	Keratinized gingiva experienced increased tensile strength (3.94 ± 1.19 MPa) and stiffness (Young's modulus 19.75 ± 6.20 MPa) in non-keratinized mucosal areas with elastin fibers which contributed to the viscoelastic behavior.
Sawada et al., (2011)[23]	Clinical Studies - In vivo	Individuals with missing posterior maxillary teeth on one side who experienced no aches and pains (N = 5; mean age, 64.2 years; range, 55–74 years)	• Average G0 = (8.0 ± 3.0) × 10-5 GPa (τ) = 494 ± 8 seconds • Maximum stretch under sustained load is increased in the superficial mucosa. However, the deep mucosa remained constant, suggesting that the superficial mucosa underwent tissue creep/deformation behavior • Sustained and repeated loads accumulate as tension on the mucosal surface giving rise to creep.
Lacoste-Ferré et al., (2011)[22]	Experimental Study – in vitro	N=2 samples of porcine mandibular mucosa (hydrated and dehydrated samples), N=6 soft liners (2 acrylics, 4 silicone, and polyisoprene permanent soft liners)	• When the load is removed there is a 3.2% deformation of the oral mucosa with an instant elastic strain of 0.01 (1%) • When a load is applied: strain increases after 5 minutes with deformation of the mucosa 3 times = 9.6 % (creep strain) • Creep recovery of the oral mucosa is observed for 30 minutes : Residual stretch 0.25%

Table 3. Oral mucosal dynamic response .

Author	Design Study	Sample	Result
Chen et al., (2015)[5]	Experimental Study - in vivo/in silico (komputasi)	A 66-year-old female with a removable partial denture (RPD) in the mandible.	• The total occlusal force on the entire dental arch is 438.7 N, and the total force on the denture is 84.6 N. • ν (Poisson ratio) and f c (friction coefficient) significantly affect the oral mucosa's response; this is indicated by changes in the distribution of contact pressure and their maximum value. • When the modeled mucosa is well lubricated (ν = 0.499: f c = 0.02), the maximum contact pressure can reach 1.8 MPa, 21 times that of the lowest Poisson's ratio case (ν = 0.30 f c = 0.02). • When (f c = 0.40) the predicted contact pressure reaches 2.69 MPa at ν =0.499 • ν has a more dominant effect on tissue displacement when pressure is applied; the Poisson's ratio of the mucosa and the coefficient of friction between the denture and the oral mucosa has the minimum deviation value (1.57 kPa), and the value is most consistent with previous research, namely ν = 0.402 and f c = 0.213

Table 4. Interactive response of the oral mucosa with the friction coefficient parameter.

Author	Design Study	Sample	Result
Ramakrishnan et al., (2021)[15]	Experimental Studies - Numerical/In silico	A geometric 3D model with jaw components, oral mucosa, and GTSL was developed from 3 CT-Scan data of jaw bones and removable partial dentures (RPD).	Poisson Ratio Oral Mucosa is 0.4
Chen et al., (2015)[5]	Experimental Study - in vivo/in silico (komputasi)	A 66-year-old female with a removable partial denture (RPD) in the mandible.	The Poisson Ratio (ν) of the mucosa and the coefficient of friction (f c) between the denture and the oral mucosa, which has the minimum deviation value (1.57 kPa) and the value most agrees with previous studies, namely ν = 0.402 and f c = 0.213

Suenaga et al., (2014)[18]	Clinical Studies - in silico/finite element study	A 66-year-old woman who had a CT scan of the mandible and RPD	• Poisson Ratio 0.37 • Pressure on the residual ridge = 0.09-0.87 MPa with a maximum pressure of 0.87 MPa on the lingual side of the residual ridge
J. B. G. Lima et al., (2013)[6]	Experimental Study - in silico/finite element study	~N=2 CT scans of patients with complete edentulous ~N=5 3D models	• Poisson Ratio Oral Mucosa is 0.45 • When a 60N force is applied to the occlusal denture, the maximum principal stress (MPS) value on the mucosal surface is 0.1462 MPa • Comparison of mucosal thickness and maximum stress distribution, Mucosal thickness of 3 mm produces the least stress, while a thinner (1 mm) or thicker (5 mm) mucosa produces higher stress.

Table 5. Oral mucosa volumetric response.

Author	Design Study	Sample	Result
Ramakrishnan et al., (2021)[15]	Experimental Studies - Numerical/In silico	A geometric 3D model with jaw components, oral mucosa, and GTSL was developed from 3 CT-Scan data of jaw bones and removable partial dentures (RPD).	• PPT on the oral mucosa shows 0.25 MPa in the buccal region of the mandible, 1 MPa in the palatal area
Inamochi et al., (2019)[16]	Clinical Studies - In Vivo	N = 333 patients using removable dentures (mean age 71.2 years, male 33.3%). Midline oral mucosa around maxillary and mandibular central incisors.	• Mean PPT = 2.00 ± 0.26 for patients with oral dryness • PPT = 2.04 ± 0.22 for normal patients • This shows that there is a relationship between oral dryness and lower PPT values in patients with complete dentures but not in patients with removable partial dentures
Isobe Akio et al., (2013)[19]	Clinical Studies - In vivo	Three sections of the palatal mucosa: median palate, lateral first molar and midpoint between the two sections were taken from N=17 dentate subjects (6 males and 11 females: mean age 29.5 years)	• Pressure Pain Threshold (Mpa) on the oral mucosa are: - Palatal median : 0.29-0.97 MPa - Midpoint: 0.27-0.69 MPa - Lateral M1: 0.34-1.72 MPa
Suzuki et al., (2011)[24]	Clinical Studies - In vivo	N=8 Partially edentulous patients after tooth extraction without complications (1 male and seven female, mean age 75 years)	• PPT 7 days after extraction on Maxilla: 230-640 gf, Mandibule: 240-430 gf (PPT Maxilla: 0.0226-0.0628 MPa Mandibule: 0.0235-0.0422 MPa) • At 7 ; 30 ; 90 days after extraction is 358.5gf respectively; 662.5gf ; 978.1 gf. (100 gf/cm² = 0.0098 MPa)

Tabel 6. Pressure-Pain Thresold mukosa oral.

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