Finite element analysis of soft tissue pressure at different fixation positions of tracheal catheter in oral cavity

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Abstract

Background: The primary method of respiratory support for critically ill patients in the ICU is oral tube intubation, which ensures airway patency, increases ventilation volume, and enhances lung function. However, the use of oral tube intubation may lead to Oral Mucosal Pressure Injury (OMPI) due to excessive or prolonged pressure, friction, and shear forces [1]. OMPI can increase patient pain, elevate the risk of infection, impose a financial burden on healthcare, increase staff workload, and even result in medical disputes. Studies indicate that the incidence of OMPI in ICU patients ranges from 2.95% to 49.2%, with different fixation positions and methods of tracheal catheterization influencing its occurrence [2]. While numerous factors contribute to OMPI, including patient-related factors, physiological conditions, the use of specific medications, and nursing-related aspects, there are limited reports addressing the mechanical factors that cause OMPI [3-5]. The International Guidelines for the Clinical Prevention and Treatment of Stress Injuries (2019) suggest that finite element models can be employed to evaluate mechanical factors by assessing stress distribution characteristics within tissue structures and predicting the risk of cellular and tissue damage [6]. This study utilizes a finite element theory contact algorithm to simulate the compression process of oral soft tissue when the tracheal catheter is fixed in various positions within the oral cavity. It aims to analyze the stress distribution characteristics under this action to more accurately evaluate the actual stress state within the oral soft tissue structure, thereby preventing the occurrence of OMPI.

Objective: This study aimed to establish finite element models for different fixation positions of tracheal catheters in the oral cavity to identify the optimal fixation position that minimizes the risk of oral mucosal pressure injury.

Methods: CT data of the head and face from healthy male subjects were selected, and a 3D finite element model was created using Mimics 21 and Geomagic Wrap 2021 software. A pressure sensor was utilized to measure the actual pressure exerted by the oral soft tissue on the upper and lower lips, as well as the left and right oral angles of the tracheal catheter. The generated model was imported into Ansys Workbench 21.0 software, where all materials were assigned appropriate values, and boundary conditions were established. Vertical loads of 2.6 N and 3.43 N were applied to the upper and lower lips, while horizontal loads of 1.76 N and 1.82 N were applied to the left and right corners of the mouth, respectively, to observe the stress distribution characteristics of the skin, mucosa, and muscle tissue in four fixation areas.

Results: The equivalent stress of the skin mucosa was ranked as follows: left oral angle < right oral angle < upper lip < lower lip, with values of [(28.42±0.65) kPa, (30.72±0.98) kPa, (35.20±0.99) kPa, (41.79±0.48) kPa] (P<0.001). The equivalent stress of muscle tissue, from smallest to largest, was: right oral angle < left oral angle < upper lip < lower lip, with values of [(34.35±0.52) kPa, (35.64±1.18) kPa, (43.17±0.58) kPa, (43.17±0.58) kPa]?P<0.001?. The shear stress of the skin mucosa tissue also followed the same order: left oral angle < right oral angle < upper lip < lower lip, with values of [(6.58±0.16) kPa, (7.05±0.32) kPa, (7.70±0.17) kPa, (10.02±0.44) kPa] (P<0.001). The shear stress of muscle tissue increased in the following order: right oral angle < left oral angle < upper lip < lower lip, with values of [(5.69±0.29) kPa, (5.74±0.30) kPa, (8.91±0.55) kPa, (11.96±0.50) kPa] (P<0.001). The equivalent and shear stresses of muscle tissue were significantly higher than those of the skin mucosal tissue across all four fixation positions, with statistical significance (P<0.05).

Conclusions: Fixation of the tracheal catheter at the left and right oral corners results in the lowest equivalent and shear stresses, while the lower lip exhibits the highest stresses. It is recommended to minimize the contact time and area of the lower lip during tracheal catheter fixation, and to alternately replace the contact area at the left and right oral corners to prevent oral mucosal pressure injuries.

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Finite element analysis of soft tissue pressure at different fixation positions of tracheal catheter in oral cavity

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Abstract: Objective: This study aimed to establish finite element models for different fixation positions of tracheal catheters in the oral cavity to identify the optimal fixation position that minimizes the risk of oral mucosal pressure injury. **Methods:** CT data of the head and face from healthy male subjects were selected, and a 3D finite element model was created using Mimics 21 and Geomagic Wrap 2021 software. A pressure sensor was utilized to measure the actual pressure exerted by the oral soft tissue on the upper and lower lips, as well as the left and right oral angles of the tracheal catheter. The generated model was imported into Ansys Workbench 21.0 software, where all materials were assigned appropriate values, and boundary conditions were established. Vertical loads of 2.6 N and 3.43 N were applied to the upper and lower lips, while horizontal loads of 1.76 N and 1.82 N were applied to the left and right corners of the mouth, respectively, to observe the stress distribution characteristics of the skin, mucosa, and muscle tissue in four fixation areas. **Results:** The equivalent stress of the skin mucosa was ranked as follows: left oral angle < right oral angle < upper lip < lower lip, with values of [(28.42±0.65) kPa, (30.72±0.98) kPa, (35.20±0.99) kPa, (41.79±0.48) kPa] (P<0.001). The equivalent stress of muscle tissue, from smallest to largest, was: right oral angle < left oral angle < upper lip < lower lip, with values of [(34.35±0.52) kPa, (35.64±1.18) kPa, (43.17±0.58) kPa, (43.17±0.58) kPa]（P<0.001）. The shear stress of the skin mucosa tissue also followed the same order: left oral angle < right oral angle < upper lip < lower lip, with values of [(6.58±0.16) kPa, (7.05±0.32) kPa, (7.70±0.17) kPa, (10.02±0.44) kPa] (P<0.001). The shear stress of muscle tissue increased in the following order: right oral angle < left oral angle < upper lip < lower lip, with values of [(5.69±0.29) kPa, (5.74±0.30) kPa, (8.91±0.55) kPa, (11.96±0.50) kPa] (P<0.001). The equivalent and shear stresses of muscle tissue were significantly higher than those of the skin mucosal tissue across all four fixation positions, with statistical significance (P<0.05). **Conclusion:** Fixation of the tracheal catheter at the left and right oral corners results in the lowest equivalent and shear stresses, while the lower lip exhibits the highest stresses. It is recommended to minimize the contact time and area of the lower lip during tracheal catheter fixation, and to alternately replace the contact area at the left and right oral corners to prevent oral mucosal pressure injuries.

Key words: Tracheal catheter; Fixed position; Oral mucosal pressure injury; Finite element.

The primary method of respiratory support for critically ill patients in the ICU is oral tube intubation, which ensures airway patency, increases ventilation volume, and enhances lung function. However, the use of oral tube intubation may lead to Oral Mucosal Pressure Injury (OMPI) due to excessive or prolonged pressure, friction, and shear forces [1]. OMPI can increase patient pain, elevate the risk of infection, impose a financial burden on healthcare, increase staff workload, and even result in medical disputes. Studies indicate that the incidence of OMPI in ICU patients ranges from 2.95% to 49.2%, with different fixation positions and methods of tracheal catheterization influencing its occurrence [2]. While numerous factors contribute to OMPI, including patient-related factors, physiological conditions, the use of specific medications, and nursing-related aspects, there are limited reports addressing the mechanical factors that cause OMPI [3-5]. The International Guidelines for the Clinical Prevention and Treatment of Stress Injuries (2019) suggest that finite element models can be employed to evaluate mechanical factors by assessing stress distribution characteristics within tissue structures and predicting the risk of cellular and tissue damage [6]. This study utilizes a finite element theory contact algorithm to simulate the compression process of oral soft tissue when the tracheal catheter is fixed in various positions within the oral cavity. It aims to analyze the stress distribution characteristics under this action to more accurately evaluate the actual stress state within the oral soft tissue structure, thereby preventing the occurrence of OMPI.

1. Data and methods

1.1 A finite element model of the tracheal catheter positioned at various locations within the mouth was established.

The selected participant for the head and facial CT scan was a 28-year-old male volunteer with a normal BMI, measuring 175 cm in height and weighing 72 kg. A total of 512 images, each with a thickness of 0.625 mm, were obtained. The DICOM format data was imported into the 3D reconstruction software Mimics 21.0 and Geomagic Wrap 2021 for model fitting and structural segmentation. A resistive film pressure sensor was employed to measure the actual pressure exerted by the tracheal catheter in different areas of the patient’s mouth, with each measurement being repeated 100 times to calculate an average value using the gravitational formula. Subsequently, Ansys 22.0 software was used to import the optimized model, define material properties, remesh the model, and generate an accurate finite element model to conduct finite element analysis based on the defined elastic modulus, Poisson’s ratio, boundary conditions, and simulated loads for various tissues (skin mucosa, muscle tissue), as well as the tracheal catheter and bone, using measured pressures from solid models as input data.

Table 1 Material properties of finite element model

Materials	Modulus of elasticity（Mpa）	Young's modulus（Mpa）	Shear modulus（Mpa）	Poisson's ratio（%）
Tracheal catheter	3.0	—	1500	0.38
skeleton	13400	18000	—	0.25
muscle	0.045	0.25	—	0.49
Cutaneous mucosa	—	3	2	0.49

1.2 Setting of Boundary Conditions

In this study, four models representing the upper lip, lower lip, left oral angle, and right oral angle were established. The fixed support areas of the models were designated as the top and bottom, allowing for rigid support to be simulated through fixed constraints. A sliding friction contact was implemented between the lip and the tracheal tube, with a friction coefficient set at 1. A bonded connection was established among the skin, mucous membrane, and muscle tissue. The model accounted for the effects of gravity in a vertical downward direction, with a gravitational acceleration of 9.8 m/s^2.

1.3 Measurement Indicators

The equivalent stress and shear stress of the skin mucosa and muscle tissue were measured under different fixed positions of the tracheal catheter within the mouth. The stress distribution characteristics of the pressure injury model were analyzed for the fixed positions of the upper lip, lower lip, left oral angle, and right oral angle. Each stress measurement for each part was conducted ten times to obtain an average value.

1.4 Statistical Methods

Statistical analysis was performed using SPSS 25.0. Measurement data were expressed as mean ± standard deviation ($\bar{x} \pm s$). One-way analysis of variance was employed for comparisons between groups, while the T-test was used for intra-group comparisons. A p-value of less than 0.05 was considered statistically significant.2 Results

2.1 Model Verification

A finite element model of the tracheal catheter was established with a total of 14,635 nodes and 8,267 elements at various fixed positions within the oral cavity. This model included the ilium of the upper and lower jaws, as well as the skin, mucosa, and muscle tissues of the oral cavity. The extreme values and distribution trends of stress at the mouth angle and lower lip were consistent with the findings of Amrani et al[7], indicating the effectiveness of the modeling approach employed in this study.

2.2 Equivalent Stress

The equivalent stress of the skin mucosa was observed in the following order: left oral angle < right oral angle < upper lip < lower lip. In contrast, the equivalent stress of muscle tissue, arranged in descending order, was as follows: right oral angle < left oral angle < upper lip < lower lip. Notably, the equivalent stress of muscle tissue was significantly greater than that of the skin mucosal tissue ($P < 0.001$) (Table 2).

Table 2 Comparison of equivalent stress results between skin mucosa and muscle tissue (kPa,n=10)

position	Cutaneous mucosa	Muscle tissue	*t*	*p-value*
labium	35.20±0.99	43.17±0.58	-18.083	□0.001
Labium inferior	41.79±0.48	43.17±0.58	-14.858	□0.001
Left side Angle	28.42±0.65	35.64±1.18	-20.270	□0.001
Right side Angle	30.72±0.98	34.35±0.52	-9.070	□0.001
F	417.929	169.847		
p-value	□0.001	□0.001		

2.3 Shear Stress

The shear stress of the skin mucosal tissue was ranked from smallest to largest as follows: left oral angle < right oral angle < upper lip < lower lip. In contrast, the shear stress of the muscle tissue was ranked from smallest to largest as: right oral angle < left oral angle < upper lip < lower lip. At the four fixed positions, the shear stress of the left and right oral muscle tissue was lower than that of the skin mucosa, while the shear stress of the upper and lower lip muscle tissue was higher than that of the skin mucosal tissue ($P < 0.005$). (Table 3)

Table 3 Comparison of shear stress results between skin mucosa and muscle tissue (kPa,*n*=10)

position	Cutaneous mucosa	Muscle tissue	*t*	*p-value*
labium	7.70±0.17	8.91±0.55	-11.828	□0.001
Labium inferior	10.02±0.44	11.96±0.50	-11.015	□0.001
Left side Angle	6.58±0.16	5.74±0.30	3.948	0.001
Right side Angle	7.05±0.32	5.69±0.29	13.789	□0.001

F	344.71	452.44
p-value	<0.001	<0.001

2.4 Comparison of Equivalent Stress and Shear Stress in the Mucosal Tissue of the Upper and Lower Lips and the Left and Right Oral Corners

Equivalent stress was found to be lower in the upper lip compared to the lower lip, and the left oral angle exhibited lower stress than the right oral angle (P < 0.001). In terms of shear stress, the upper lip also showed significantly lower values than the lower lip (P < 0.001), while the left oral angle had lower shear stress than the right oral angle (P < 0.001) (Table 4).

Table 4 Comparison of the results of equivalent stress and shear force in the skin mucosal tissue of the upper and lower lip, left and right oral corners (kPa,*n*=10)

position	labium	Labium inferior	*t*	*p-value*	Left side Angle	Right side Angle	*t*	*p-value*
Von Mise sstress	35.20±0.99	41.79±0.48	-14.119	<0.001	28.42±0.65	30.72±0.98	-4.954	<0.001
Shear stress	7.70±0.17	10.02±0.44	-22.901	<0.001	6.58±0.16	7.05±0.32	-5.060	<0.001
t	95.682	85.307			90.365	84.766		
p-value	<0.001	<0.001			<0.001	<0.001		

2.5 Comparison of Equivalent Stress and Shear Stress in the Muscle Tissue of the Upper and Lower Lips, Left and Right Oral Angles.

Equivalent Stress: Upper Lip < Lower Lip (P < 0.001); Left Oral Angle > Right Oral Angle (P = 0.004); Shear Stress: Upper Lip < Lower Lip (P < 0.001); Left Mouth Angle > Right Mouth Angle (P = 0.298). (Table 5)

Table 5 Comparison of equivalent stress and shear force results in muscle tissue of upper and lower lip, left and right corner of mouth (kPa,*n*=10)

position	labium	Labium inferior	*t*	*p-value*	Left side Angle	Right side Angle	*t*	*p-value*
Von Mise sstress	43.17±0.58	48.35±0.92	-12.274	<0.001	35.64±1.18	34.35±0.52	3.273	0.004
Shear stress	8.91±0.55	11.96±0.50	-8.045	<0.001	5.74±0.30	5.69±0.29	1.071	0.298
t	98.670	105.603			102.750	78.662		
p-value	<0.001	<0.001			<0.001	<0.001		

2.6 Stress Distribution Rules of Four Groups of Models

The equivalent stress range of the skin mucosa and muscle tissue gradually extends from the stress center to the periphery. In this study, the application direction of the forces on the upper and lower lips is vertical, with the maximum peak values of both equivalent stress and shear stress occurring at the stress point and subsequently radiating outward in the vertical direction. Conversely, the forces applied at the left and right mouth corners are horizontal, causing the stress range to spread horizontally, with the highest stress values appearing at the direct contact point between the tracheal catheter and the mucosal tissue. The distribution of shear stress is centered on the soft tissue stress point and encompasses the entire lip, mandibular region, and both sides of the face, resulting in a broader range of stress. The equivalent stress and shear stress at the mouth corners are significantly lower than those at the upper and lower lips.

To explore the underlying reasons, when the tracheal catheter is fixed at the corner of the mouth, it makes contact with the corner, the upper lip, and the lower lip. The pressure, shear force, and friction generated by this contact are dispersed across the three contact surfaces of the mouth and the upper and lower lips. The contact surface between the tracheal tube and the upper and lower lips serves as the primary stress point, leading to greater stress values at the upper and lower lips compared to the corners of the mouth, with the lower lip experiencing the highest stress. The results of the finite element analysis indicate that the stress at the corners of the mouth is lower, followed by that at the upper lip. (Figure 1-2)

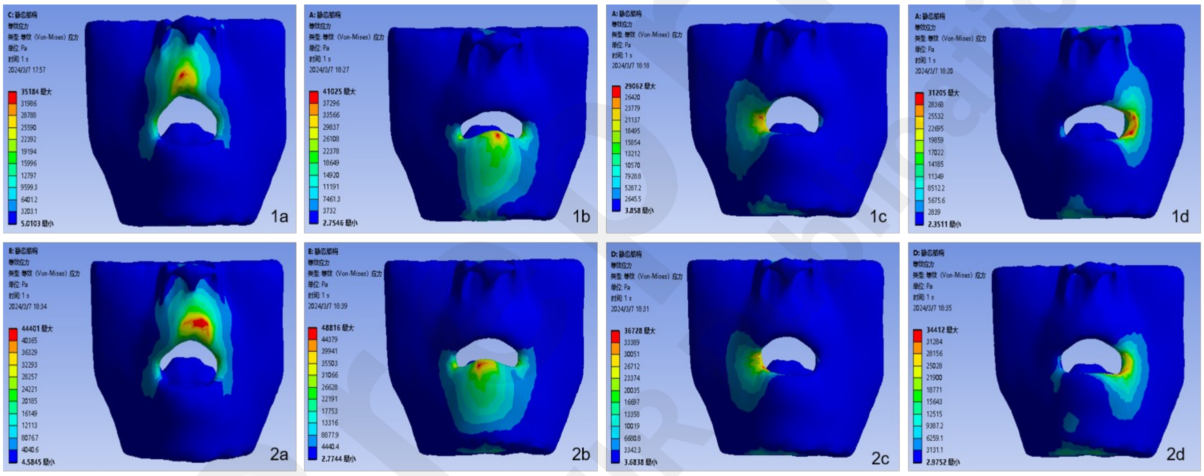

FIG. 1 1a-1d equivalent stress nephogram of two tissues at 4 fixed locations: upper lip, lower lip, left oral Angle, right oral mucosa; 2a-2d: Equivalent stress nephogram of muscle tissue of upper lip, lower lip, left oral Angle and right oral Angle

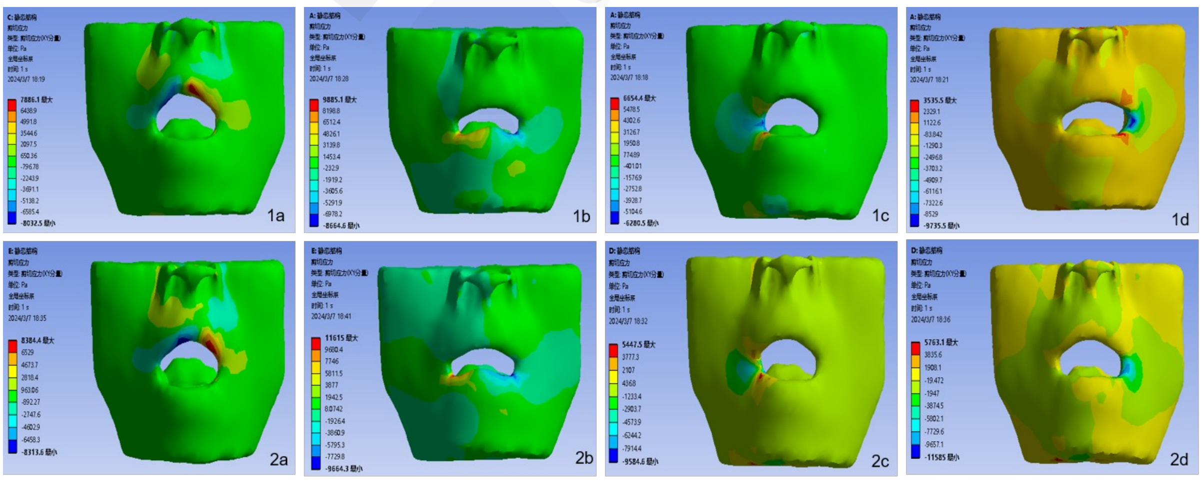

FIG. 2 Shear stress nephogram of two tissues at 4 fixed locations. 1a-1d: shear stress nephogram of mucosa tissue

of upper lip, lower lip, left oral Angle and right oral Angle; 2a-2d: Shear stress nephogram of upper lip, lower lip, left Angle of mouth, right Angle of mouth muscle tissue

3 Discussion

Finite Element Analysis (FEA) modeling is a powerful bioengineering technique employed to assess tissue loading, encompassing the interactions between tissues, objects, and medical devices. This numerical method effectively addresses mechanical problems [8]. It enables rapid and accurate stress-strain analysis of the structure, shape, load, and mechanical properties of materials in any given model [9]. Moreover, FEA objectively and accurately reflects the distribution of stress, strain, and deformation, and has gained widespread application in oral biomechanics research in recent years [10].

The tracheal catheter is a critical instrument for mechanical ventilator-assisted therapy in ICU patients; however, the catheter itself and improper fixation methods may lead to Oral Mucosal Pressure Injury (OMPI) [11]. From a biomechanical perspective, the OMPI associated with tracheal catheters primarily results from vertical pressure, shear forces, and friction [12]. Continuous mechanical loading on soft tissues is the main contributor to stress injuries, typically occurring at bony prominences or in areas contacting medical devices. When skin or deep tissue deformation persists for a certain duration under the pressure from medical devices, pressure injuries may develop [13]. In this study, the mechanical load originated from the force exerted by the tracheal catheter on the oral soft tissue. Contact between the tracheal catheter and the oral mucosal tissue resulted in continuous pressure, leading to tissue deformation in the mucosa. Research indicates that tracheal catheters and their fixation devices are stiffer than oral soft tissues. When the mechanical properties of these instruments do not align with those of the soft tissues, deformation occurs in the latter, concentrating mechanical stress and strain at the points of direct contact, which then gradually extends to surrounding areas [14, 15].

Continuous vertical pressure on soft tissues is a significant factor in the occurrence of stress injuries. The incidence of OMPI correlates with the intensity and duration of pressure; the greater the pressure and the longer its application, the higher the risk of developing OMPI [16]. Furthermore, when the tracheal tube is improperly fitted and fixed too tightly, the pressure and shear force exerted will increase [13]. Shear forces applied to deep skin tissues can obstruct capillaries, leading to localized ischemia and hypoxia, which may result in deep tissue necrosis. Consequently, damage from shear forces is often undetected in the early stages and is more challenging to heal than damage from typical wounds [12]. Friction arises from the movement between the oral mucosal tissue and the surface of the tracheal tube; while it does not directly cause OMPI, it can compromise the epidermal cuticle, leading to the shedding of the mucosal surface layer and heightened sensitivity to pressure injuries. Once the compromised oral mucosal tissue is subjected to stimuli from saliva and other secretions, the risk of pressure injury escalates. Additionally, friction raises the temperature of the local mucosal tissue, disrupts the local microenvironment, alters pH levels, and increases tissue oxygen consumption, further exacerbating tissue ischemia and heightening the risk of OMPI [15].

It was found that the magnitude of the internal mechanical load required to cause tissue damage depends on the duration of the applied force and the specific biomechanical tolerance of the stressed tissue, which is influenced by factors such as age, shape, health status, and the functional capacity of the body systems, including tissue repair ability. Both high loads applied for short durations and low loads sustained over extended periods can lead to tissue damage [17-19]. Continuous loading is one of the primary contributors to this damage; it refers to loads applied over prolonged periods (ranging from a few minutes to several hours or even days), also known as quasi-static mechanical loading. Research indicates that when soft tissues come into contact with the support surfaces of medical devices, pressure and shear forces are generated between the soft tissues and these surfaces. This interaction results in distortion and deformation of the soft tissues under pressure, affecting both the skin and deeper tissues (including fat, connective tissue, and muscle), leading to stress and strain within the tissues [20]. Excessive internal stress in the tissues can disrupt intracellular material transport by damaging cellular structures (such as the cytoskeleton or plasma membrane) or by hindering the transport process itself (for example, by reducing blood perfusion, impairing lymphatic function, and affecting material transport in the interstitial space), which can ultimately result in cell death and trigger an inflammatory response. Concurrently, the emergence of endothelial cell spacing increases vascular permeability, leading to inflammatory edema, which further exacerbates the mechanical load on cells and tissues due to elevated tissue pressure, thus contributing to the development of pressure injuries [21-23].

According to the results of finite element analysis, the stress experienced by the lower lip is the highest, followed by the upper lip, with levels significantly exceeding those at the corners of the mouth. Therefore, in clinical practice, when fixing a tracheal catheter, it is advisable to select the oral angle to maximize the contact surface area between the catheter and this region. Placing the tracheal catheter in the middle of the mouth minimizes the contact time between the catheter and the oral mucosa. Additionally, regular changes in the fixation position can help redistribute pressure, thereby reducing pressure, shear forces, and friction on the oral mucosa, ultimately lowering the risk of oral mucosal pressure injury (OMPI).

This study analyzed alterations in the stress experienced by oral soft tissue under pressure at various fixation positions of the tracheal catheter within the mouth, from a biomechanical perspective. It provides a theoretical foundation for preventing OMPI in patients with tracheal catheters in the intensive care unit (ICU). While this study effectively simulates the biomechanical effects of contact between oral soft tissue and the tracheal catheter, it does not fully replicate the actual forces experienced by oral soft tissue in real-life situations, as the area of contact between the tracheal catheter and the oral soft tissue cannot be completely simulated. Additionally, the study included only one young adult male, which limits the generalizability of the findings. Therefore, it is essential to include participants of varying genders and ages to enhance the scientific validity of the research. Furthermore, improvements in the identification rate and curvature of the three-dimensional grid of the model should be pursued to generate higher-quality three-dimensional models, thereby enhancing data accuracy.

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest, other than those disclosed in the Acknowledgements section.

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DATA AVAILABILITY STATEMENT

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

References:

[1] Yang Maofan, Zhou Huilan, Chen Keyu, et al. Research progress on oral mucosal pressure injuries in patients with oral tube intubation in the ICU [J]. Journal of Nursing, 2023, 38(2): 21-24.

[2] Li Qian, Wang Lizhu, Zhu Yirong, et al. Research progress on oral mucosal pressure injuries in patients with

oral tube intubation in the ICU [J]. Chinese Journal of Acute and Critical Care, 2023, 4(5): 473-477.
[3] Tang Li, Li Min, Yao Qian. Research progress on nursing care for oral mucosal pressure injuries in patients with oral catheterization [J]. Nursing Research, 2023, 37(20): 3682-3686.
[4] Choi B K, Kim M S, Kim S H. Risk prediction models for the development of oral mucosal pressure injuries in intubated patients in intensive care units: A prospective observational study [J]. Journal of Tissue Viability, 2020, 29(4): 252-257.
[5] Liu Tian-kuang, Long Yu-Juan, Liu Huan, et al. Research progress on the characteristics and nursing care of mucosal pressure injuries in different parts of ICU patients [J]. Journal of Nursing, 2022, 29(8): 35-39.
[6] American European Stress Ulcer Advisory Committee, American Stress Injury Advisory Committee, Pan Pacific Stress Injury Alliance, eds. Wang Ling, translated by Hu Ailing. International Guidelines for Clinical Prevention and Treatment of Stress Injuries, 2019, 3rd edition [M]. Beijing: People's Medical Publishing House, 2021.
[7] Amrani G, Gefen A. Which endotracheal tube location minimizes device-related pressure ulcer risk: the center or a corner of the mouth? [J]. International Wound Journal, 2020, 17(2): 268-276.
[8] Welch-Phillips A, Gibbons D, Ahern D P, et al. What is Finite Element Analysis? [J]. Clin Spine Surg, 2020, 33(8): 323-324.
[9] Wang C X, Rong Q G, Zhu N, et al. Finite element analysis of stress in oral mucosa and titanium mesh interface [J]. BMC Oral Health, 2023, 23(1): 25.
[10] Guo R, Lam X Y, Zhang L, et al. Biomechanical analysis of miniscrew-assisted molar distalization with clear aligners: a three-dimensional finite element study [J]. European Journal of Orthodontics, 2024, 46(1).
[11] Liang Hansheng, Feng Yi. Research progress on the selection of endotracheal intubation approaches and complications [J]. China Medical Guide, 2022, 24(1): 61-67.
[12] Ren Zhijun, Xia Xinhua, Cheng Anqi, et al. New progress in the prevention of stress injuries induced by mechanical factors [J]. Nursing Research, 2017, 31(10): 1167-1170.
[13] Wang Na, Lin Yuan-Ting, Xiong Yin-shi, et al. Summary of evidence for the prevention of medical device-related stress injuries in ICU patients [J]. Chinese Journal of Practical Nursing, 2022, 38(13): 992-997.
[14] Gefen A. The etiology of medical device-related pressure ulcers and how to prevent them [J]. British Journal of Nursing (Mark Allen Publishing), 2021, 30(15): S24-S30.
[15] Mak A F, Zhang M, Tam E W. Biomechanics of pressure ulcers in body tissues interacting with external forces during locomotion [J]. Annual Review of Biomedical Engineering, 2010, 12: 29-53.
[16] Lustig A, Margi R, Orlov A, et al. The mechanobiology theory of the development of medical device-related pressure ulcers revealed through a cell-scale computational modeling framework [J]. Biomechanics and Modeling in Mechanobiology, 2021, 20(3): 851-860.
[17] Grigatti A, Gefen A. The biomechanical efficacy of a hydrogel-based dressing in preventing facial medical device-related pressure ulcers [J]. International Wound Journal, 2022, 19(5): 1051-1063.
[18] Gefen A, Levine J. The false premise in measuring body-support interface pressures for preventing serious pressure ulcers [J]. Journal of Medical Engineering & Technology, 2007, 31(5): 375-380.
[19] Gefen A, Brienza D M, Cuddigan J, et al. Our contemporary understanding of the etiology of pressure ulcers/pressure injuries [J]. International Wound Journal, 2022, 19(3): 692-704.
[20] Gawlitta D, Li W, Oomens C W, et al. The relative contributions of compression and hypoxia to the

development of muscle tissue damage: an in vitro study [J]. Annals of Biomedical Engineering, 2007, 35(2): 273-284.
[21] Caulk A W, Chatterjee M, Barr S J, et al. Mechanobiological considerations in colorectal stapling: implications for technology development [J]. Surgery Open Science, 2023, 13: 54-65.
[22] Pan Y, Yang D, Zhou M, et al. Advances in topical biomaterials and mechanisms for the intervention of pressure injuries [J]. iScience, 2023, 26(6): 106956.
[23] Peko Cohen L, Ovadia-Blechman Z, Hoffer O, et al. Dressings cut to shape alleviate facial tissue loads while using an oxygen mask [J]. International Wound Journal, 2019, 16(3): 813-826.

Supplementary Files