The Relationship Between Seat Inclination Angles and Physical Strain When Using Sloped Stools

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Prolonged static postures during dental procedures, such as implant surgeries, often lead to significant physical fatigue, especially in the lumbar region of dental professionals. To address this, a dental operating stool (OS) with an adjustable seat tilt was developed and evaluated. The study aimed to determine the optimal seat tilt angle to reduce physical strain and improve work efficiency.

An experiment was conducted with four seat tilt angles: 0°, 3°, 5°, and 7°. Data on physical fatigue and postural stability were collected. Results showed that a 3° tilt significantly reduced physical strain, while a 5° tilt was preferred for usability and task visibility. These findings highlight the importance of seat tilt in reducing fatigue and enhancing operational efficiency. A 3° tilt is recommended for general fatigue reduction, while a 5° tilt is optimal for tasks requiring better visibility and precision during dental procedures.

Keywords: Dental operating stool (OS); Seat tilt angle; Physical strain;

1. Research Background

Figure 1. Illustration of OS seat inclination

In recent years, dental procedures such as implant surgeries, which require prolonged periods of maintaining static postures, have increased, leading to significant physical fatigue among dental professionals. Surveys indicate that approximately 70% of dental professionals experience physical pain, with lumbar fatigue being particularly prominent (Yamada, 2019). This persistent strain often manifests as discomfort in the neck, shoulders, and lower back, potentially leading to chronic musculoskeletal disorders and affecting career longevity and quality of life. The prolonged static postures restrict natural movement and can lead to localized muscle fatigue, reduced blood circulation, and increased disc pressure, underscoring the critical need for ergonomic interventions. Figure 1 illustrates the seat inclination of the OS.

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Existing dental operating stools often lack mechanisms to effectively alleviate these specific postural stresses. Recognizing this challenge, we have been developing a dental operating stool (OS) equipped with a seat inclination mechanism. Seat inclination has demonstrated potential in other ergonomic applications, such as office chairs, to redistribute pressure and promote a more natural spinal alignment, thereby reducing strain. However, despite its potential, evidence regarding the effectiveness of seat inclination in reducing physical strain specifically in dental settings, and crucially, the identification of the optimal inclination angle for various dental tasks, remains unclear. Determining this optimal angle is essential, as an inappropriate tilt could negate ergonomic benefits or even introduce new forms of discomfort. This research aims to fill this critical gap by providing empirical data to guide the design of more ergonomically sound dental operating stools.

2. Research Objectives

The objectives of this study are twofold: (1) to determine the optimal seat inclination angle for the dental operating stool (OS) from multiple perspectives, and (2) to obtain robust empirical evidence of the effectiveness of seat inclination in reducing physical strain during simulated dental procedures. Building upon the current understanding that prolonged static postures contribute significantly to musculoskeletal pain among dental professionals, this study specifically aims to identify inclination angles that not only alleviate physical burden but also maintain or enhance usability, stability, and visibility during various dental tasks.

To achieve these objectives, a controlled experiment was designed where inclination angles were set at 3 °, 5 °, and 7 °, in addition to a 0 ° (no inclination) baseline. Usability was comprehensively evaluated through subjective assessments provided by participants. Physical strain was objectively assessed using advanced measurement techniques, including motion capture analysis to quantify changes in posture and joint angles, and pressure mapping to evaluate pressure distribution on the seat, during simulated dental treatment tasks. By systematically varying seat inclination angles and directions, this study seeks to verify the effectiveness of strain reduction and establish data-driven recommendations for the ergonomic design of dental operating stools, ultimately contributing to the improved health and well-being of dental practitioners.

3. Research Methods

3.1 Experimental Equipment

Table 1 shows the list of sensors used in this study.

Table 1. List of Sensors

Sensor Name	Manufacturer	Purpose
mocopi	Sony	Motion Capture
SR Soft Vision	Sumitomo Riko	Pressure Mapping Sensor

The sensors were selected based on their ability to visualize the degree of lumbar fatigue and their efficiency in installation and analysis, considering their use in clinical experiments targeting dental professionals. Figure 2 shows the sensor attachment positions.

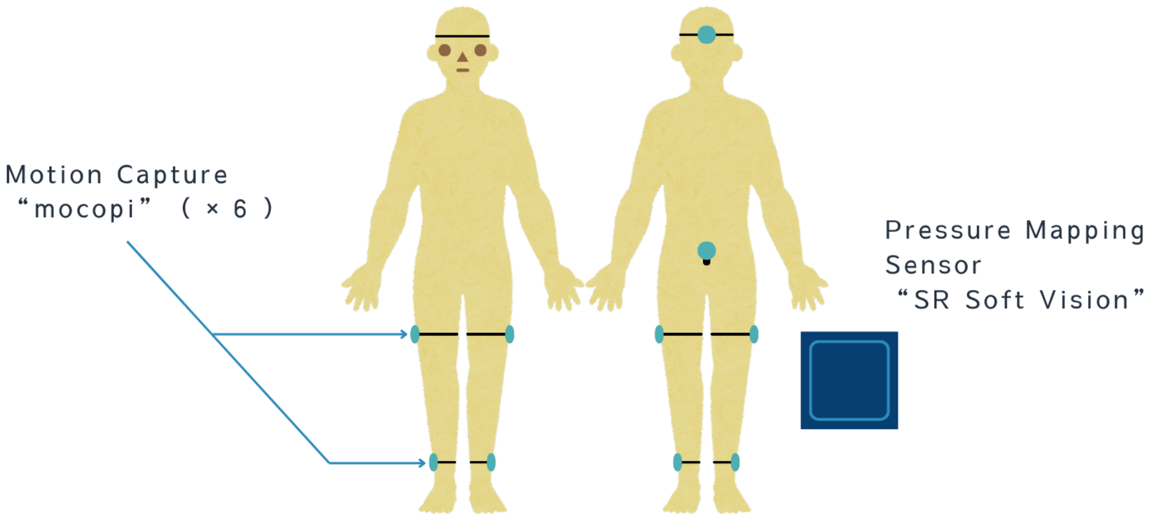

Figure 2. Sensor attachment positions

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The "mocopi" is a sensor system developed by Sony, which allows for easy motion capture by wirelessly connecting six sensors to a smartphone. It is widely known for its use in industries such as the VTuber community and 3D film production. In this study, motion data obtained from "mocopi" was analysed primarily using Autodesk's software "Motion Builder."

Figure 3 illustrates the process of capturing human motion using the motion capture system "mocopi" and modelling it with the software "Motion Builder."

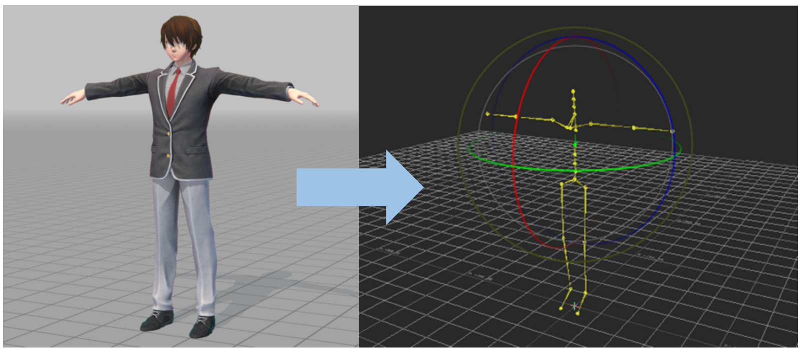

Figure 3. Motion capture of human movement using the "mocopi" system and modeling performed with "Motion Builder."

Each motion sensor is compact and lightweight, with a diameter of approximately 3 cm and a weight of about 8 g, making it easy to handle. The system also integrates seamlessly with its dedicated application. Since the purpose of this experiment is to reduce "lower back fatigue," the "lower-body priority mode," a motion capture mode designed for VR, was utilized to acquire more accurate motion data of the lower back.

Motion capture systems, especially IMU systems (Inertial Measurement Units), are cost-effective, portable, and capable of real-time analysis, making them highly effective in addressing ergonomic risks and improving diagnostic accuracy (Salisu et al., 2023).Motion capture systems, particularly those using wearable sensors on the pelvis and lower back, have been shown to effectively detect physical fatigue by analyzing changes in spine kinematics, supporting their application in assessing lumbar fatigue (Chan et al., 2020). Therefore, in this study, an inertial motion capture system was attached to the lower back to measure physical fatigue.

The "SR Soft Vision" is a sensor developed by Sumitomo Riko Co., Ltd., capable of visualizing the pressure distribution on specific parts of the body, such as the buttocks. It can be connected to a PC via wired or wireless means, allowing real-time observation of changes in pressure distribution. Using dedicated software, the data can be quantified, enabling the verification of pressure at specific points in time. Figure 4 illustrates the measurement of pressure distribution and the center of gravity using a pressure mapping sheet sensor.

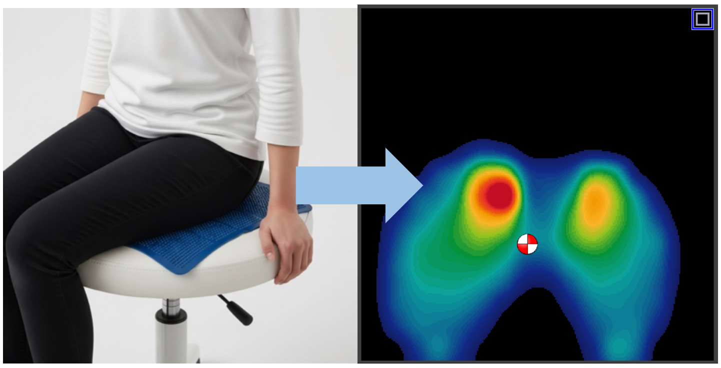

Figure 4. the measurement of pressure distribution and the center of gravity using a pressure mapping sheet sensor

The size of the pressure mapping sensor sheet is 450 mm × 450 mm, with a sensing range of 350 mm × 350 mm. The measurable pressure range is 20–200 mmHg; however, in some cases, the pressure exceeded this range depending on the subject. To address this limitation, solutions such as placing a cushion between the seat and the sensor sheet can be employed.

The pressure-sensitive mat described by Martinez-Cesteros et al. (2021) is cost-effective and adaptable for analyzing center-of-pressure (CoP) displacements. This approach can also be applied to seated conditions using pressure mapping sensors, potentially enabling the evaluation of body fatigue by analyzing shifts in the center of gravity. Therefore, this study utilized pressure mapping sensors to measure the displacement of participants' center of gravity in seated conditions.

3.2 Experimental Conditions

In this experiment, 11 students from our university participated as subjects. A phantom head currently used in dental clinics and a dental experimental head model previously created by our laboratory were utilized to simulate a dental treatment environment. The position of the experimental equipment was set following prior studies, with the height of the phantom head set at 850 mm and the angle of the phantom head adjusted to 40°. Additionally, an experimental OS capable of fixing the inclination angle was created and used for the experiment. The seat height of the experimental OS was set at 520 mm from the floor. Figure 5 shows the experimental OS, and the experimental setup.

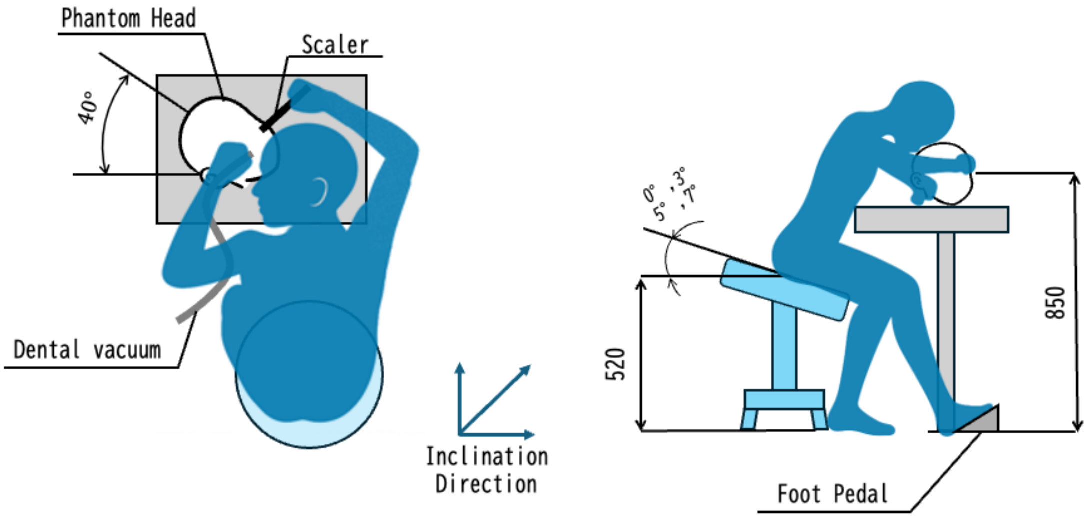

Figure 5. The experimental OS, and the experimental setup.

3.3 Experimental Procedure and Patterns

The participants performed simulated dental treatment tasks. Specifically, the experimental task involved scaling all teeth of the phantom head in a predefined sequence, starting from the maxillary left molars, proceeding to the maxillary right molars, then the mandibular left molars, and concluding with the mandibular right molars. Participants were instructed to use universal curettes and complete the scaling of all accessible tooth surfaces.

The experiment was conducted a total of ten times: once without any seat inclination, followed by three patterns of inclination directions combined with three patterns of inclination angles. To minimize the influence of order effects on subjective evaluations, the inclination angles were not disclosed to the participants during the experiment. Between each experimental condition, participants completed a subjective evaluation questionnaire assessing physical strain, comfort, and visibility. During this inter-experimental period, they were seated on a standard dental stool without inclination features for a specified duration to allow for sensory reset and minimize carry-over effects from the previous condition. In cases where a malfunction or connection loss of the motion capture system occurred during an experiment, the session was immediately interrupted, and the experimental trial for that specific condition was restarted from the beginning to ensure data integrity and reliability.

4. Experimental Results

The experimental results were analysed using data collected during scaling tasks on the "lower anterior teeth to the lower right molars," which were frequently reported as causing high physical strain in the subjective evaluation questionnaire.

4.1 Motion Capture

The motion capture system was used to measure the rotational displacement of the subject's waist. Motion capture systems and rotational displacement analysis are widely applied to evaluate human motion patterns, including fatigue-related changes, as highlighted by Ma et al. (2023), who reviewed advancements in biomechanics-based motion analysis, particularly using validated multibody and finite element models.

Motion data were analysed by calculating the composite displacement of the rotational angles along the X, Y, and Z axes. The maximum, average, standard deviation, and RMS values of the composite displacement were computed and compared. If the rotational angle displacements along the X, Y, and Z axes are denoted as ΔX, ΔY, and ΔZ, respectively, the composite displacement D,can be calculated using Equation (1).

$$D = \sqrt{(\Delta X)^2 + (\Delta Y)^2 + (\Delta Z)^2} \tag{1}$$

Among these metrics, the RMS value represents the "magnitude of lumbar movement" during the task. Lower RMS values indicate smaller body movements, which can be interpreted as contributing to a reduction in dynamic physical strain. Figure 6 shows an one of the experimental results.

In many datasets, smaller inclination angles were associated with lower RMS values, suggesting that smaller angles may help reduce physical strain.

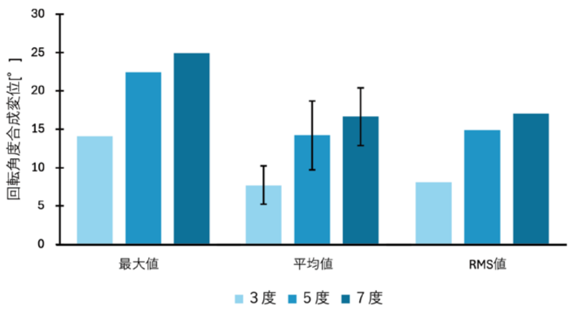

Figure 6. Comparison of Composite Displacement of Lumbar Rotational Angles (During Forward Seat Inclination).

4.2 Pressure Mapping Sensor

Pressure distribution data were analyzed by calculating the composite displacement of the center of pressure movement along the X and Y axes. The maximum, average, standard deviation, and RMS values of the composite displacement were computed and compared. Figure 7 shows one of the experimental results.

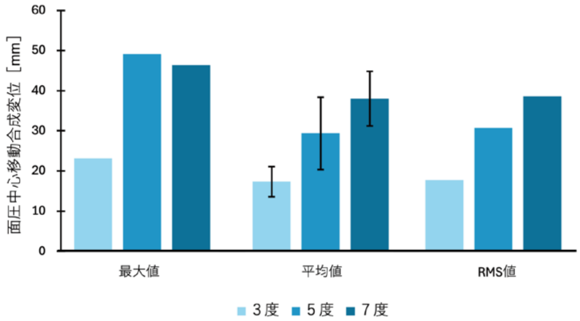

Figure75. Comparison of Composite Displacement of Center of Pressure Movement (During Forward Seat Inclination).

However, in some cases, a 5-degree or 7-degree inclination showed favourable effects in reducing physical strain. Compared to motion data, the OS showed slightly greater variability, possibly due to differences in user interaction.

4.3 Subjective Evaluation

According to the results of the subjective evaluation questionnaire, most respondents indicated that a 5-degree inclination was the most optimal angle. This was based on a balance of factors such as perceived physical strain, ease of viewing inside the oral cavity, and body stability. Participants were asked to rank the angles based on their overall usability and suitability for dental procedures. In the subjective evaluation, points were assigned as follows: 3 points for first place, 2 points for second, and 1 point for third. Figure 8 presents the results.

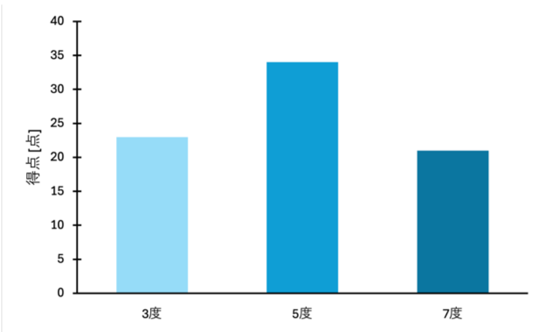

Figure 8. Survey Results for Optimal Inclination Angles of the OS.

5. Conclusion and Discussion

From the results obtained in this study, it was concluded that the optimal inclination angle for the OS is 3 ° from the perspective of reducing physical strain and 5 ° from the perspective of usability. In dental treatment settings, it is considered appropriate to set the inclination angle to 5 °, particularly during tasks that require leaning forward, and to adjust it to 3 ° during other tasks. This approach can help reduce the overall physical burden during treatment.

However, this study has several limitations that should be acknowledged. Firstly, the experiments were conducted with university students as participants, who may not fully represent the demographic and physical characteristics of experienced dental professionals. Secondly, the dental treatment tasks were simulated in a controlled environment, which might not entirely replicate the complexities and unpredictable nature of actual clinical settings. Furthermore, the study focused on specific tasks and a limited range of inclination angles (0 °, 3 °, 5 °, and 7 °), potentially limiting the generalizability of the findings to all dental procedures or a wider range of ergonomic adjustments. Future research should address these limitations by involving a more diverse participant pool, conducting studies in authentic clinical environments, and exploring a broader spectrum of task variations and ergonomic parameters.

6. Prospects

In this study, experiments involving students were conducted to investigate the relationship between inclination angles and their effects on reducing physical strain. Moving forward, further validation of the OS’s utility will be pursued through experiments using the prototype OS and by analysing a larger dataset. Additionally, as the experimental methods were reviewed during the data analysis process, these improvements will be applied to future research.

Specifically, future work will involve conducting experiments with an advanced prototype of the OS in a simulated clinical environment, and ideally, in actual dental clinics. The participant pool will be expanded to include experienced dental professionals such as dentists and dental hygienists, enabling a more direct assessment of the OS's effectiveness in real-world scenarios. We plan to incorporate a broader range of objective physiological indicators, such as electromyography (EMG) to measure muscle activity and heart rate variability (HRV) to assess physiological stress, in addition to motion capture and pressure mapping data. Furthermore, the dataset will be significantly expanded by increasing the number of participants, diversifying the simulated dental tasks to cover a wider array of common procedures, and potentially conducting longer-term observational studies. The refinements identified during the data analysis, such as optimizing sensor placement and adjusting task protocols, will be systematically implemented to enhance the precision and reliability of future experimental designs. Ultimately, the insights gained from these comprehensive studies aim to contribute to the development of ergonomic dental operating stools, improving the working conditions and long-term health of dental professionals, and potentially informing future ergonomic guidelines in dentistry.

7. References

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