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Research Article

Investigation of optimum reclining angles for wheelchair recliners during dental treatment

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ABSTRACT

This paper discusses the development of a wheelchair recliner for dental treatment that can accommodate users of different body mass index (BMI) categories. The study aims to identify the ergonomic angle for a dental chair, design a wheelchair recliner with appropriate reclining angles, and analyse its performance using simulations and user testing with different BMI subjects. The simulation of the wheelchair recliner was performed using the Motion of Inspiration (MOI) 3D to analyse the withstanding load, including the wheelchair load and subject load (2000 N). The displacement and safety factor for the long pin of the recliner was also analysed. The study's main findings indicate that the developed wheelchair recliner can withstand a load of 2000N, which includes both the wheelchair load and the subject's load. The study tested the wheelchair recliner with three reclined angles: 40º, 45º, and 50º. It found that regardless of their BMI category, all subjects were comfortable using the wheelchair recliner at these angles during dental treatment. Overall, the study suggests that the developed wheelchair recliner has the potential to provide comfort to wheelchair users with various BMI categories during dental treatment, eliminating the need for uncomfortable transfers from the wheelchair to the dental chair.

1. INTRODUCTION

According to the Department of Social Welfare in Malaysia, 548,186 individuals were registered as persons with disabilities (PWD) in 2019 [1]. PWD in the physical category had the highest percentage (36.0%), followed by PWD in the learning disability category (34.1%) and PWD in the visually impaired category (8.9%) [2]. One of the types of PWD in the physical category is wheelchair users. During dental treatment, wheelchair users need to undergo the treatment in their wheelchairs. As a result, the prolonged awkward position during the procedures might result in muscle strain for both patients and clinicians. Transferring a patient from a wheelchair to a dental chair involves effort from the patient, dentist, clinical staff, and their caretakers [3-4] and a long transferring time [5]. This transferring process causes embarrassment to the patient and leads to the patient's muscle strain as well to the dentist, clinical staff, and caretakers [3,6,7]. These problems usually arise when the patients are adults and at their elderly age. Due to budget constraints, patients with physical impairments who cannot afford to buy proper seating equipment will use their wheelchairs during dental treatments. This can cause posture discomfort where patients suffer from strenuous neck pain, leading to back pain [8]. To avoid this, the wheelchair user can either use the self-recliner wheelchair and wheelchair tilt-in-space, the hoist, or the wheelchair tipper to provide comfort during dental treatment [9]. Each of these equipment has its own advantages and drawbacks.

The dental chair should provide comfort and total body support for the patient. Moreover, proper patient positioning can assist the dentist in having optimal visibility of the mouth area [10]. The most preferred operating positions are upright, almost supine, and reclined at 45° [11]. Tilt-in-space and self-recliner wheelchairs can provide optimal positions for wheelchair users during dental treatment [12-14]. Wheelchair recliners are designed to provide comfort and total body support for patients during dental treatment. They offer different reclining positions, including an almost supine position and reclined at 45°, which are considered optimal for dental procedures. Self-recliner wheelchairs allow users to adjust their seating positions without exerting excessive energy and help distribute body weight, reducing the risk of pressure sores. They also encourage proper back posture and reduce the chance of developing back pain. Dental procedures can be performed directly on the patient's wheelchair, eliminating the need for transferring patients to a dental chair [15]. Jan et al. [12,16] used two Wixey digital angle gauges to measure wheelchair tilt-in-space and recline angles. The peak pressure index (PPI) needs pressure mapping with varying degrees of wheelchair tilt-in-space and reclining in people with spinal cord injury. A commercial interface pressure measurement system like XSensor® is now an accepted method researchers use to evaluate pressure redistribution in seating [17]. However, this type of wheelchair is expensive to be personally owned and not affordable for many.

Hoists are another option for transferring wheelchair users from their wheelchair to the dental chair [6,18]. There are three hoists: ceiling hoists, portable overhead hoists or gantry hoists, and mobile hoists. Each type has its advantages and drawbacks, and it's essential to rely on professional guidance from occupational therapists and provide proper caregiver training to ensure safe and effective use [19]. However, there is a risk of accidents or injuries if the hoisting equipment is not adequately maintained or safety measures are not followed.

Lastly, the wheelchair tippers can tilt the wheelchair to a suitable degree for dental treatment while the patient remains seated in the wheelchair [20]. The optimum reclining angle for dental procedures is suggested to be around 45° to 60° [21]. These wheelchair tippers come with features such as a cradle-shaped backrest and adjustable head and neck support, making them suitable for users of various heights. However, they may be heavy, bulky, and expensive.

In Malaysia, only eight clinics provide services for persons with physical disabilities, and five of them are run by the Ministry of Health Malaysia. Furthermore, there is a sole distributor for wheelchair recliners in Malaysia. Besides, there is previous research in assisting the wheelchair user to be self-reliant using suitable sensors [22], actuators and control [23-24], such as self-transfer wheelchairs [3,7,25,26], assistive walkers for wheelchair users [27] and human-machine interface for wheelchair control [28-29], especially while transferring the wheelchair user from his wheelchair to another place. Thus, there is a need to develop a cheap and safe wheelchair recliner for wheelchair users. Such a facility would assist patients undergoing dental treatment and prevent users and dentists from musculoskeletal pain. The objectives of the study are (a) to identify the ergonomic angle of dental chairs, (b) to develop a wheelchair recliner according to the identified range of reclined angles, and (c) to analyse the performance of the developed wheelchair recliner. This paper is arranged as follows: Methods and Materials section depicts the experimental setup for analysing the wheelchair recliner. The design of the wheelchair recliner and the product development would also be presented in this section. The simulation, experimental results, and discussion of the results are presented in the discussion and results section. Lastly, the conclusion of the study is presented.

2. MATERIAL AND METHODS

2.1 Simulation Study: Design of the Wheelchair Recliner

The simulation design of the wheelchair recliner was made using Moment of Inspiration 3D, one of CAD software. The engineering drawing of the design was performed to determine the size and specifications of the design, as presented in Figures 1 & 2. The most important part of the engineering drawing is shown in the detailed view of the actuator (Figure 3) and explained in Table 1. This ensures that the parts to assemble the actuator to the wheelchair recliner are correct and in the right place.

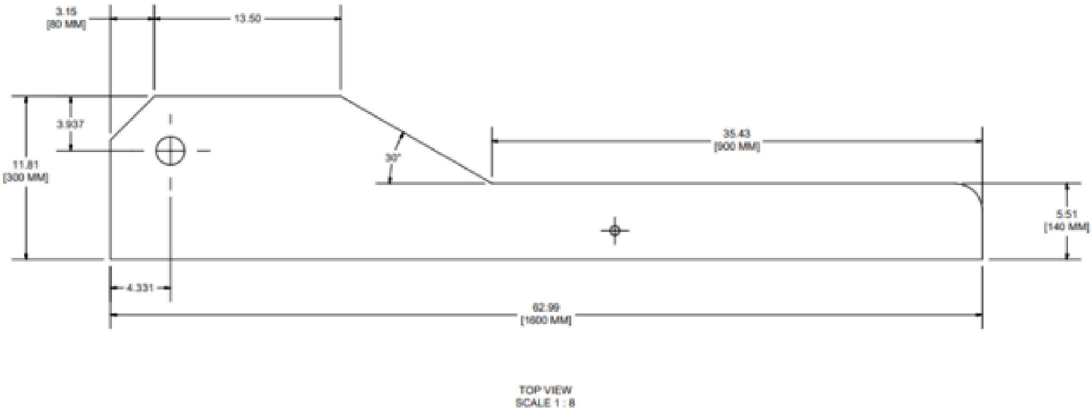


Figure 1. Outer side.

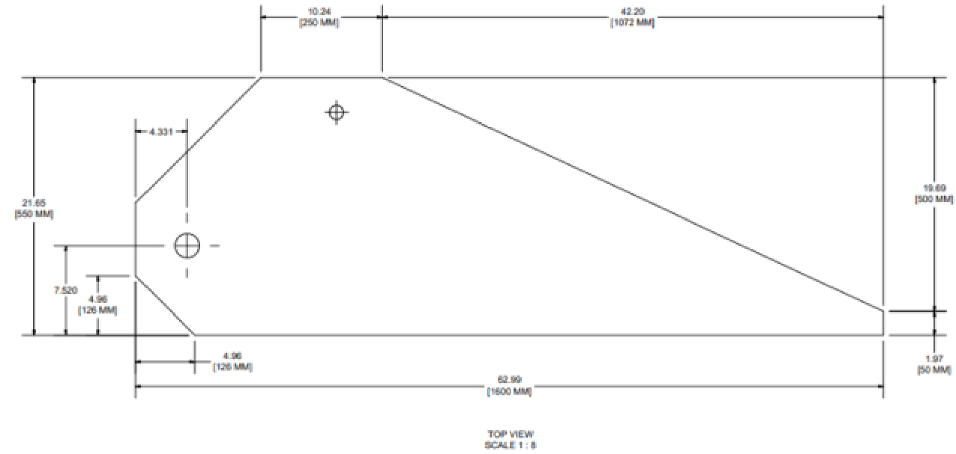


Figure 2. Inner side.

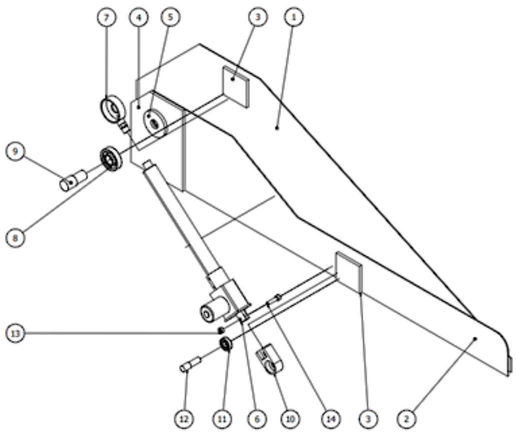


Figure 3. The detailed view of the actuator.

Table 1. Details of each part of the actuator.

Item no.	Part	Quantity	Item no.	Part	Quantity
1	Inner Side	1	8	Bearing SKF 7306 BE	1
2	Outer Side	1	9	Actuator Shaft Part 2	1
3	Rectangle Cheek Plate	2	10	Actuator Connector	1
4	Outer Side Support	1	11	Bearing SKF 7203 BE	1
5	Round Cheek Plate	1	12	Actuator Shaft Part 1	1
6	Linear Actuator	1	13	M10 Nut	1
7	Weld Nut and Pinnion Assembly	1	14	Capscrew M10 x 40MM	1

Figures 4 and 5 depict the overall design of a wheelchair recliner for dental treatment and a detailed view of the design, respectively. The wheelchair recliner's maximum mass was set at 200 kg. This is to ensure the wheelchair recliner can withstand the maximum load, which is the total mass of the wheelchair at 100 kg and the subject's mass at 100 kg.

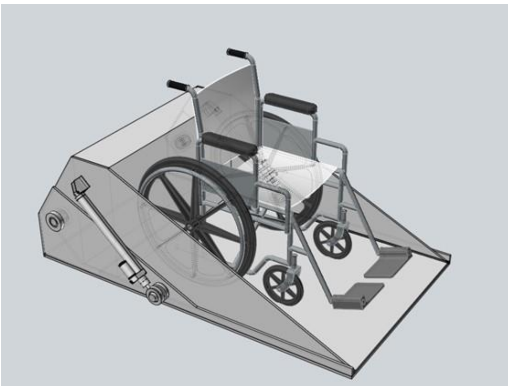


Figure 4. Overall design.

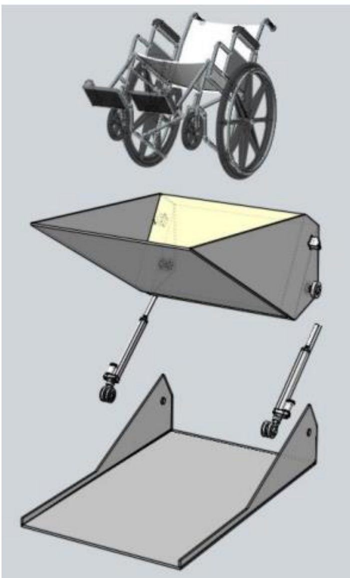


Figure 5. A detailed view of the design.

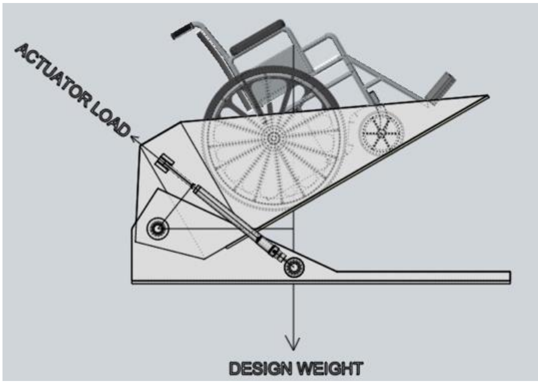


Figure 6. The direction of actuator load and design weight.

Based on Figure 6, the actuator load is calculated using the following formula:

Design mass x (Perpendicular length from pivot point/length from pivot point to actuator) x gravitation =

200 kg x (600 mm/250 mm) x 10 m/s^2 = 4800 N

The load should be divided by two since two actuators are being used. Conclusively, each actuator will need to withstand a load of 2400 N. The length of the actuator can be determined based on the primary specifications of the design, which was created in Moment of Inspiration 3D. The required length of the actuator is 549 mm. but it can be rounded off to a 550 mm actuator. Meanwhile, the required extension is until 728mm, which can also be rounded off to 750 mm. Based on this analysis, the suitable range of the actuator's length can be determined, which is between 550 mm and 650 mm.

The displacement of the bottom plate and safety factor for the pin used for the wheelchair platform based on the simulation results were analysed. The analysis was run using Inventor Professional software's Static Stress Analysis function. A long pin was used in this simulation. The projected angle for the wheelchair platform was 40°, 45°, 50°, 55°, and 60°.

A wheelchair recliner was developed based on the simulation design and analysis. The analysis of displacement and safety factors of the design and the development of the wheelchair recliner is presented in the results and discussion section.

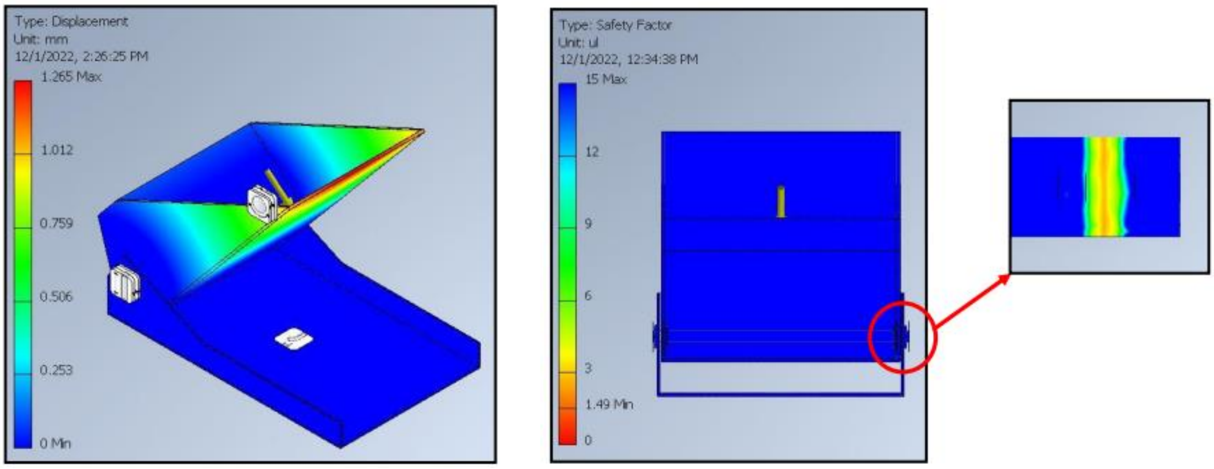
2.2 Experimental Setup

An experimental study to investigate the optimum reclining angles for different BMI subjects of the developed wheelchair recliner was conducted. Three healthy male subjects (age: 34.3 ± 21 years; height: 1.7 ± 0.1 m; mass: 80.0 ± 18.0 kg) with different BMI (normal (Subject 1): 22.8; overweight (Subject 2): 28.7; obese (Subject 3): 31.3) were recruited to test the comfort of using the wheelchair recliner. All subjects participated in the experiment with a reclined degree between 40º and 60º with a 5º increment. The BMI was calculated by dividing the subjects' weight in kilograms by the square of their height in meters. For this experiment, five reclination angles, which are 40º, 45º, 50º, 55º and 60º, were measured using an ADXL335 accelerometer. The wheelchair recliner was at 0º during the onset and increased until it reached the desired reclination angle. At the end of the experiment, all subjects were instructed to complete a questionnaire to rate their comfort level during the investigation. The comfort scale was based on a rating of 1 to 10, with one corresponding to "poor" and ten corresponding to "very good". The questionnaire includes whether they felt safe and comfortable at a certain reclination angle.

3. RESULTS AND DISCUSSION

3.1 Simulation: Analysis of Displacement and Safety Factor

A simulation study was conducted on different projection angles (40º, 45º, 50º, 55º and 60º) of the wheelchair by using a long pin. A cheek plate was added to the inner and outer plates of the wheelchair platform. The function of a cheek plate is to reinforce the main plate around the hole. Figure 7 depicts the representative simulation analysis on displacement and the safety factor for 50º. Table 2 presents the results of the overall analysis.



(a) (b)

Figure 7. (a) Safety factor of 50º angle projected and (b) The displacement of 50º angle projected (right)

Table 2. Results of the analysis

No	Angle Projected (º)	Displacement [mm]	Safety Factor
1	40	1.230	1.49
2	45	1.260	1.51
3	50	1.265	1.72
4	55	1.261	1.67
5	60	1.231	1.49

Based on Table 2, the maximum displacement obtained at the 40º projected angle is less (1.230mm) than the other angles. In other words, the reclined angle of 40° provides low stress on the structure. Meanwhile, the minimum safety factor for the 50º projected angle was higher compared (1.72) to the other angles. Overall, all the projected angles' displacement and safety factors are still within a safe region and can deflect without adverse effects.

3.2 Product Development

The wheelchair recliner was developed based on the simulation analysis. Figures 8 to 10 show the process of creating the wheelchair recliner. Figures 11 to 13 show the isometric view of the finished product and its components.

(a) (b)

Figure 8. (a) Marking and measuring on mild steel and (b) Welding of the outer side of the wheelchair recliner.

(a) (b)

Figure 9. (a) Welding of the inner side and (b) Painting process.

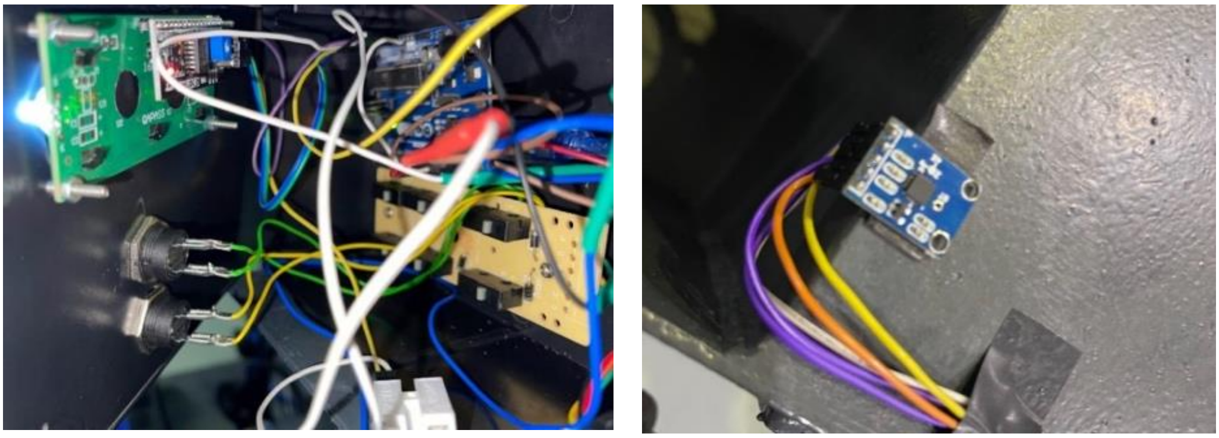
(a) (b)

Figure 10. (a) Installation of pinion and cheek plate and (b) Wheels position.

Figure 11. Isometric view of the wheelchair recliner.

(a) (b)

Figure 12. Liquid-crystal display (LCD) and switches for (a) the actuator and (b) the actuator for the wheelchair recliner.



(a) (b)

Figure 13. (a) Wiring of Arduino, LCD, and switches and (b) the ADXL335 accelerometer attached to the body of the wheelchair recliner.

(a) (b)

Figure 14. Subject at (a) 0° reclination angle and (b) 45° reclination angle.

3.2 Results from the experimental study (Comfort Scale Questionnaire)

Figure 14 illustrates how the experiment was conducted. All subjects underwent five trials, each with a different reclination angle of the wheelchair recliner, specifically at 40º, 45º, 50º, 55º and 60º. The results of the comfort scale questionnaire, which was answered by all subjects upon completing the experiment, are summarised in Table 3.

Based on the questionnaire, all the subjects felt safe and comfortable when the reclination angle of the wheelchair recliner was at 40º. They also felt safe and comfortable when the reclination angle was at 45º. However, the comfort level decreased to 7.7 when the reclination angle was 50º. Moreover, all the subjects felt neither safe nor comfortable when the reclination angle was 55º and 60º. Conclusively, the subjects felt safe and comfortable with the 40º, 45º and 50º reclination angles.

Based on the results, the wheelchair recliner can recline to 60º. However, the subjects did not feel safe or comfortable in the wheelchair on the wheelchair recliner at 55º and 60º reclination angles. This is due to a possible risk for the subjects to fall backwards as the wheelchair becomes unstable, affecting their comfort. This study's results align with previous research where the optimum reclining angle is approximately 45º to 60º since it is the most efficient position for performing dental treatment [20].

Safety precautions need to be added to the wheelchair recliner, such as a safety belt, so the wheelchair recliner can safely tilt the subjects to the desired angle. One of the limitations of the design is the subject's centre of gravity on the wheelchair as it tilts was neglected. Therefore, when it reclines to more than 50º, the subject might fall backwards as the load is added and the centre of gravity changes. A headrest should also be added to the design. The headrest can avoid the subjects' neck pain and provide stability for their head.

Table 3. The results of the comfort scale questionnaire (Visual analogue scale: 0 = poor, 10 = very good).

Reclination angle	40^0	45^0	50^0	55^0	60^0
Subject 1	10	10	8	1	1
Subject 2	10	9	8	2	1
Subject 3	10	9	7	3	1
Mean ± SD	10.0 ± 0.0	9.3 ± 0.6	7.7 ± 0.6	2.0 ± 0.0	1.0 ± 0.0

4. CONCLUSION

In conclusion, the developed wheelchair recliner platform can withstand the load of 2000 N and can tilt the wheelchair to 40°,45º, 50º, 55º and 60º, which are within the optimum tilt angle for dental treatments. The developed wheelchair recliner is also suitable for wheelchair users with different BMI categories.

CONFLICTS OF INTEREST

The authors reported no potential conflict of interest.

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