Stress Distribution and Displacement Analysis to Design of Patient Lifting Equipment

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Abstract. Patient lifting equipment can help the lifting of patient movement completely. It can help reduce the risk of disease that can be caused by lifting the patient and reduce the impact on the patient caused by lifting the patient in the wrong way. In addition, it can help to reduce the working time and reduces the number of personnel in moving patients. Including it can be to prevent the occupational disease on the service providers. This study aims to analyze the stress distribution and displacement to design of patient lifting equipment. The three weight conditions of 60 kg, 80 kg, and 120 kg are considered for studying about stress distribution and displacement at various points. In this test, ASTM A36 steel is used as a strength material tester. The results found that the maximum stress distribution and displacement is in the sling bar of the equipment. The obtained values will provide a basis for the guideline to design of patient lifting equipment to lift patients to suit in each situation such case from a private car go to bed or and wheelchair and from bed or and wheelchair go to a private car.

1. Introduction

Nowadays, the number of patients has been increasing every year that does not include patients who can help and move themselves. According to Ramathibodi Facilities Services (RFS) survey, there were patients average more than 350 people per day who come to healed at Ramathibodi hospital and they are necessary to use wheelchair or stretcher, as shown in Figure 1 [1]. For handling of patients who are unable to help themselves, it is necessary to have relatives or service staff in moving patients. Especially hemiplegia case and paraplegia case, the handling in movement needs to be accurate according to the principles of physiology for increase safety of moving patients from car to wheelchair or stretcher and moving patients from wheelchair or stretcher to car. However, the handling of patients who are unable to help themselves by carrying, lifting by hand, bearing, or lifting that incorrect according to the principles of physiology may cause harm to the patients [2-3]. In addition, it may result in the relatives and the service staffs being injured by handling the patient in moving or lifting patients such as low back pain (LBP), musculoskeletal disorders (MSD) and joint disease [3]. Many researches have been done to develop and evaluate of a multifaceted ergonomics program to prevent injuries associated with patient handling tasks [4-5]. Nelson A et al. [4] designed and implemented a multifaceted program that successfully integrated evidence-based practice, technology, and safety improvement to evaluate the impact of the program on injury rate, self-reported unsafe patient handling acts, level of support for program, staff and patient acceptance, program effectiveness and costs. The program elements resulted
in a statistically significant decrease in the rate of musculoskeletal injuries of staffs as well as the number of modified duty days taken per injury. Reviewing the research related to the implementation of comprehensive patient-handling programs to improve staff quality retention and reduce time-to-injury was presented by Wardell H [5]. Efforts to reduce injuries associated with patient handling are often based on tradition and personal skills include using patient lifting and movement equipment. The utilization of patient-handling equipment and devices is a more efficient engineering control strategy within the health care for both of patients and staffs [6]. Many researchers studied about the preventing injuries using patient-handling equipment in movement. For example, Bernice D and Owen R N [7] studied the preventing of problem of nurses’ back and shoulder overexertion injuries in patient-handling tasks (e.g. transferring patients on and off stretchers, repositioning patients on operating room (OR) beds) using an assistive devices include the stand-up mechanical lift. The results showed that the using the patient-handling equipment can decrease the perceived physical stress and the injury rate of nurses.

The patient handling tasks with high risk for musculoskeletal disorders in health care using a powered transport device was studied by Waters T R et al. [8]. Burdorf A et al. [9] evaluated the effect of manually lifting patients on the occurrence of low back pain (LBP) among nurses and estimated the impact of lifting device use on the prevention of LBP and musculoskeletal disorder (MSD) injury claims. The results indicated that the lifting device provides a good result in significantly reducing the injuries of LBP and MSD. Therefore, several technologies were presented to improve the effectiveness of patient handling in movement tasks and reduce the risk for musculoskeletal disorder significantly for caregivers such as gait belts, transfer chairs, powered stand-assist and repositioning lifts, powered full-body sling lifts, sliding boards, gait belts and stand-assist and repositioning aids [10]. However, each device has different strengths and limitations as well as suitable for different usage situations. Traditionally, gait belts are a popular for transferring patients from a sitting to a standing position without any assistive device due to it is low-cost solution [6]. However, gait belts are not suitable for vertical transfers of weight-bearing patients. The handling of patients from bed to chair transfers using gait belts is difficult because lifts are involved. The sliding boards use for seated bed to chair or chair to toilet transfers, low-cost, rigid and smooth, low-friction material and act as a supporting bridge when seated slide transfers are done but some manual lifting is required. The stand-assist and repositioning aids can support patients that need only minimal assistance to stand up. In the operating room needs to use the moving equipment to help horizontal transfers of patient from bed to stretcher or operating room table [11]. The bed repositioning, performing tasks alone, features of a bathroom, and height-adjustable beds are required for safe patient handling and movement in home care [12]. Although there are many devices to help handling of patient, the lifting of the patient is still not complete, especially moving the patient in a restricted area such as from car to wheelchair or stretcher and moving patients from wheelchair or stretcher to car. In addition, the basis of the strength analysis of the structure design to analyze the stress distribution and displacement of the device is still minimal due to computer program limitations. A comprehensive understanding of the fundamentals of strength analysis will help the recommendation to design of patient lifting equipment to lift patients for appropriate use in each situation.

In this study focuses on the analysis of stress distribution and displacement to design of patient lifting equipment. The variations in three weight conditions i.e. 60 kg, 80 kg, and 120 kg are investigated. The ASTM A36 steel is considered as a material for strength testing. The Solidworks simulation program is used for structural analysis of patient lifting equipment design. The main components of the patient lifting equipment are built and simulated via a three-dimensional model. The results obtained from the simulation solution are examined and compared with the analytical solution using two-dimensional model to verify the accuracy of the present numerical model. The obtained results of this work will used to capture design knowledge for patient lifting equipment to lift patients and may be of assistance in determining practical guideline to improve handling of patient process in patient-care situations.
2. Designs

2.1. Structural design

The design must comply with structural calculations to refer to the height, width and weight of the patient lifting equipment. From the general car survey at the lowest altitude to the highest altitude that leads to the most appropriate level of access to design the patient lifting equipment. For a more efficient, it is necessary to measure the distance of the equipment to the point where the patient is sitting in the car to be a component of the equipment and the length and width of the equipment that the patient will be able to be balanced while lifting and moving patients. In addition, it is necessary to survey and store the height of the car door gap in each model. The design of the equipment size must be most convenient to use for smallest vehicle condition.

The design will start with a literature review and summary of information related to the general procedure to transfer patient, conceptual design, preliminary design and structural design analysis. Due to the cost, size factor and convenience, the computer program is choose to analyze the strength of the structure. The ASTM A36 steel is used as a test material for structural strength. Table 1 shows the mechanical properties of ASTM A36 steel material used in the computations. The stress distribution and displacement are analyzed to design of patient lifting equipment. The three weight conditions of 60 kg, 80 kg, and 120 kg are considered for studying about stress distribution and displacement at various points. The basic feature, part functions, advantages and limitations have been analyzed accordingly. Improving the design and mock-up inspection is prepared before proceeding to the final design concept and creating the actual equipment. The design process flowchart is shown in Figure 2. From all information, the design specification is shown as follows:

- For user with weight supports up to 120 kg on each position for lifting the patient.
- The maximum overall size of 1010 mm x 1150 mm x 1130 mm (shown in Figure 3).
- The overall weight of equipment is 75 kg.

The equipment design is shown in Figure 3. The components of the equipment can be divided into three major components, namely the sling bar, boom lift and core and base, as shown in Figures 4-6, respectively.

2.2. Computer simulation

The computer simulation of the preliminary design is performed using Solidworks simulation program. The analysis of stress distribution and displacement using finite element method on one of the most critical part, which is the sling bar at various weight conditions are performed. The three-dimensional model is discretized using triangular elements to approximate the stress distribution and displacement...
variations across each element. A grid independence test is carried out to identify the appropriate number of elements required. This grid independence test leads to a mesh with approximately 59,052 elements. It is reasonable to assume that, at this element number, the accuracy of the simulation results is independent of the number of elements. To obtain a good approximation, a fine mesh is specified in the sensitive areas. This study provides a variable mesh method for solving the problem as shown in Figure 7. During the preliminary design stage, a more detailed design has been considered based from the conceptual data. For this simulation, the load of 60 kg, 80 kg, and 120 kg are applied of sling bar which represent the weight of the patient. The boundary condition for analyzing stress distribution and displacement at various points are also shown in Figure 7. To verify the accuracy of the present numerical model, the results obtained from the simulation solution are compared with the analytical solution using two-dimensional model.

Table 1. The mechanical properties of ASTM A36 steel material used in the computations used in the numerical simulation.

| Property           | Value     | Units   |
|--------------------|-----------|---------|
| Elastic Modulus    | 2x10¹¹    | N/m²    |
| Poisson’s Ratio    | 0.26      | -       |
| Shear Modulus      | 7.93x10¹⁰ | N/m²    |
| Mass Density       | 7850      | kg/m³   |
| Tensile Strength   | 4x10⁸     | N/m²    |
| Yield Strength     | 25x10⁷    | N/m²    |

Figure 2. The design process flowchart.
3. Results and Discussion

Figure 3. The equipment design.

Figure 4. The sling bar component.

Figure 5. The boom lift and core component.

Figure 6. The base component.

Figure 7. The three-dimensional mesh generation of equipment design and boundary condition.
3.1. Verification of the model

The accuracy of the present numerical model is verified with the analytical solution using twodimensional model at various loads. The equation below is used to calculate the stress distribution of sling bar.

\[ \sigma = \frac{Mc}{I} \]  

(1)

where \( M \) is the maximum bending moment (N.m), \( c \) is the distance from the neutral plane (m) and \( I \) is the moment of inertia (m^4)

The comparison of stress distribution of simulation results with the analytical results in case of load of 60 kg, 80 kg, and 120 kg are shown in Figures 8-10, respectively. The calculation of the stress distribution using the analytical solution in case of load test of 60 kg, 80 kg, and 120 kg are shown in Equations (2)-(4), respectively. It is found that the stress distributions of sling bar of simulation results are in excellent agreement with the stress distributions of sling bar of analytical solution. Certain amounts of mismatch between the simulation results and the analytical results are caused by the numerical scheme. Figures 8-10 show that an increase in the load test results in an increase stress distribution. The comparisons of the percent error between simulation results and the analytical results are displayed in Table 2.

\[ \sigma = \frac{Mc}{I} = \frac{32Fl}{\pi d^3} = 91.91 \text{ MPa} \]  

(2)

\( L = 470 \text{ mm} \)

\( F = 600 \text{ N} \)

\( l = 235 \text{ mm} \)

\( d = 32 \text{ mm} \)

\( F_l = 600 \text{ N} \)

86.78 MPa

**Figure 8.** The comparison of stress distribution of analytical result with the simulation result in case of load of 60 kg (a) analytical method and (b) simulation method.
\[ \sigma = \frac{Mc}{Fl} = \frac{32Fl}{\pi d^3} = 122.56 \text{ MPa} \] (3)

Figure 9. The comparison of stress distribution of analytical result with the simulation result in case of load of 80 kg (a) analytical method and (b) simulation method.

\[ \sigma = \frac{Mc}{Fl} = \frac{32Fl}{\pi d^3} = 183.34 \text{ MPa} \] (4)

Figure 10. The comparison of stress distribution of analytical result with the simulation result in case of load of 120 kg (a) analytical method and (b) simulation method.
Table 2. The comparisons of the percent error between simulation results and the analytical results.

| Weight (N) | Analytical Method (MPa) | Numerical Method (MPa) | Error (%) |
|------------|-------------------------|------------------------|-----------|
| 600        | 91.91                   | 86.78                  | 5.58      |
| 800        | 122.56                  | 115.70                 | 5.60      |
| 1200       | 183.34                  | 173.60                 | 5.31      |

3.2. The effects of load test on the stress distribution

The effects of load test on the stress distribution of equipment design in case of load of 60 kg, 80 kg and 120 kg are shown in Figures 11–13, respectively. Figures 11–13 show the corresponding results, the maximum stress distribution occur at the position of sling bar because it is the part that accepts weight from patient. In addition, also found that the maximum stress distribution occur at the joints of the lower sling bar and the upper sling bar. Considering the influences of load test on the maximum stress distribution in each case, it can be seen in case of load of 120 kg has more maximum stress distribution than in case of load of 80 kg and in case of load of 60 kg, respectively. It is found that the maximum stress value in case of load of 60 kg is 76.76 MPa, in case of load of 80 kg is 105.00 MPa and in case of load of 120 kg is 157.50 MPa, respectively. Moreover, considering the maximum stress value, it is found that in each case will not exceed the yield strength (refer to the Table 1) which it shall not reach the failure state based from the design specification.

![Figure 11](image1.png)  
**Figure 11.** The stress distribution of simulation result in case of load of 60 kg.

![Figure 12](image2.png)  
**Figure 12.** The stress distribution of simulation result in case of load of 80 kg.
3.3. The effects of load test on the displacement

Figures 14–16 displays the effects of load test on the displacement of equipment design in case of load of 60 kg, 80 kg and 120 kg, respectively. It is found that the displacement results follow the stress distribution results. The maximum displacement occurs at the position at the end of the sling bar. This is due to the distance between load and fulcrum point, which is accepts weight from patient. The higher load results in higher stress distribution and greater stretching displacement. It can be seen in case of load of 120 kg has more maximum displacement than in case of load of 80 and in case of load of 60, respectively. It is found that the maximum displacement in case of load of 60 kg is 8.111 mm, in case of load of 80 kg is 10.82 mm and in case of load of 120 kg is 16.22 mm, respectively.

4. Conclusions

This research is carried out to prepare the preliminary design of the equipment design (using lifting mechanism) by focusing on the engineering design process and simulation the strength of the structure through simulation software. The effects of load test on the stress distribution and displacement variations in three weight conditions i.e. 60 kg, 80 kg, and 120 kg are investigated. The ASTM A36 steel is considered as a material for strength testing. The finite element method is performed for structural analysis of patient lifting equipment design. Three-dimensional model of equipment design are considered in this work. The simulation results with computer programs are validated with analytical results using two-dimensional model. The results show that the higher load results in higher stress distribution and greater stretching displacement. It is found that the maximum stress distribution and displacement occurs at the position at the sling bar. The obtained results in this research will provide basic concept on the design in respect of the equipment to help handling of patient. In the future, further investigation and design improvement shall be made to improve the preliminary design and lead to the creation of a prototype.
Figure 14. The displacement of simulation result in case of load of 60 kg.

Figure 15. The displacement of simulation result in case of load of 80 kg.

Figure 16. The displacement of simulation result in case of load of 120 kg.
5. References

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