**Authors:** Faisal Fakhouri[1,2], Abdulaziz Fakhouri[1,2], Muhammad Farzik Ijaz[3,2], Majed Alotaibi[1], Abdulqader Almalki[1]
**Affiliations:** department of biomedical technology, college of applied medical sciences, king saud university, riyadh, 12372, saudi arabia[1], king salman center for disability research, riyadh, p.o. box 94682. riyadh 11614, saudi arabia[2], department of mechanical engineering, college of engineering, king saud university, po box 800, riyadh, 11421, saudi arabia[3]
**Orcid ids:** 0000-0002-1185-8067[1,2], 0000-0002-9856-3412[1,2], 0000-0003-2338-023X[3,2]
**Contact e-mail:** ffakhouri@ksu.edu.sa

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*Article*

# Improvisation of Finite element analysis for designing an After Fall Assistive Device for the Elderly Patients

**Faisal S. Fakhouri [1,2,*], Abdulaziz S. Fakhouri [1,2], Muhammad Farzik Ijaz [2,3], Majed Alotaibi [1], and Abdulqader Almalki [1]**

[1] Department of Biomedical Technology, College of Applied Medical Sciences, King Saud University, Riyadh, 12372, Saudi Arabia
[2] King Salman Center for Disability Research, Riyadh, P.O. Box 94682. Riyadh 11614, Saudi Arabia
[3] Department of Mechanical Engineering, College of Engineering, King Saud University, Po Box 800, Riyadh, 11421, Saudi Arabia
* Correspondence: author: Faisal Saud Fakhouri, ffakhouri@ksu.edu.sa

**Abstract:** Falling on the ground can cause serious injuries such as bruises, broken bones, head injuries, etc. Annually 684,000 individuals die globally from falling on the ground. There are more than 37 million fall injuries that requires medical care each year. The Center for Disease Control and Prevention (CDC) anticipates seven fall deaths every hour by 2030. In Saudi Arabia, falls are the 6th major cause of death, and the 7th major cause of living with a disability. Furthermore, falling on the ground becomes a risk factor with age, obesity, and presence of balance affecting diseases due to fact that individuals have difficulty getting up after a fall, and the majority of them stay on the ground for more than an hour. As a result, the risk of multiple injuries, dehydration, pressure ulcers, rhabdomyolysis, hypothermia, and pneumonia increase. This study aims to design and analyze a device that can assist individuals, especially seniors, at risk to rise up after a fall on the ground with no external help from others. The design of the device was modelled using SolidWorks 2017 (Dassault Systems, Waltham, MA, US). Also, finite element analysis (FEA) was performed to study von Mises stresses and total deformation on the model. FEA results showed that the device could withstand to lift an overweight individual from the ground without reaching the maximum failure stress of a conventional material such as aluminum.

**Keywords:** Balance disability; After-fall assistive device; Design; Finite element analysis; Walking Aid; Rise-up aid; After falling aid

## 1. Introduction

Falling on the ground and rising up from a fall has emerged as a major challenge recently. As defined by the World Health Organization, a fall is an act of "inadvertently coming to rest on the ground, floor or other lower level, excluding intentional change in position to rest in furniture, wall, or other objects". A fall can cause serious injuries such as bruises, broken bones, head and neck injuries, and/or emotional distress[1]. Annually, 684,000 individuals die from falls globally, which is considered the second largest cause of unintentional injury death. There are more than 37 million fall injuries that requires medical care yearly[2]. The Center for Disease Control and Prevention (CDC) of the United States of America anticipates seven fall deaths every hour by 2030[3,4]. In Saudi Arabia, falls are the sixth major cause of death and the seventh major cause of living with a disability[5].

Falling on the floor is associated with multiple risk factors such as 1) Biological factors, which cannot be modified such as age, gender, race, and chronic diseases. 2) Behavioral factors, which focus on human actions, emotions, daily choices, drug interactions, and excess alcohol use. 3) Environmental factors, where most of the falls occurred indoors, due to poorly designed houses, poor lighting rooms, and slippery floors such as the bathroom wherein most falls occur. 4) Socioeconomic factors, such as living alone, low education, low salary, social isolation, restricted health care, and limitation of resources[2]. In addition to the risk factors mentioned above, obesity can be considered as a risk factor that plays a role in all previously mentioned factors[6].

Given that seniors are a vulnerable segment of society, obese seniors who have a body mass index (BMI) of ≥ 40 $\mathrm{kg/m^2}$ face a greater risk of falling by 16% compared with a nonobese seniors[1,7]. In a study by Cameron et al. on resident seniors in long-term facilities health care it was found that %56.2 of seniors fell once at least during six months' time span[8]. A study performed on 269 seniors found that 84.7% of the falls were indoors such as the washroom (27.8%), stairs (25%), and bedroom (16.7%)[1]. Occasionally there are falls which occur at the front doorstep (15.3%) or in the kitchen (12.5%). Outdoor falls were infrequent with only 15.3%[1] of reported total falls.

With aging, falling can be considered as a risk factor, as well as the inability to rise up after a fall[3,4,9]. 50% of the seniors face difficulties in rising up after falling on the ground and most of them stay laying on the floor for more than one hour, which may increase the risk of pressure sores, pneumonia, and even death[10]. In a study conducted on 110 seniors, it was reported that 60% fell on the floor in which the majority fell at least twice[11]. And among them 265 fall incidents were reported from which 54% were found on the floor. Of those who fell, 82% said that they were alone at the time of the fall. Furthermore, four out of every five people needed assistance getting up, and one-third remained on the floor for more than an hour[11]. Those who remained on the floor for more than 2 hours after a fall, faced an increased risk of dehydration, pressure ulcers, rhabdomyolysis, hypothermia, and pneumonia[12].

There are multiple techniques to reduce the risk of falls and help to stand after a fall. These techniques include devices that prevent from falling or assist after a fall. Some examples of these devices include but are not limited to, a motion sensing device that follows postoperative senior patients in the hospital to ensure their safety from falling by catching the patient and preventing their fall[13]. Another example, a chair like device that assists users to rise after a fall by lifting them up. However, in these solutions, there is a need for a third-party assistance to deliver the chair and assist the user[14]. Furthermore, a sling-like device is needed to lift the user after a fall, then transport him/her with lifting and mobility mechanisms to the chair or bed. The device can be used for different purposes; however, it is mostly used in hospitals for lifting patients as needed[15].

In addition to devices that assist users after a fall, there are also devices that detect falls either during or after happening, which account for the majority of devices in the market[16]. Wearable fall detection devices use an accelerometer to detect falls when they happen. During a fall, the accelerometer triggers the system to send an alert to previously designated personnel. The detector is located mostly on the waist (lumbar area) [17,18]. Another technique, is mounting detection cameras on walls, which detect a fall when any part of the body touches the ground (except the feet, to prevent false positive detection when the person is walking)[19,20].

To this end, this study aims to design a device that assists users to rise after a fall independently while maintaining the device's mobility, low cost, and easiness of use (no third-party assistance needed). The proposed device is to be able to withstand vast range of weights and heights. Furthermore, this study aims to analyze total deformation and von-Misses stresses on the design by using finite element analysis (FEA) methods to ensure suitability of design to withstand applied loads.

## 2. Methods

### *2.1. Operational Steps:*

The focus in this study is to design a device that can carry a heavy weight senior or patient and be mobile at the same time. The general idea of the proposed design is a walker aid with piston leg support and foldable seat; the seat can be rotated by 90 degrees to allow the senior to sit on. The piston allows the walker to be lowered to half of the leg length and assist the senior during rising action (Figure 1). A three-dimensional computer aided design (3D CAD) model was designed by using SolidWorks 2017 (Dassault Systems, Waltham, MA, US). As shown in Figure 1 below, (A) is the walker's grip on which the user will support him/herself and move the walker as needed. The walker's grip needs to be comfortable (soft on the hands) as well as strong to handle the force created by the user's weight. (B) is the seat that is connected to the pole (C) which is also attached to the grip (A). (D & E) are the pistons that are responsible for the ascendance and descendance of the walker aid.

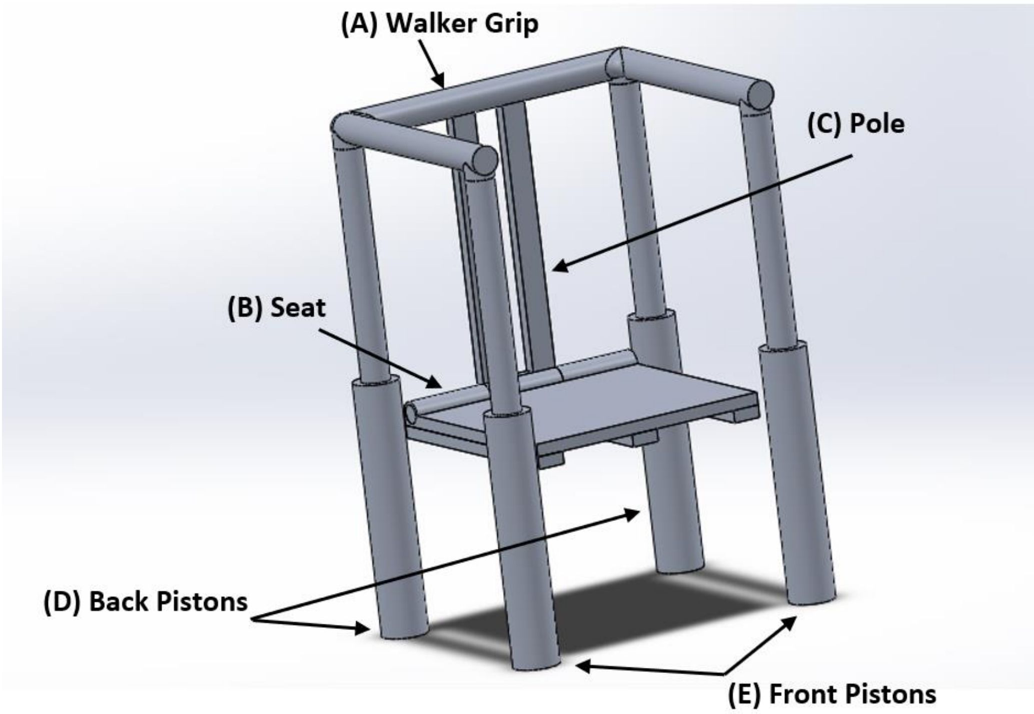


**Figure 1.** Fully assembled device parts. (A) is the walker hand grip. (B) is the seat which is supported by pole (C). (D & E) are back and front pistons which perform the lifting mechanisms.

As shown in the steps of operation flow chart below (Figure 2) when a user falls, he/she should press a button in which the seat will rotate by 90° from a standing position to seating position (Figure 2a to 2b). This will cause the piston to lower itself by half the height in which the seat will reach the ground (Figure 2b to 2c). Then, the senior can sit on the seat that is flat on the ground and press the button again which will result in the pistons going back to their original height. After that the seat will be in the normal standard seating high (around 45cm from the ground) (Figure 2b) allowing the senior to stand up again as if they are standing up from a normal chair. After the rise of the senior the seat will lock to its initial standing state (Figure 2a) allowing the senior to use the walker as a conventional walker again.

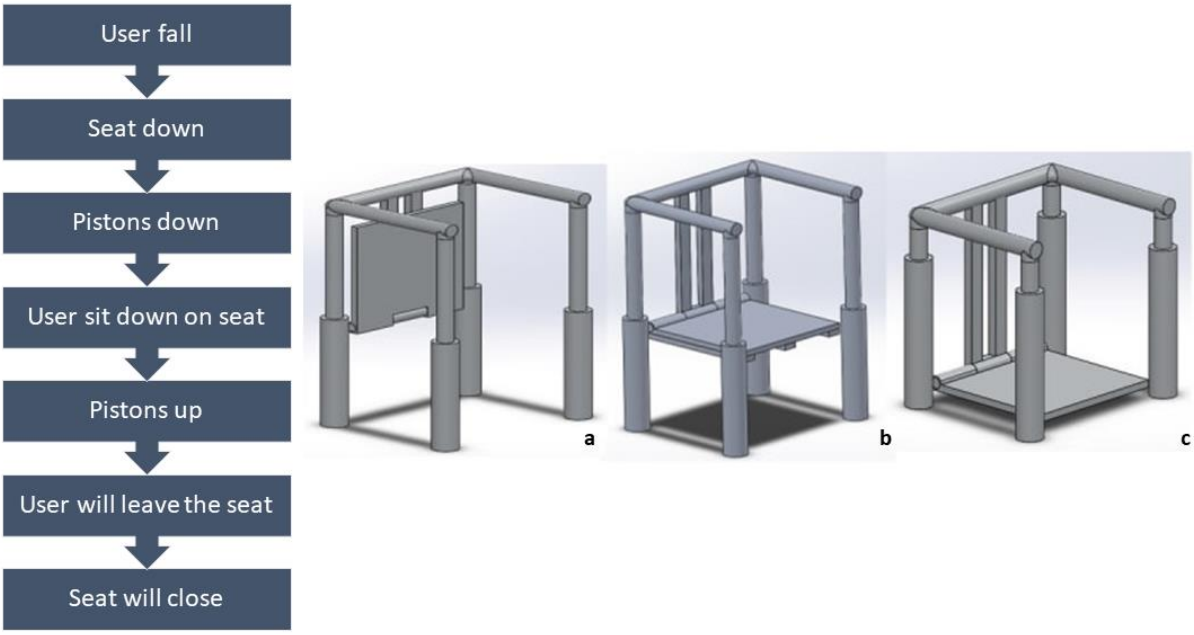


**Figure 2.** Device's operational steps (flow chart) and the procedure for rising a user up. (a) the device in normal position. (b) when the user unfolds the seat. (c) the device is lowered for lifting up the senior. During rising up, the procedure is reversed from step (c) to step (a).

### *2.2. Stress Analysis*

Stress analysis using the von Mises yield criteria is used to study the material's yield point and show the locations of stress concentration on the actual design. Von Mises analysis is mostly used for ductile materials such as metals, in which aluminum was used for this walker. Furthermore, total deformation was investigated, in which it measures how much plastic strain is the model facing due to external loads. For the Finite Element Analysis (FEA) simulation, aluminum alloy was assumed for the U-shaped walker grip due to its lightweight and durability, which is expected to be used in the prototype to make the walker light and mobile. For the pistons and seat supporting pole, stainless steel was used due to its high stiffness and endurance.

## 3. Results

### *3.1. Finite Element Analysis*

For FEA, Ansys 2022 R1 (Ansys Inc., Canonsburg, PA, US) was used to perform static structural analysis on the proposed design to get total deformation and von Mises stresses on the walker's different parts.

The walker system was meshed as shown in Figure 3a using tetrahedral elements, as this element type is suitable for irregular meshes. The number of nodes in the model were 88400 nodes and the number of elements were 47187 elements with a size of 2 cm = 0.02 m. The walker was fixed (boundary condition) at the base of each piston at the bottom of the four pistons. This was done at full expansion and full retraction of the four pistons (Figures 3b & 3c).

The walker was fixed at the base of the pistons and two loads were applied separately. The first load was applied on the seat with a magnitude of 1400 N (i.e. a mass of approximately 142 kg) while the seat was elevated and lowered, respectively (**Error! Reference source not found.**a & b). The second load was applied on the grip with a magnitude of 504 N on each side, which is considered 36% of the senior's weight during a full stand up (Figure 4c)[22].

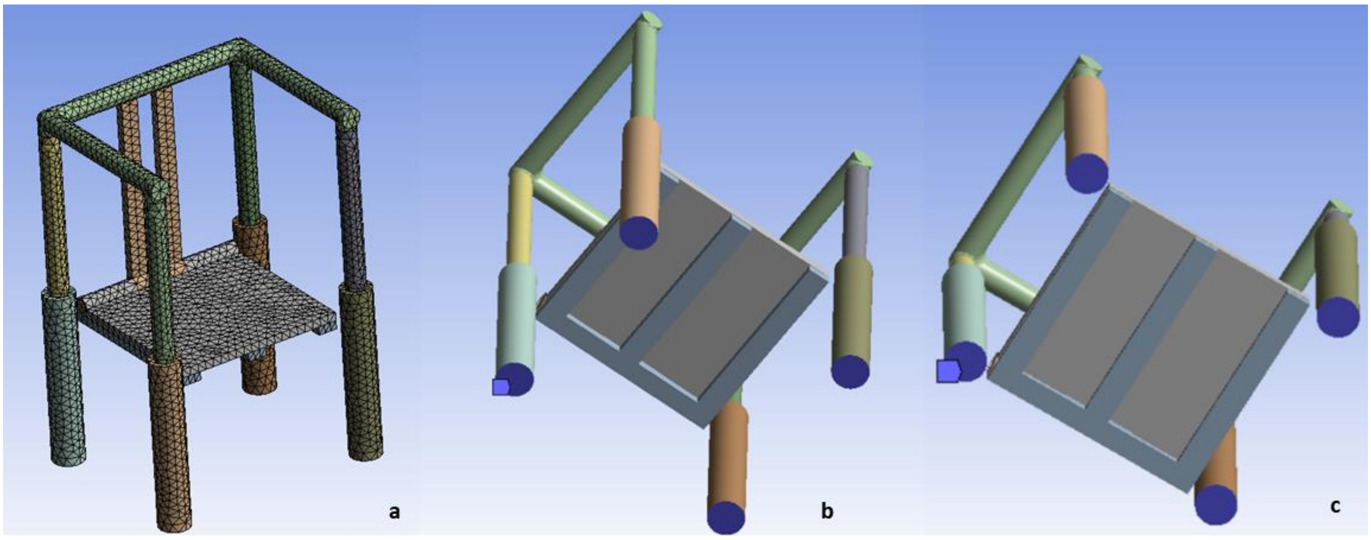


**Figure 3.** Finite element meshed walker (a), walker fix points (boundary condition) at full expansion of pistons (b) and full retraction of pistons (c).

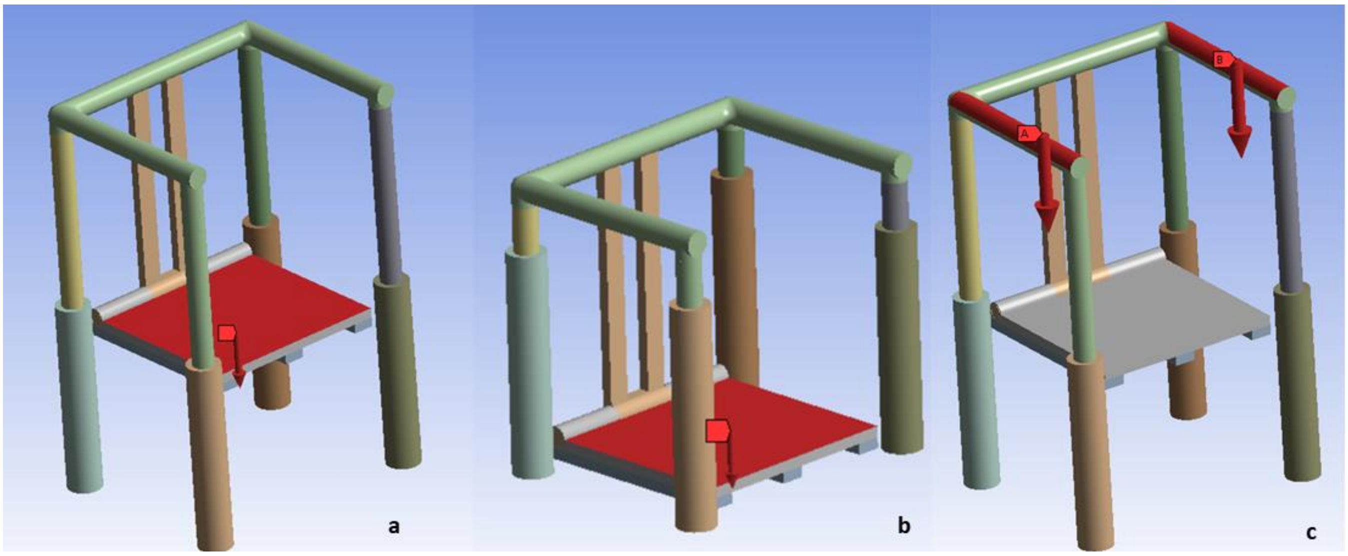


**Figure 4.** The load on the seat during full expansion of pistons (a) and full retraction of pistons (b). Also, the load on the grip during full expansion of pistons – fully standing (c).

*3.2. Weight Impact on the Seat*

As the seat is lowered to the smallest distance above the ground, by fully retracting all pistons, and the load of 1400 N was applied to the seat as shown in Figure 5, the total deformation was increasing starting from the supporting pole (96.07 μm) to the distal end of the seat (245.41 μm - maximum deformation) (Figure 5a). Whereas the supportive pole and the grip experienced lower deformation, 66.04 μm and 5.52 μm, respectively. The von Mises stress analysis shown in Figure 5b shows that maximum stress of 19.78 MPa was in the connections between parts (i.e. seat and poles).

When the pistons are at full expansion, the total deformation was increasing from the supporting pole (153.61 μm) to the distal end of the seat (345.63 μm - maximum deformation). Regarding the von Mises stresses (d), the maximum stress was 24.73 MPa at the connection between the seat and the supporting pole.

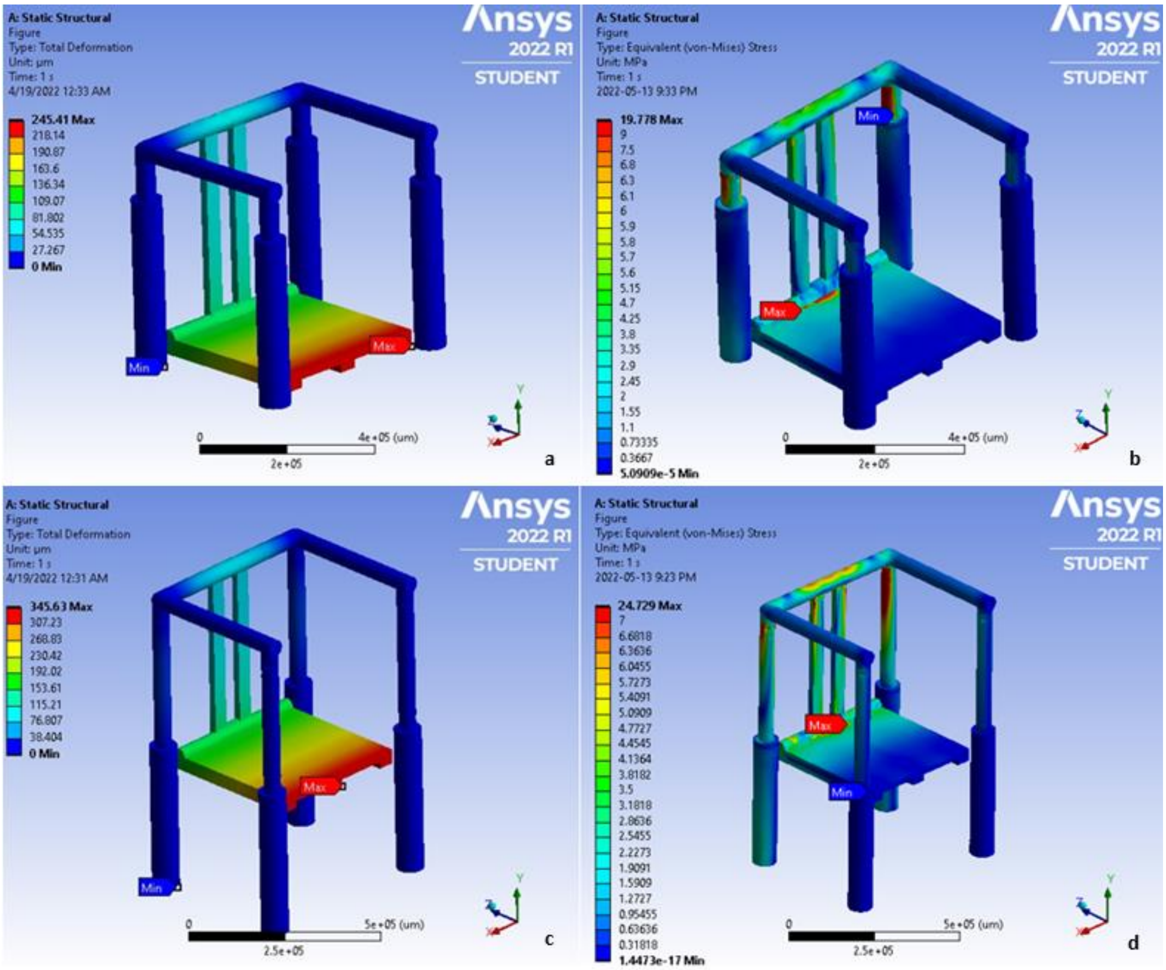


**Figure 5.** Full retraction and expansion of pistons results. (a) Total deformation and (b) von Mises stress at retracted pistons. (c) Total deformation and (d) von Mises stresses at full expansion of pistons.

## *3.3. Weight Impact on the Hand Grip*

Figure 6a shows that the maximum deformation was located where the user holds the walker aid with a magnitude of 16.43 µm. Concerning von Mises stresses (Figure 6b), the maximum stress is located at the connection between the piston and hand grip with a stress of 3.57 MPa.

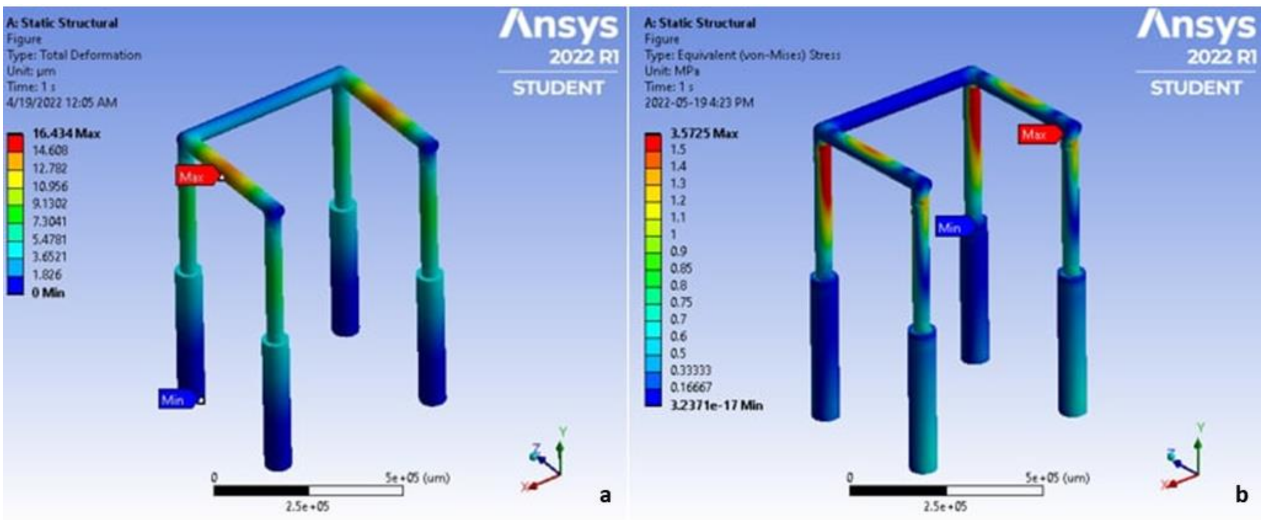


**Figure 6.** Hand grip results. (a) Total deformation and (b) von Mises stress.

## 4. Discussion

The present research was aimed to design a mobile and easy to use after fall assistive device based on a conventional walker. For the CAD model, Solidworks 2017 was used, and FEA was performed by using Ansys 2022 R1 to analyze von Mises stresses and the total deformation on walker aid as a whole and during operation. It was found that the von Mises stresses reached a maximum of 24.73 MPa. And it was found that the total deformation reached a maximum of 345.63 μm.

The results of the weight impact on the seat indicate that the total deformation of lowered pistons (Figure 5a) on the pole was 96.07 μm and the amount increases until it reaches the distal end of the seat which has the maximum deformation of 245.41 μm on the seat. This is due to the seat support location and connection in which the supporting pole is located at one end of the seat only, while the distal end (i.e. other end) of the seat has no supports to allow the user to access the seat. Regarding the full expanded pistons (Figure 5c), the maximum total deformation was 345.63 μm which was greater than fully retracted pistons due to the lack of support of the ground under the seat and the higher the center of gravity of the patient. The deformation of the seat from the furthest end can be managed by adding a rope or a metal string that passes under the seat and latches to the grip. This string will act like a hanged bridge's main/suspender cables.

As for the von Mises stress analyses for retracted (Figure 5b) and expanded (Figure 5d) pistons, the maximum stress on the hinge was 19.78 MPa and 24.73 MPa, respectively, which does not exceed the yield strength of the chosen material (i.e. yield stress for SAE 304 stainless steel is 515 MPa and 110 MPa for 6061 aluminum), taking into consideration that it is subjected to a load of 1400 N (i.e. a mass of 142 Kg). Additionally, the results of the FEA shows that when the pistons are at full height the maximum stress is larger in comparison to when the pistons are lowered. This is due to the support of the lead screw inside the piston tube. The von Mises stress on the hand grip (Figure 6b) as a result of the user's weight shows that the maximum stress was 3.57 MPa in the connection between the piston and hand grip due to the higher load of the upper body in comparison to lower body. Von Mises stress analysis shows that the device experienced significantly lower stresses than yield stress of the material. Given that, the safety factor of the material is approximately 515/24.73 = 20.82 for stainless steel and 110/3.57 = 30.81 for the aluminum.

The design of the device combines two ways of assistance. In the expanded position the device prevents the user from falling with four point of floor contact to increase the area of support base and keep center of gravity within the device, that allows more stable walking action. In the incident of falling, the user can push a button once to open the seat and lower the pistons to half the height of the device conveniently. Then, the seat will be located at the smallest distance above the ground which allows the user to sit on. After that the user has to press the button again to raise him/her up with the pistons. The mobility of the design allows the user to have the device most of the time with him/her to use as a conventional walker or as an after fall assistive device.

As mentioned earlier in the introduction, there is a general issue of rising up after a fall especially for seniors and people with diseases that affect their balance such as Multiple Sclerosis, Arthritis, Parkinson's, Osteoporosis, etc., as more than half of them stay on the floor for more than an hour. After falls, 75% of seniors visit the doctor's office and 33.3% call for healthcare professionals[23]. During hospital discharge plan, they advise patients to get home care services (i.e., home health agencies and visiting nurse) for the concern from the risk of falling, in addition to providing assistance if a falling incident occurs[24]. The CDC shows that falling once among seniors and obese individuals doubles the chances of falling again[6]. Due to high cost of home care, low salary is considered as a risk factor with 54% of middle-income individuals cannot afford health care and functional need[25]. Obese individuals who have a BMI $\geq 40\ \text{kg/m}^2$ have a 16% higher risk of falling than nonobese individuals[1,7]. Therefore, obesity has also been associated with an increased risk of multiple falls. Obese individuals are less likely to sustain hip fractures. However, humerus, leg, and ankle fractures are more likely to get injured[7]. The results indicate that the model is able to withstand a load of 1400 N, which corresponds to a senior with a mass of approximately 142 kg who is considered obese.

There are some restrictions in this study, first, the mesh element size of the model was limited to a relatively low-resolution mesh due to licensing issues of Ansys 2022 R1 (Ansys Inc., Canonsburg, PA, US) software. Second, a physical prototype of the model was not built. This will be considered in future work.

## 5. Conclusion

This study focused on designing a device to support individuals after fall withstanding fairly large weight. A 3D CAD design was modelled according to the standard dimensions of a conventional walker aid. FEA was done which showed that the design can lift an overweight individual with a weight of 142 kg and still being able to withstand heavier weight. The results of FEA could be the reference in any future improvement of the design.

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