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STRESS ANALYSIS OF LOWER LIMB EXOSKELETON ROBOT FOR WALKING ASSISTANCE USING FINITE ELEMENT MODELING

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ABSTRACT

This study conducted a stress study on the proposed design with the use the finite element analysis (FEA). The commercial finite element analysis (FEA) program ANSYS that employed. Simulation results show that the improved design of the exoskeletons of the lower extremities is safe to aid in walking. This result can be a guide for reliable exoskeleton design work. The theoretical underpinnings of finite element analysis are explained. The static characteristic analysis was performed using the human body in its normal walking stance. Results from this research reveal that the strength and stiffness of the exoskeleton can be designed to satisfy the demands of patients weighing up to 100 kg, and the stress and deformation values of the exoskeleton's larger area have been achieved as a result.

Keywords: ANSYS: Finite Element Analysis; Statics Analysis; Lower Limb Exoskeleton

1. Introduction

Lower limb rehabilitation exoskeleton robot design and research are intended to assist patients with lower limb impairment in completing the rehabilitation process or performing important daily activities [1]. Numerous medical institutions also scientific research institutions in the United States and abroad are investing heavily in the research and development of exoskeleton robots for lower limb rehabilitation. LOKOMAT is a commercial rehabilitation training robot created by the Federal Institute of Technology in Zurich, Switzerland [2]. The rehabilitation robot has four degrees of freedom and is propelled by a weight loss device also a treadmill to aid the patient with reciprocating gait movements. Nanyang Technology University developed the NaTUre-gaits 14-degree-of-freedom gait rehabilitation training robot system to assist hemiplegic patients with floor walking. On the basis of the weight loss mechanism, the system may do rehabilitative training. It may be used to regain pelvic control, balance, then gait control [3]. The University of Delaware research team created ALEX, a 4-degree-of-freedom active exoskeleton robot. The control strategy included a force field controller in combination with visual input, which added more power to the patient's demands. [4]. Zhejiang University has developed a wearable lower limb exoskeleton device with four degrees of freedom [5][6]. Shanghai University has created a 4-degree-of-freedom gait therapy robot. On the treadmill, the patient may conduct gait rehabilitation exercises [7][8][9]. These devices, however, have a number of drawbacks, including a bulky construction, difficulty controlling, poor motion synchronization, and inadequate energy supply time. Additionally, there are limited research in China on the exoskeleton rehabilitation robot for lower limb rehabilitation after knee replacement surgery. The purpose of this article is to determine the necessity for rehabilitation training after knee replacement. It presents a unique lightweight exoskeleton robot for spinal cord injury rehabilitation that acts as the basis for the research of rehabilitation training following spinal cord injury.

2. Static Analysis:

Static analysis is used for determine the deformation, stress, also strain of a structure under a given load in order to verify the structure's strength then stiffness and to guarantee that the structure meets the required security then stability requirements. The term "fixed load" refers to both fixed inertial loads and loads that are essentially comparable to the static load that fluctuates slowly over time. To the proposed model, we developed the static Analysis using ANSYS Software and studied various analyses which were performed during the stimulating work. On observing various parametric results, the equivalent von misses’ stresses and different types of deformations were observed predominantly.

3. Theoretical basis for finite element analysis

The technique of Finite Element Analysis (FEA) considered one of the effective methods for calculating the stresses and strains of continuous bodies, as the continuous integrated structure can be divided into a limited number of units, and it is also defined for each unit such as determining the properties of the unit material, some real physical constants, also other mechanical features. Each unit is first computed, then the separate units are collected to analyze and calculate their properties, some mechanical properties stress and strain have been achieved for all nodes and cells, then solve the properties of this region in general, where the problem's answer is discovered. This is an approximation, but the number of units is increased to obtain the desired accuracy, as the number of units increases the approximate solution approaches the real solution [10]. The accuracy of finite element method calculation is of high accuracy, and this method can be used for all complex shapes, and it is an effective method for geometrical properties analysis. Finite element analysis theory is the principle of variance and elastic mechanics, It covers basic equations such as differential equations of equilibrium, geometric equations, and physical equations represented in rectangular coordinates, among others.

4. Anthropometric Analysis

Considering the dimensions obtained by anthropometric analysis, the mechanical structure of exoskeleton was modeled. Anthropometry gives the information necessary to make an indirect assessment of body composition. Using skin folds and girths as inputs to a series of equations, we may estimate total body fat, body density, and subcutaneous fat. Additionally, trunk and limb girths offer estimations of muscle mass relative to body weight.

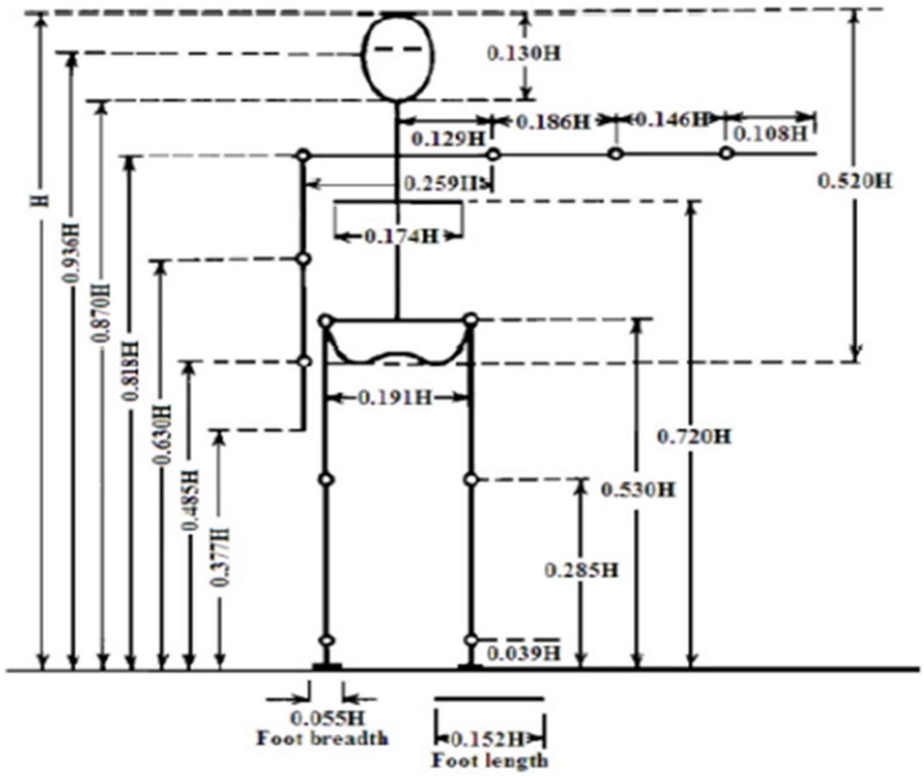


Figure 1: Anthropometric dimensions of human model, Body segment lengths expressed as a fraction of body height H [11].

5. Analysis of the Lower Limb Rehabilitation Exoskeleton Robot's Overall Design Requirements

The examination of the external skeletal robot's design approach reveals that an anthropogenic design concept based on ergonomics is utilized, also the "human-exoskeleton" method is based on the binding method of the large leg, soles of the feet, also the back. The propagation of fundamental design concepts. The system as a whole built mostly of the primary body of the exoskeleton's hardware, a sensor, a control system, then several auxiliary peripheral equipment. Figure 2 depicts the general construction of the exoskeleton robot for the lower limbs.

Table 1: Humanoid model dimensions [12]

Body	Mass(kg)	Length(m)	Mass Percentage
Hand	0.48	0.202	1.2%
Forearm	1.28	0.36	3.2%
Upper arm	2.24	0.295	5.6%
ankle	1.16	0.27	2.9%
shank	3.72	0.443	9.3%

thigh	8	0.441	20%
Head and neck	6.64	0.35	8.10%
Trunk	28	0.575	49.70%
Pelvis	11. 6	0.25	20.70%

The dimensions of the thigh, shank and ankle are obtained from the anthropometric data adopted in Table 1, which is depicted above. The anthropometric data of a 180 cm healthy person was collected and according to it, the structure was designed.

Figure 2: CAD model of lower limb exoskeleton robot.

6. Exoskeleton grid partitioning

The mesh grip model was simplified Following rehabilitation of the lower limbs the 3D model of the exoskeleton has been simplified. In the finite element analysis process, meshing is critical since the quality of meshing directly affects the accuracy and believability of the results. [12].

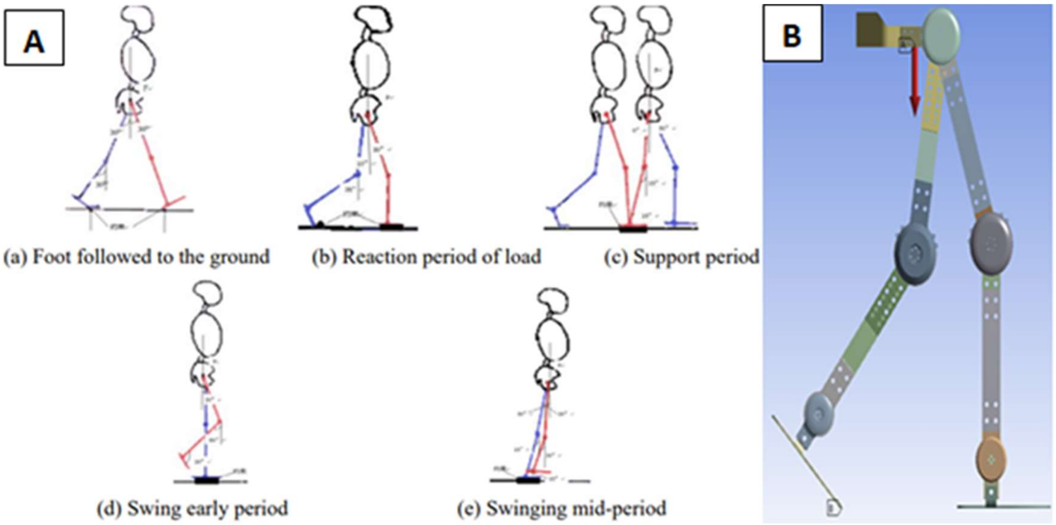
ANSYS A is for automatic classification, B is for tetrahedral partitioning, C is for scanning, and D is for domain. Workbench supports these meshing techniques.

Using the automated meshing approach, it is possible to divide a tetrahedron grid into a scanning-type grid and an automatic grid, depending on the geometry, in the process of splitting the grid. Lower limb rehabilitation exoskeleton grid was divided into eight-centimeter squares using an automatic classification technique. Figure 3 depicts the outcome of the grid division. The grid exoskeleton for lower limb rehabilitation has been divided using the automated classification technique, the grid was set to a size of 8 mm, also the partition into grids result is displayed in Figure 3. The element used in this instance is tetrahedral. There are about 57,065 elements and 31,855 nodal.

Figure 3: partition into grids and loading of the exoskeleton of the lower leg

7. Constraints loading

The human body's mass, the motor, the battery, and the system of quality control were the primary loads on the lower limb rehabilitation exoskeleton. also, other components, as well as by gravity. With the exception of bone's intrinsic weight, all of these qualities ought to be put together during design. The heaviest combined weight was 100 kilograms. The load loading zone corresponds to the human body's gravitational position throughout its usual lower limb walking phase: the weight was 1000N, equal to the total of the body weight of a person; the orientation has been vertical downhill also vertical to the surface; the load figure loaded is as seen in Fig 4-11. A.



(a) Foot followed to the ground
(b) Reaction period of load
(c) Support period
(d) Swing early period
(e) Swinging mid-period

Figure 4: A) Lower limb constraints load loading [13]. B) Loading F applied on the back of exoskeleton.

The mass of the body is equal to the loading F (1000N in this example) given to the rear of the exoskeleton during the simulation, as seen in Figure 4 B: It should be noted that the weight is expected to be on the back support during walking activity. The application point of force is assumed based on the reality of the situation, i.e., standing circumstances. In this study's computer model of the exoskeleton, the foot part is locked in place and cannot move in any direction. While standing, the rear of the exoskeleton is believed to move in the direction of the y-axis or vertical axis of the body. The sides of both the right and left legs are rendered immobile.

8. Structural evaluation of the exoskeleton of the lower limb.

When a structure is subjected to a certain load, static analysis is conducted to identify the displacement, tension, and pressure, and it is used to ensure the structure's stability and safety. Loads that do not change over time, such as inertia and static loads, are considered "fixed loads". The proposed model, we developed the static Analysis using ANSYS Software and studied various analyses which were performed during the stimulated work. On observing various parametric results, the equivalent von misses’ stresses and different types of deformations were observed predominantly. The Table 2 summarizes the material's mechanical characteristics. The aluminum composite 7075 are utilized in high burden structure though the polyamide 6 are applied in low burden construction to make the exoskeleton as light as could be expected.

Table 2: Material properties of Aluminum Alloy 7075-T6[14]

Property	Value	Unit
Elastic Modulus	72,000	N/mm2
Poisson’s	0.33	-
Mass Density	2,810	Kg/m3
Tensile Strength	570	N/mm2
Yield Strength	505	N/ mm2

9. Loading and constraints of each posture.

When the human lower leg is regularly walking, the human body's center of gravity swings in the frontal plane. As a result, the applied force should be proportional to the swing location of the center of gravity. According to hip department dynamics study, the load on the support leg's hip throughout the gait cycle and response phase was about four times the body weight. Assume that a half of entire stress strength of the exoskeleton was developed, this is equivalent to 26001 N. The rest force was applied in line with a total force of 1000 N designed in.

While the feet followed the ground, so left foot's tiptoe and a right foot's heel strike followed on ground, A 1000N vertical force was supplied to the left and right hips, and the tiptoe strike of a left foot also the heel strike of right foot were fixed.

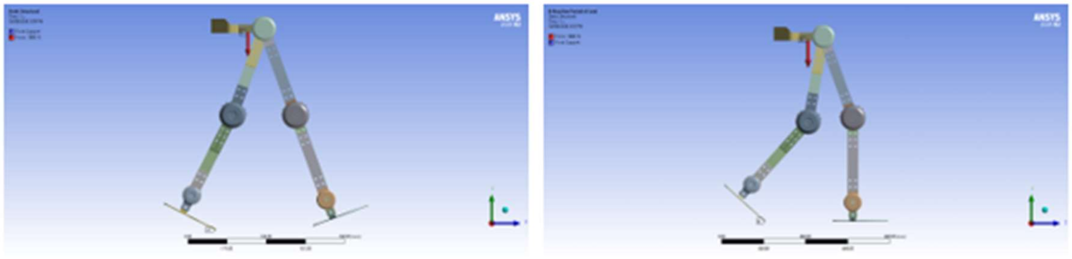
Throughout, a left foot's tiptoe and the right foot's palm remained on the ground the load response period, the constraint was loaded in the left toe and palm of the right foot, right hip was subjected to a vertical force of 1600N, whereas the left hip was subjected to a vertical force of 1000N.

During the support phase, the right foot's palm was on the ground. The left foot was suspended, and set restrictions were imposed on the palm of the right foot. an 800 N vertical force was applied to a right hip, also a 200N vertical force has been applied to the left hip.

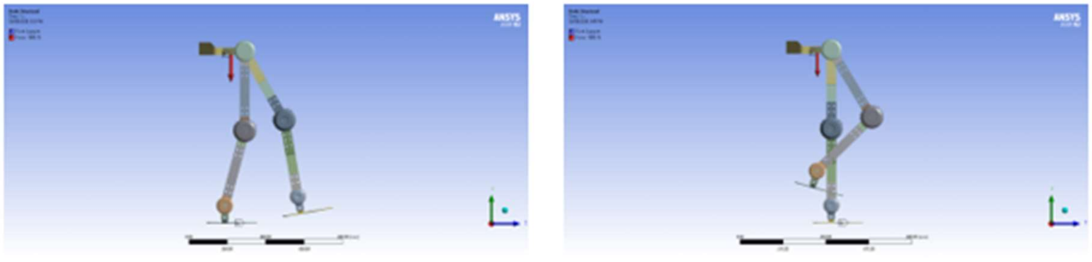
During the early swing phase, left foot's palm has been on the ground, As the right foot approached, a fixed restriction was applied to the palm of the left foot, 900 N of vertical force was applied to the left hip, then 300 N of vertical force was applied to the right hip.

In swinging mid-period, a left foot's palm has on the ground, imminently approaching was the right foot., a fixed constraint was put onto the left foot's palm, a 1000 N vertical force was applied to the left hip, and a 200N vertical force was applied to the right hip.

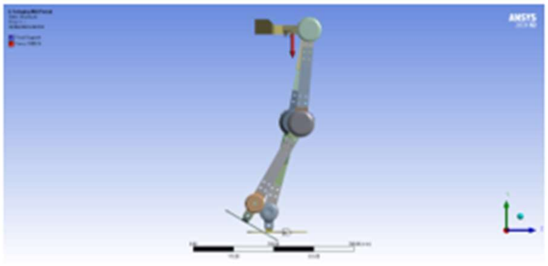
Swinging end-period position was identical to that of the foot following the ground, i.e., lower limb movement into the next cycle. As a result, the load also limitations imposed by a gait cycle was satisfied while swinging in the mid-period. Figure 5 illustrates the methods for applying constraint loads.



(a) Foot followed to the ground (b) Period of load reaction position.



(c) Support period position. (d) Early swing era position.

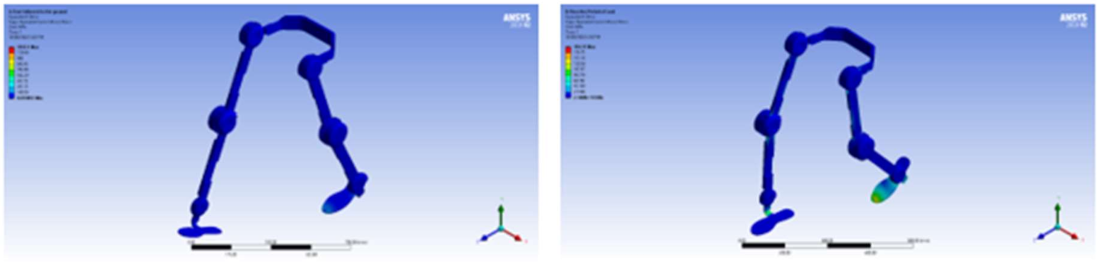


(e) Swinging mid-period position.

Figure 5: Constraints and applied force on the exoskeleton

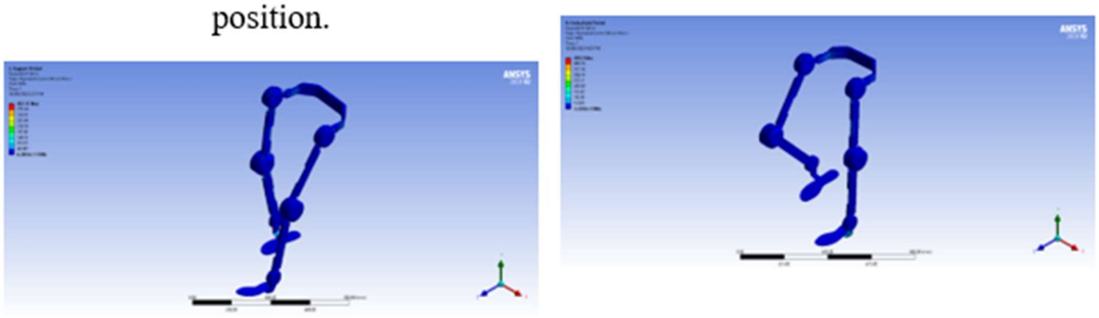
10. Static structural analysis results by using ANSYS:

Following the application of load, restrictions, also analysis, stress schematics exoskeletons for lower limb rehabilitation were created, as seen in figure 6.



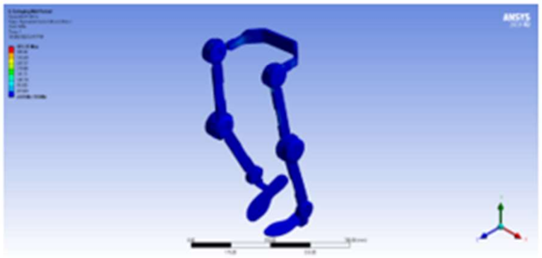
(a) Foot tracked down to the floor position.

(b) Period of load reaction position.



(c) Support period position.

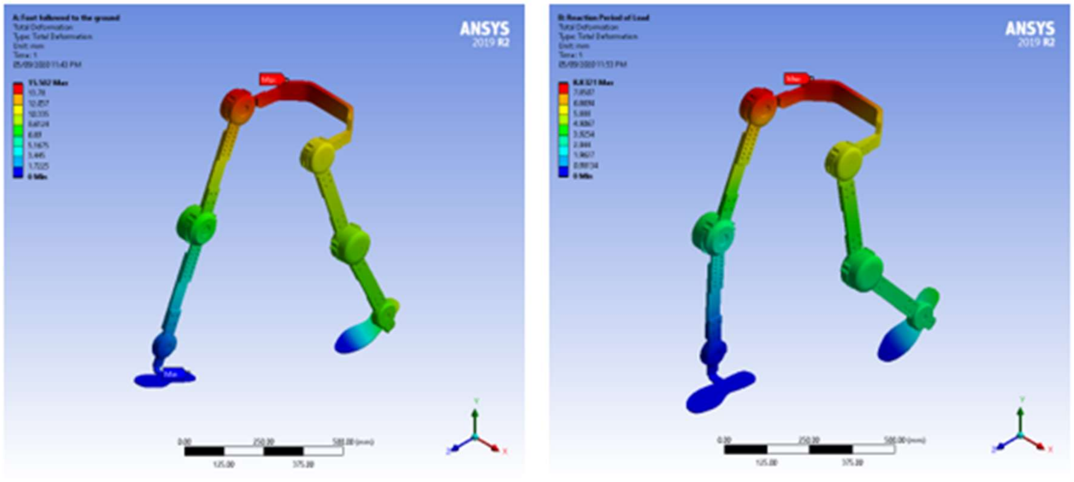
(d) Early swing era position.



(e) Swinging mid-period position.

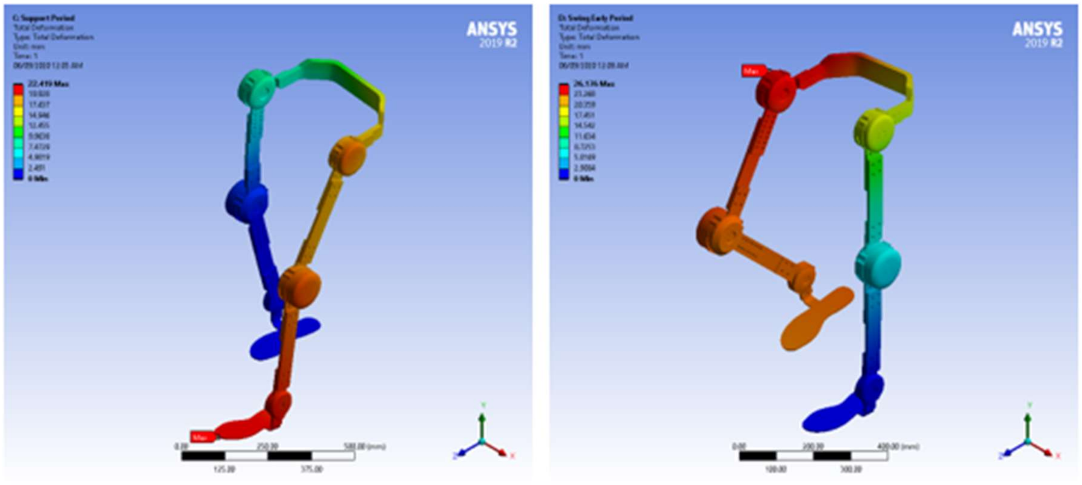
Figure 6: Stress analysis exoskeletons for rehabilitation of the lower limbs.

Lower limb rehabilitation exoskeleton elastic strain patterns from static characteristic analysis are displayed in fig 7.



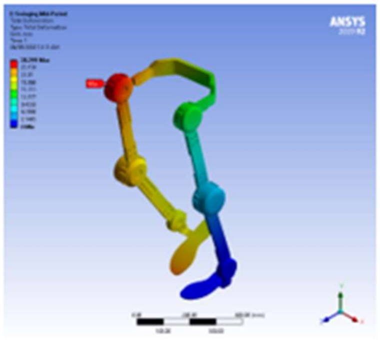
(a) Following foot to the surface position.

(b) Period of reaction of the load position.



(c) Position of assistance throughout

(d) Early phase swing position



(e) Mid-period swinging posture.

Figure 7: Elastic strain study of the exoskeleton used in rehabilitation of the lower limbs

The figs demonstrate that a max exoskeleton structure's stress value of the lower limb has been 425 MPa, which occurred while supporting the right hip, the lower limb exoskeleton structure deformed to a maximum of 0.0097 millimeters; and the lower limb exoskeleton structure exhibited a more homogeneous distribution of stress. with the majority of the stress concentrated between 65 and 260 MPa. A significant joint in the exoskeleton of the lower limb was the hip joint. At the time of position change, the hip joint's force was increased by a factor of three. However, the max stress then deformation values were within the material's permitted range, indicating that the exoskeleton structure's stiffness and strength were adequate.

11. Conclusion

The theoretical foundations of finite element analysis are discussed in this section. The static characteristic study was carried out utilizing the human body in its usual walking posture, according to the ANSYS Workbench commercial software. This study has shown that the exoskeleton's strength and stiffness can be tailored to meet the needs of patients weighing up to 100 kg, and that the stress and deformation values of the exoskeleton's wider area have been attained as a consequence of this design. It contributed theoretical data regarding the security of the exoskeleton that was developed later.

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