RP Materials: Proceedings (e-ISSN: 2583-8342)
Vol. 5, Part 1 (2026) pp. 91–98

RESEARCH PLATEAU PUBLISHERS

Cite this article: K S Suraksha Jain, A.K. Prajapati, Design and finite element analysis of modified patient lift for locomotor parkinsonism rehabilitation, *RP Materials: Proceedings* Vol. 5, Part 1 (2026) pp. 91–98.

Original Research Article

Design and finite element analysis of modified patient lift for locomotor parkinsonism rehabilitation

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Selection and Peer-Review under responsibility of the Scientific Committee of the 4th International Conference on Recent Trends in Materials Science & Devices 2026 (ICRTMD 2026) held at JVMGRR College, Charkhi Dadri, Haryana, India during 6–8 April 2026.

ARTICLE HISTORY
Received: 01 March 2026
Revised: 27 May 2026
Accepted: 27 May 2026
Published online: 12 June 2026

KEYWORDS
Locomotor Parkinsonism;
Axial Rigidity;
Rehabilitation Device;
Finite Element Analysis;
Patient Lift

ABSTRACT
Locomotor parkinsonism is characterized by axial rigidity, impaired trunk mobility, gait disturbances, and postural instability, significantly affecting the quality of life of individuals with Parkinson's disease. Existing rehabilitation systems mainly focus on gait training and often provide limited emphasis on trunk-specific rehabilitation. This study presents the design and structural analysis of a modified patient lift device intended to facilitate active and passive seated trunk movements, including flexion, extension, and lateral bending, with future scope for axial rotation. The device was modeled using PTC Creo Parametric and evaluated through Finite Element Analysis in ANSYS Workbench. Anthropometric considerations were incorporated to ensure patient comfort and safety. Initial simulations revealed stress concentrations at critical structural regions, which were addressed through iterative design modifications and reinforcement. The optimized structure demonstrated safe load-bearing performance up to approximately 1200 N while maintaining stresses below the yield strength of structural steel. The proposed design offers a stable and functional rehabilitation platform aimed at improving trunk flexibility, postural control, gait initiation, and fall prevention in individuals with locomotor parkinsonism.

1. Introduction

1.1 About Locomotor Parkinsonism

Locomotor parkinsonism is a disabling feature of Parkinson's disease, marked by gait, balance, posture, and turning difficulties caused by axial rigidity—a stiffness of the trunk and spine that limits mobility and anticipatory postural adjustments (APAs) necessary for gait initiation and balance [1,3,4]. Dopaminergic loss in the basal ganglia impairs motor planning and scaling, leading to delayed APAs, poor sensorimotor integration, freezing of gait, and increased fall risk [2,5,6]. Impaired trunk coordination results in an "en-bloc" turning pattern, where the head, neck, and trunk move together, reducing stability [7,8]. Trunk-focused rehabilitation—especially seated flexion, extension, and lateral bending—has strong evidence for improving balance, postural control and axial flexibility, with active participation being more effective than passive movement [4,9,10]. Though less studied, axial rotation exercises may further enhance trunk coordination and turning control [8,10] could be used in future. Conceptually, locomotor parkinsonism represents a cluster of axial and gait symptoms seen across Parkinson's disease and related syndromes, rather than a distinct diagnosis [11,12], and current research mainly addresses these features within Parkinson's cohorts, leaving gaps in targeted rehabilitation strategies [13,14].

1.2 Prevalence of locomotor parkinsonism

Parkinson's disease (PD) affects about 8.5 million people worldwide as of 2019 and is projected to surpass 25 million cases by 2050. Men are approximately 40% more likely to develop PD than women, with male-to-female ratios ranging from 1.2 to 2.0. In India, around 771,000 individuals were affected in 2019, with studies consistently showing a near 2:1 male predominance. Age remains the strongest risk factor, as prevalence rises from 42.3 per 100,000 in the general population to 308.9 per 100,000 among those aged 60 years and above [1].

1.3 Currently available rehabilitation devices for locomotor parkinsonism

Current rehabilitation devices for locomotor Parkinsonism include BWSTT, RAGT, wearable biofeedback, VR/AR systems, cueing devices, FES, and robotic exoskeletons. These technologies target axial rigidity, postural control, and gait disturbances, complementing pharmacological management.

1. Body Weight-Supported Treadmill Training (BWSTT): Integrates treadmill walking with adjustable body-weight support (e.g., h/p/cosmos airwalk® with Locomotion®), enabling safe gait training while maintaining natural stepping patterns.
2. Functional Electrical Stimulation (FES): Uses targeted electrical stimulation (e.g., WalkAide®, Bioness® L300) to activate lower-limb muscles, improving coordination, stride length, and walking efficiency.
3. Robotic Exoskeletons: Provide adaptive mechanical assistance (e.g., BEAR-H1) to support joint motion, enhance trunk stability, and promote symmetrical, balanced gait.

2. Objective of the project

The project aims to design a modified patient lift device that enables individuals with locomotor parkinsonism to perform active and passive seated trunk movements—flexion, extension, and lateral bending, with scope for future axial rotation. Unlike conventional gait-focused systems, it targets axial rigidity directly to improve trunk flexibility, postural control, and rehabilitation safety. By supporting both self-initiated and assisted exercises, the device promotes patient independence while remaining beneficial for those with advanced mobility limitations. Ultimately, it complements existing gait rehabilitation technologies by enhancing gait initiation, balance, and fall prevention in Parkinson's disease and related syndromes.

3. Method

The primary objective of this project is to modify an existing patient lift to incorporate features that facilitate flexion, extension, and lateral bending of the upper body at the trunk. The model was designed and developed using PTC Creo Parametric, while ANSYS Workbench was used for validating the structural performance of the modified design.

The process began by measuring the dimensions of the existing patient lift and creating a simplified version of the model in PTC Creo Parametric. The rough idea on how the measurement was made can be seen in the Figure 1. Basic modelling tools such as sketch and extrude were used to construct the main frame, which was designed to support both the patient and other critical components of the device.

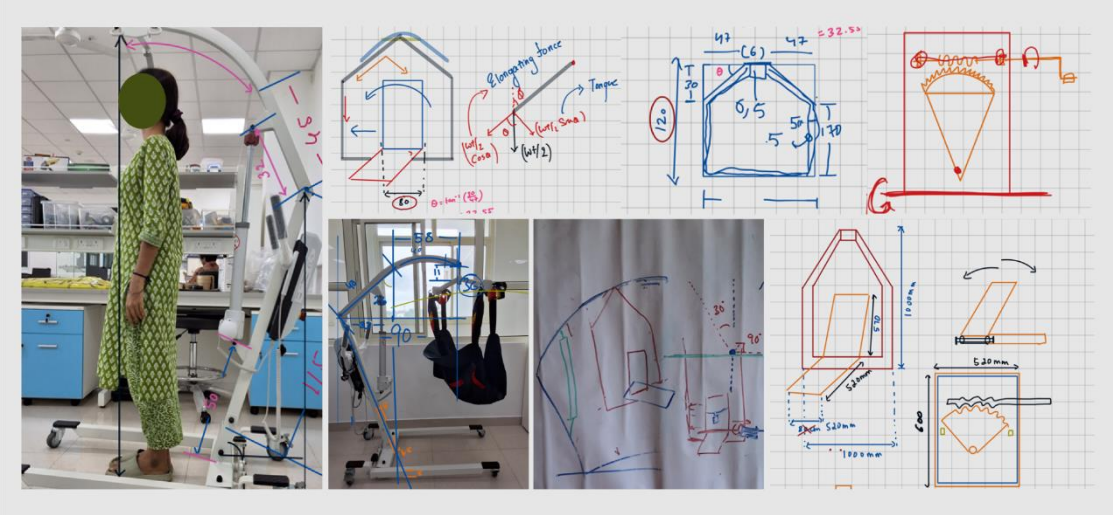

Figure 1: Rough sketch of the device and the device structure and mechanism.

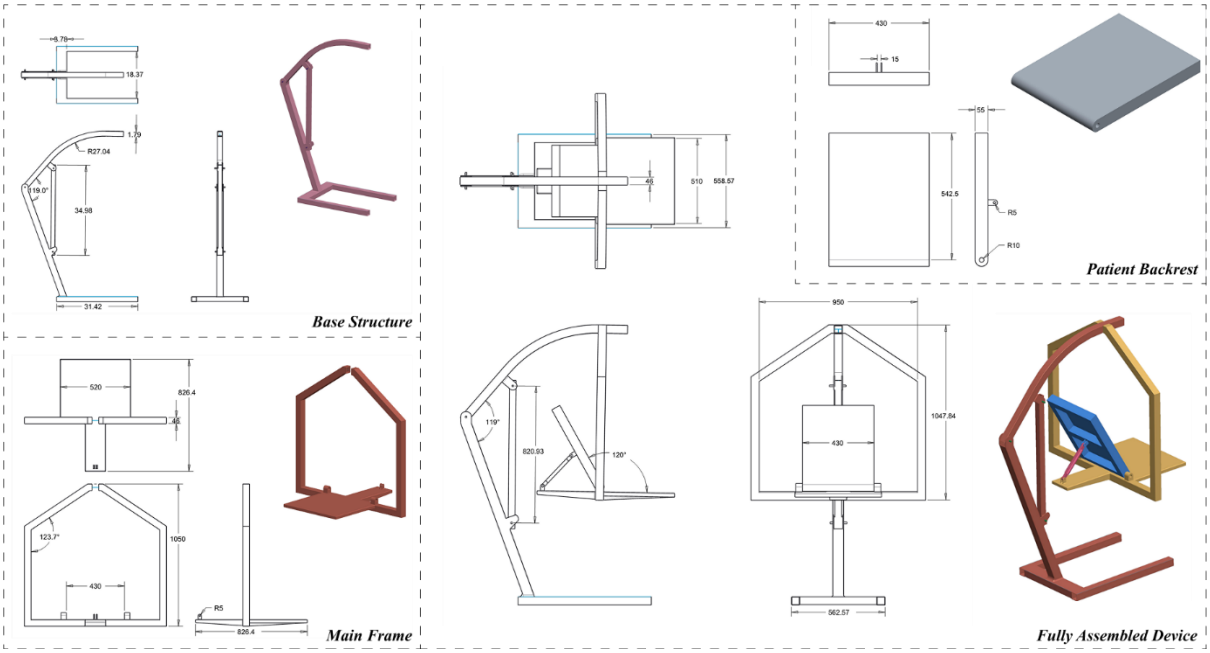

Figure 2: Dimension of the device.

The height of the model is fixed and does not contain any moving part to maintain consistency and reduce complexity. After developing the base model, additional features were integrated to meet the functional requirements. During the initial stages of model development, measurements were taken in inches and were subsequently converted to millimetres for convenience in the design process.

Dimensions of the backrest and seat were determined based on anthropometric data representative of the general adult population. Seat width was selected in the range of 400–440 mm to accommodate typical hip breadth, with a seat height of approximately 550 mm as shown in the Figure 2.

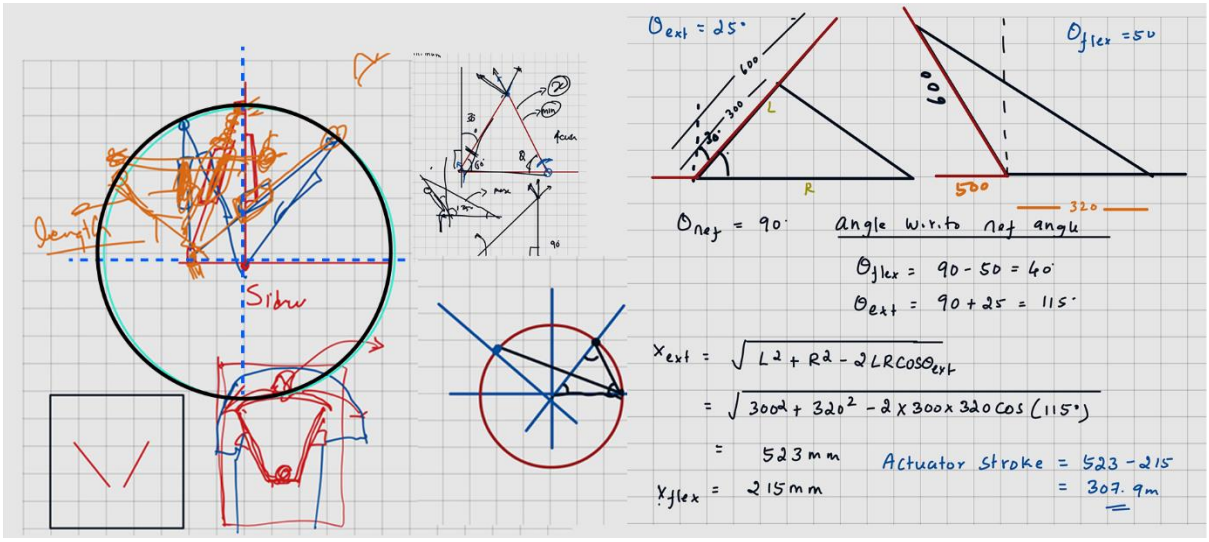

Figure 3: Calculation of stroke length for the backrest.

Backrest height was maintained between 450–550 mm to provide adequate support from the lumbar to the shoulder region [15]. The average sitting height, measured from the seat surface to the top of the head, is approximately 805 mm in the general adult population [16]. Based on these parameters, the supporting frame for the seat was designed with overall dimensions of 1000 × 1000 mm.

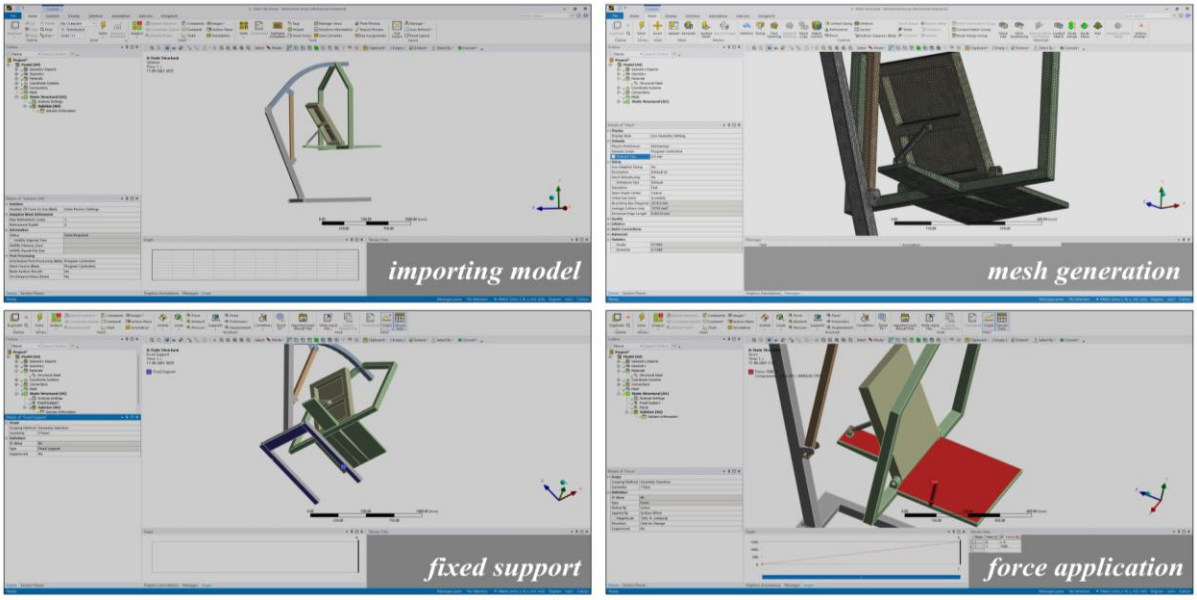

Figure 4: Steps involved in Finite Element Analysis of the device using Ansys workbench.

Once the model was made, it was exported as a .stp file and imported into ANSYS for Finite Element Analysis under different weights. The process included importing the geometry, generating the mesh, applying fixed supports, and finally applying the desired forces. After setting up the load cases as shown in Figure 4. The von Mises stress was determined to evaluate the structural behaviour of the model.

4. Result

4.1 3D Model Design

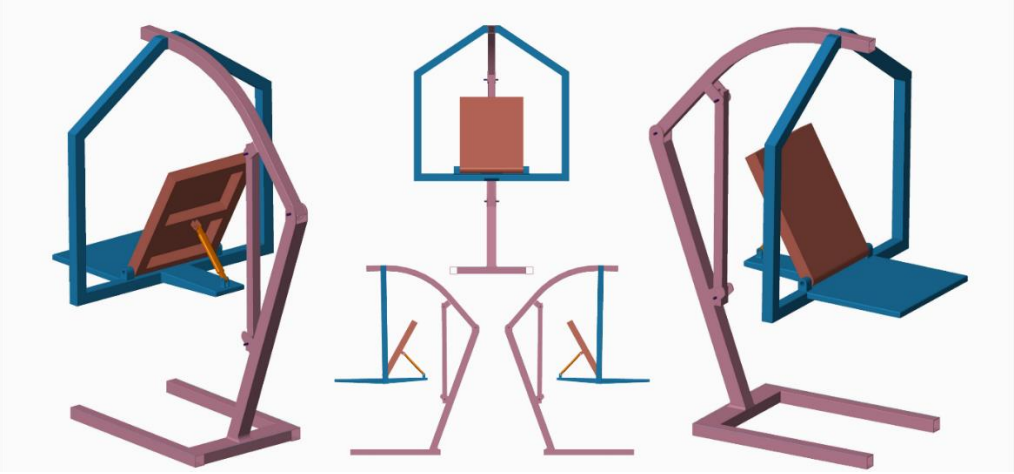

Figure 5: Final design of the modified patient lift.

The model was successfully designed using Creo Parametric. It incorporated the flexion extension mechanism for the upper body, as shown in Figure 5. The different levels of the mechanism are shown on the Figure 6.

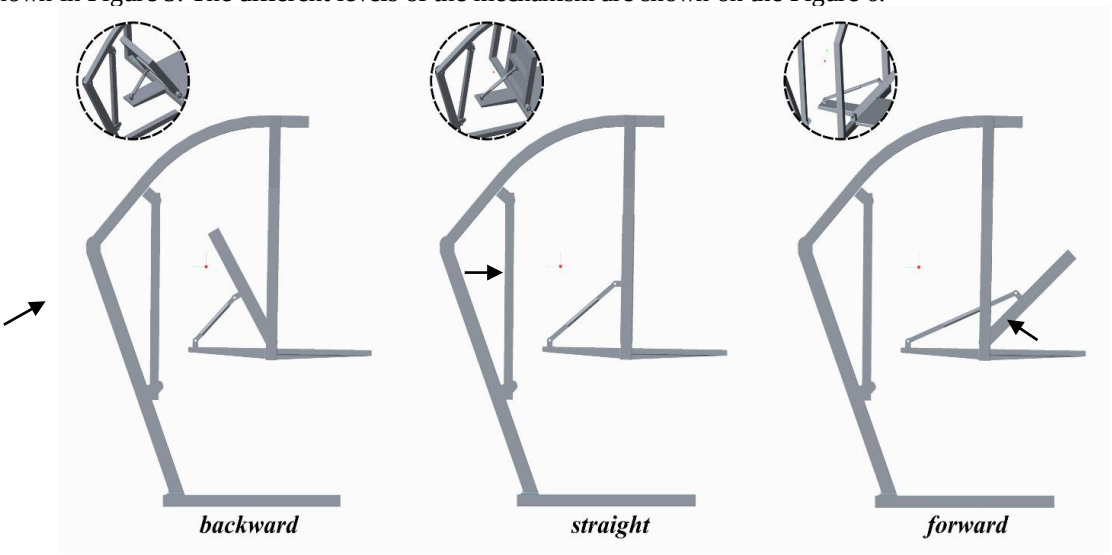

Figure 6: Different flexion and extension levels (arrow) of the backrest of the modified patient lift.

The actuator stroke length was determined based on the required range of flexion and extension. Figure 3 illustrates the conceptual approach used to calculate the necessary stroke length. Various configurations corresponding to flexion, extension, and the neutral (straight) position are presented for reference.

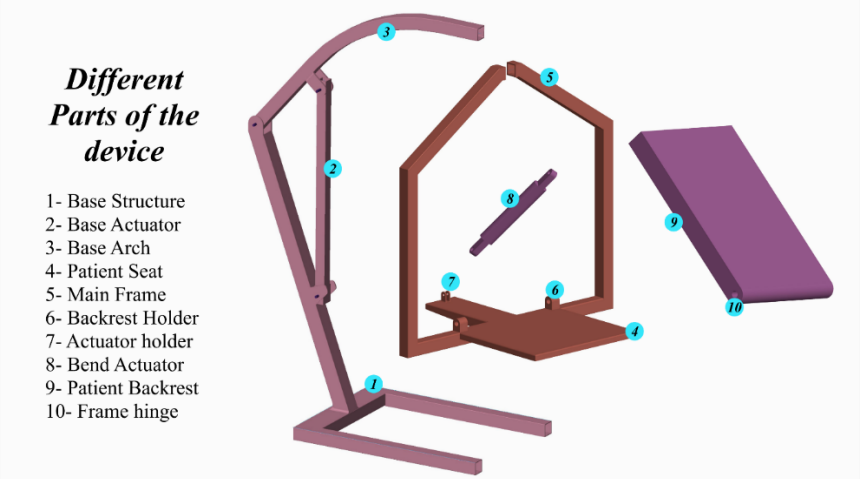

Figure 7: Different parts of the modified patient lift.

The model consists of several key components designed to ensure both stability and functionality. The base structure supports the overall system, while the base actuator and bend actuator provide controlled movements. The base arch, main frame, and frame hinge enhance strength and flexibility. For patient comfort, a seat and backrest are included, supported by the backrest holder. Finally, the actuator holder secures the actuators in place, ensuring reliable performance during operation.

4.2 Finite Element Analysis

After completing the modeling in PTC Creo Parametric, the geometry was imported into ANSYS workbench for Finite Element Analysis.

4.3 Mesh Sensitivity Analysis

The first step involved was conducting a mesh sensitivity analysis to ensure the accuracy and reliability of the simulation results. Stress values were calculated for various mesh sizes, and the percentage difference between successive stress values was evaluated. A mesh was considered optimal when the percentage difference in stress fell below 5%. In this study, a 6 mm mesh size yielded a stress difference of approximately 1%, indicating analysis outcome convergence. Further refinement beyond this size was deemed unnecessary, as it would not significantly affect the stress results. A graph was plotted with mesh size on the x-axis and the corresponding percentage difference in stress on the y-axis to visually confirm result consistency and convergence, as shown in Figure 8.

Mesh Size (mm)	%Diff Stress	Stress (MPa)
5		1743.1
6	-1.1078886	1724
7	-31.00304	1316
8	-13.644214	1158
9	-12.755599	1027
10	-25.857843	816
11	-39.965695	583
12	33.3714286	875
13	0.68104427	881
14	-47.818792	596
15	4.48717949	624
17	-37.748344	453
18	13.7142857	525
19	-16.666667	450
20	15.2542373	531
30	-1.9193858	521
40	-27.865312	407.46

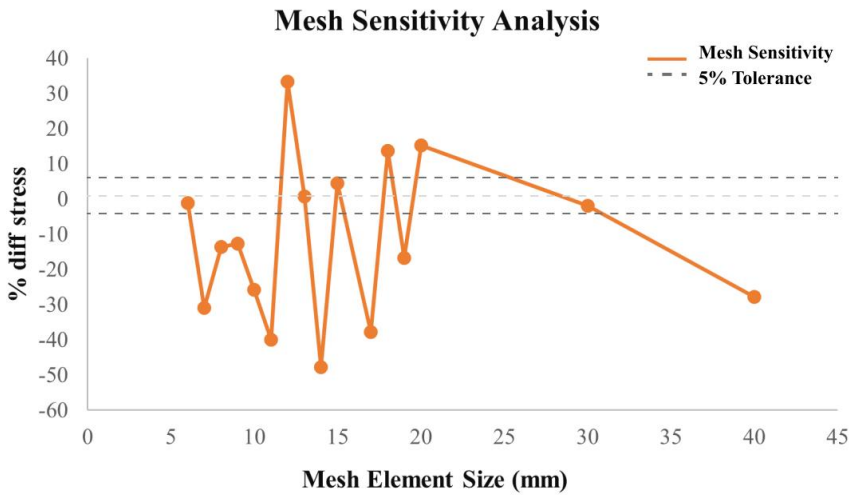

Figure 8: Mesh Sensitivity Analysis.

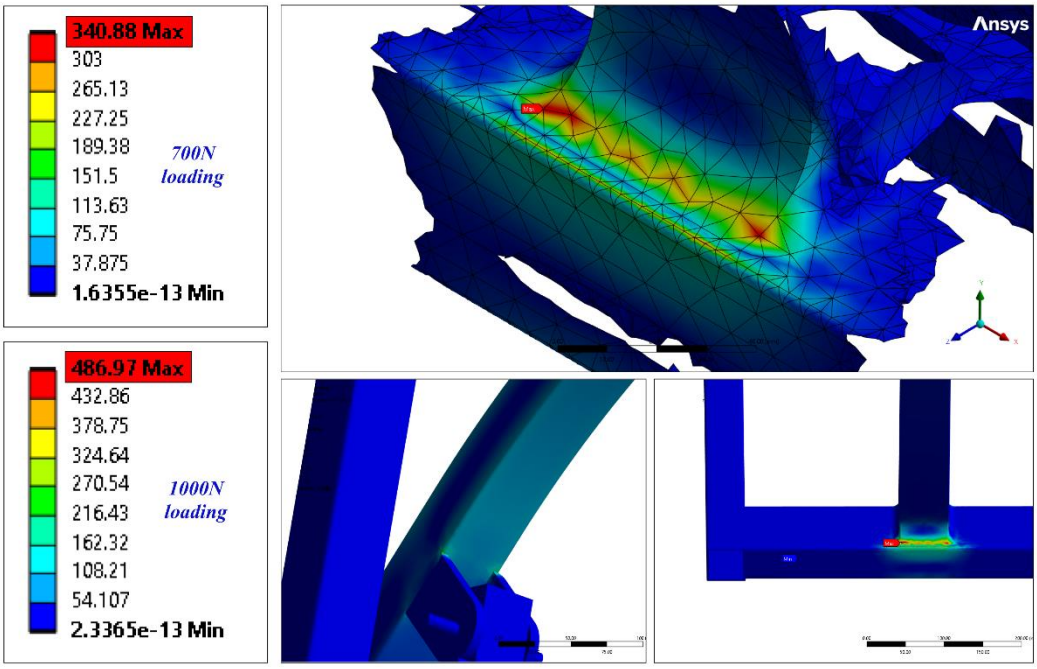

Figure 9: Structural defect due to stress induced by the 1000N and 1500N of loading.

To simulate realistic boundary conditions, the base of the model was fixed, and the joint points were constrained to prevent movement. A range of loads was subsequently applied to evaluate the resulting stress distribution throughout the structure.

Initial simulation results indicated von Mises stress values exceeding the yield strength of structural steel (250 MPa), the material used for the model. Significant stress concentrations were identified at two critical locations: the base of the upright stand of the patient lift and the arch region near the actuator mounting base, as illustrated in the Figure 9. below. These areas represent potential points of structural failure under heavy loading, highlighting the need for design modifications. The results suggest that either the geometry must be reinforced or the material properties reconsidered to ensure safety and reliability.

To enhance structural stability and ensure the model could withstand significant loading conditions, fillers were strategically added at critical locations. These modifications are clearly illustrated in the Figure 10.

Specifically, the base of the joint, where the actuator is mounted, was extended from one side and connected to the base on the opposite side of the joint. Additionally, fillers were incorporated at the base of the patient lift structure. The modified structure is shown in the above figure.

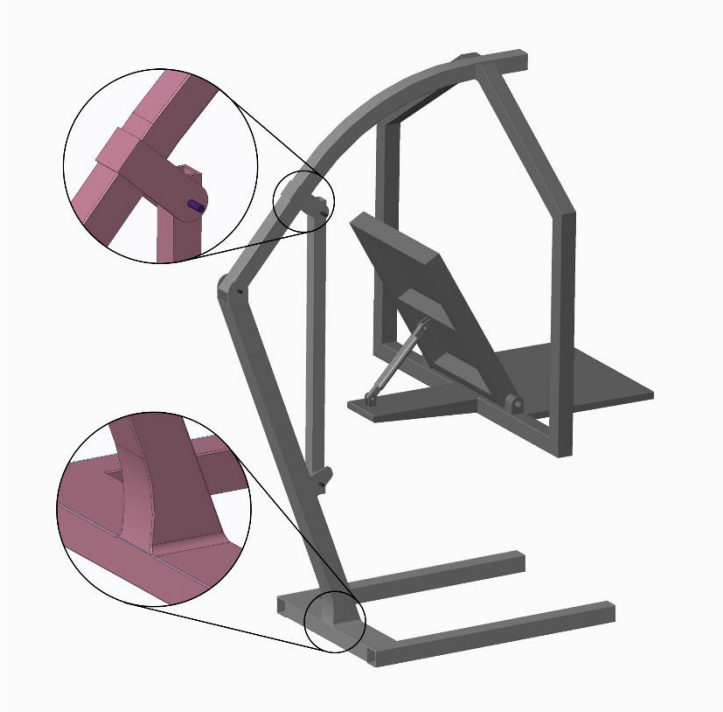

Figure 10: Structural improvement for lowering the stress at the weak points.

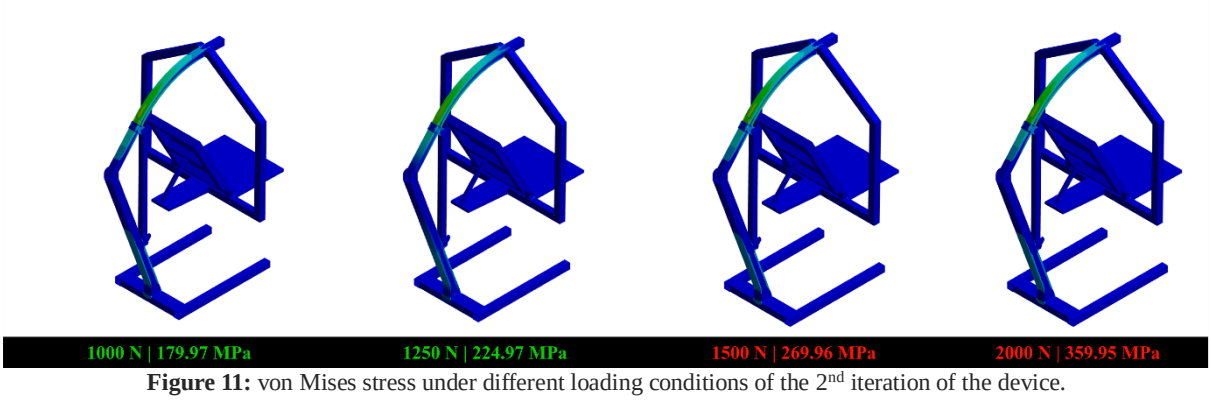

Figure 11: von Mises stress under different loading conditions of the 2nd iteration of the device.

To evaluate the load-bearing capacity of the modified design, different loads of 1000 N, 1250 N, 1500 N, and 2000 N were applied during simulation. The results indicated that the structure could reliably withstand a load of up to 1200 N while maintaining the maximum stress below the yield strength of structural steel. Loads beyond this threshold approached material limits, making 1250 N the recommended operational limit for safe and reliable performance.

5. Discussion

The present study addressed the challenge of axial rigidity and impaired trunk mobility in patients with locomotor parkinsonism by developing a modified patient lift device capable of enabling seated trunk movements. Unlike conventional rehabilitation devices that focus primarily on gait training, this design emphasizes controlled trunk flexion and

extension, which are strongly supported in literature as effective interventions for improving balance, postural control, and gait initiation in Parkinson's disease.

The device dimensions were derived from anthropometric data to ensure both safety and patient comfort, with seat height fixed at 550 mm, seat width in the range of 400–440 mm, and backrest height between 450–550 mm [15]. These values allowed adequate trunk support from lumbar to shoulder level while accommodating most of the adult population. The actuator stroke length was determined to achieve clinically relevant angles of forward flexion, upright sitting, and backward extension, thereby ensuring therapeutic effectiveness while minimizing mechanical complexity.

Initial simulations highlighted critical structural limitations, with stress concentrations exceeding the 250 MPa yield strength of structural steel at the actuator mounting arch and the base of the upright stand. These findings indicated that the original geometry could not withstand higher loading conditions without risk of failure. Through iterative redesign, fillers and reinforcements were added at weak points, which significantly improved load distribution. The final structure withstood up to 1200 N of load before reaching the yield limits, establishing a safe operational threshold for patients weighing up to approximately 125 kg.

These results demonstrate that the device successfully integrates functionality with structural stability, enabling safe trunk exercises under realistic loading conditions. The main features include a stable base, ergonomically dimensioned seat and backrest, and actuator-driven trunk mobility across essential flexion–extension angles. Clinically, the system has potential application in rehabilitation centre, hospitals, and possibly home settings under supervision, where it can improve trunk flexibility, reduce axial rigidity, and enhance gait initiation. Nevertheless, limitations include the absence of lateral bending and axial rotation movements, which are also important for improving trunk mobility and turning control. Additionally, the reliance on structural steel increases device weight, and further optimization with lighter materials may enhance usability.

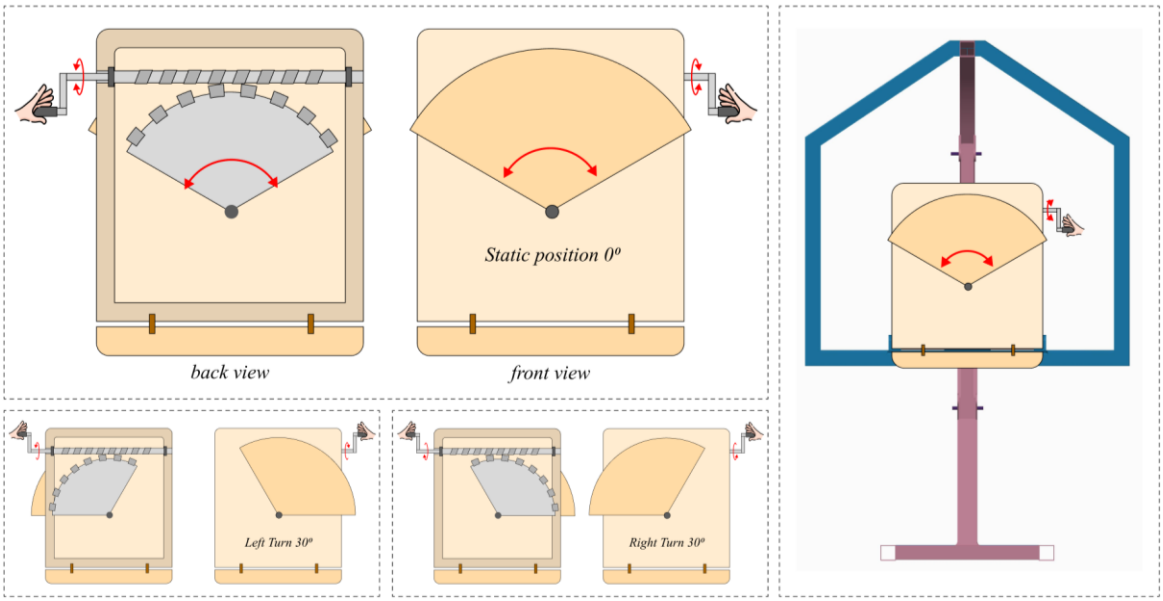

Figure 12: The concept for the lateral bending on the patient lift.

Future work will focus on extending the design to incorporate lateral bending and rotational capabilities, which would make the device more comprehensive in targeting axial symptoms. Further structural optimization with advanced materials, coupled with validation at different trunk angles, will ensure improved safety margins. Clinical testing in patient populations will also be necessary to confirm therapeutic effectiveness and usability in real-world rehabilitation scenarios.

Despite these limitations, the work led to design optimization of the device and resulted in a novel mechanism that integrates functionality with structural stability, enabling safe trunk exercises under realistic loading conditions using finite element analysis without the need to generate a metal prototype.

Authors' contributions

All authors contributed equally to the conception, design, experimental work, data analysis, interpretation of results, and preparation of the manuscript. All authors reviewed and approved the final version of the manuscript for publication.

Conflicts of interest

The author declares no conflict of interest.

Funding

This research received no external funding.

Data availability

No new data were created.

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