Biomedical Device For Back Pain Relief

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Abstract—The focus of this project is the design and development of a portable, user-friendly, and cost-effective lower back pain relief device that provides short-duration spinal traction. The methods employed began with anatomical research and benchmarking of various existing products and treatments that claim to alleviate back pain. The main point of improvement was the introduction of a more compact mechanism to apply force to induce traction on the user. Market solutions use straps to external bodies or counterweights, while the designs created use gears and pneumatics which significantly reduced cost and size.

Results include a validated set of design requirements and two distinct prototypes that function similar to a traction table by applying roughly half the user's body weight as force to stretch the user's body. In comparison to traction tables [1], these prototypes have a decreased weight between 14-23 Kilograms, lower costs below $1000, and maintain adequate traction application similar to devices on the market.

Keywords—lower back, back pain relief, spinal traction, spinal decompression, biomechanics, prototype design

I. INTRODUCTION

Globally, in 2020, there were 619 million people suffering from lower back pain [2] of 5.22 billion ages 20 and up [3] for a global back pain sufferer rate of 12%. The growing presence of this condition can also be looked at on a country-by-country basis. According to a 2018 study done by the National Center for Health Statistics, roughly 30% of U.S. citizens over 18 years old suffer from lower back pain (LBP) [4]. There are several approaches to addressing this issue. While LBP may resolve naturally in some cases, it can also persist as a chronic condition, affecting sufferers for months to decades. Unfortunately, many treatments are only marginally more effective than placebos; however, while the potential benefits of placebo effects are acknowledged, placebo-based interventions are excluded from the scope of this study. Of the treatments that are effective, none save exercise [5] and surgery are real treatments; all others only provide temporary relief. The importance of temporary relief ought not be minimized, though. The true treatments are either slow, invasive, or potentially too drastic. Sometimes a temporary reprieve may be necessary to improve a patient's quality of life. One historically effective method of temporary relief is known as "providing traction", which can be defined as stretching the lower spine, removing some of the pressure on the damaged intervertebral disks [6]. Several devices on the market are available to provide such traction, but they suffer from major design disadvantages including high cost, awkward positioning and discomfort during use. The two solutions presented in this paper work toward a lower-cost, portable and comfortable alternative which provides spinal traction in domestic applications.

II. METHODOLOGY

A. Prototype Design

After researching the various devices on the market that claimed to provide traction, the teams realized that what differentiated each device was the mode by which the traction was provided. To provide the adequate traction of between 20% and 50% of the body weight [7] required to temporarily relieve lower back pain, the team decided to design and test two modes of providing traction that had the potential to be implemented in cheaper, more portable devices. When prototyping began, the team was split into two groups which developed separate prototypes with the goal of having two unique prototypes without influencing one another during the design process.

B. Team A Methodology

The primary stakeholders for this project included the faculty advisor and individuals experiencing back pain. Key design requirements focused on portability, ease of use across different environments, and accessibility for a wide range of users.

To generate concepts, the team benchmarked existing spinal decompression devices such as the Inversion Table [8, 9], DRX 9000 [10, 11], and Neck Hammock [12]. Insights from these systems informed early design ideas, which were evaluated using a weighted decision matrix with a Likert scale. Although the highest-ranked concept was not selected, the team proceeded with the second-highest option based on feasibility and design considerations. The sketch of the design in Fig. 1 could be noted for further development in a future project.

Team A developed a fully mechanical traction system designed to provide controlled spinal decompression through underarm support without the use of electronics. The design focuses on simplicity, reliability, and user-driven control while maintaining sufficient force generation for effective decompression.

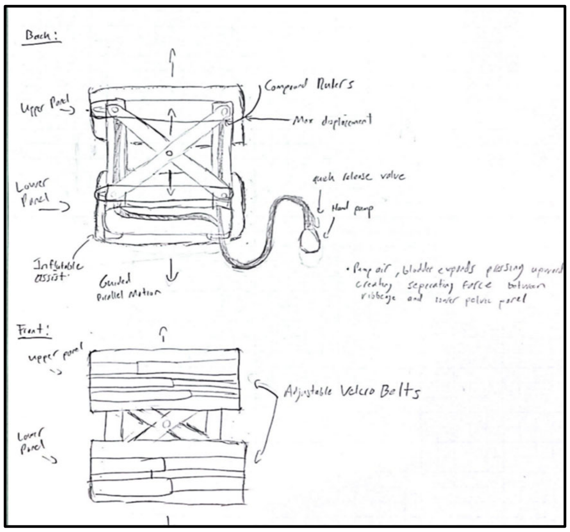


Fig. 1: Sketch of highest-ranked design from decision matrix showing an air-pumped parallel-ruler wearable device.

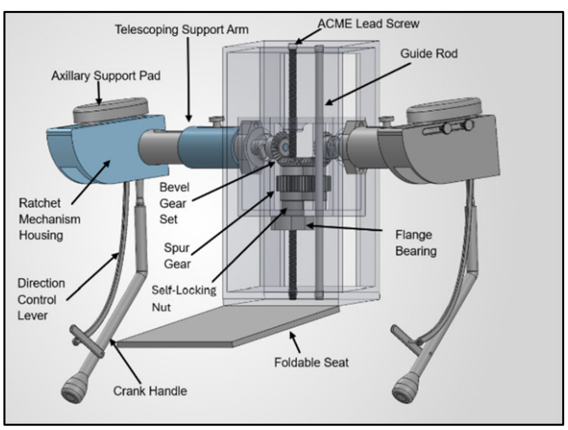


Fig. 2: CAD Model showcasing the main functional sections of Team A's model. The center housing the miter gears and spur gears to be driven up the ACME lead screw. The parts extending from the center box are the telescoping support arms and ratchet mechanism housing. The housing contains the ratchet mechanism allowing the switching of rotational direction of the gears. The rods protruding from the ratchet housing are the cranks to drive the rotation of the gears.

The core mechanism is driven by two manually operated hand cranks located beneath the underarm support pads. When the user rotates the cranks, rotational motion is transmitted through an internal gear system composed of spur and bevel gears. The spur gears enable efficient transmission of motion along parallel shafts, while the bevel gears redirect the motion between perpendicular axes, allowing the system to convert user input into vertical displacement. This gear-driven motion lifts the inner box, which houses the gear assembly, relative to the outer aluminum box. As the inner box rises, the attached arm supports and foam pads move upward, applying traction to the user through the underarm interface. The use of a gear train provides mechanical advantage, allowing the user to generate sufficient lifting force with manageable input effort.

The vertical motion of the system is guided and constrained using two key structural elements. A central threaded rod passes through both the inner and outer boxes, serving as the primary load-bearing component and ensuring controlled vertical translation. In addition, a steel guide rod is incorporated to maintain alignment between the two boxes and prevent unwanted rotation or lateral movement during operation. Together, these components improve stability and ensure smooth, consistent motion.

The underarm support components, which house the hand cranks and foam padding, were fabricated using 3D printing to allow for rapid prototyping and ergonomic customization. The main structural housing was constructed from aluminum to provide sufficient strength while maintaining a lightweight and portable design.

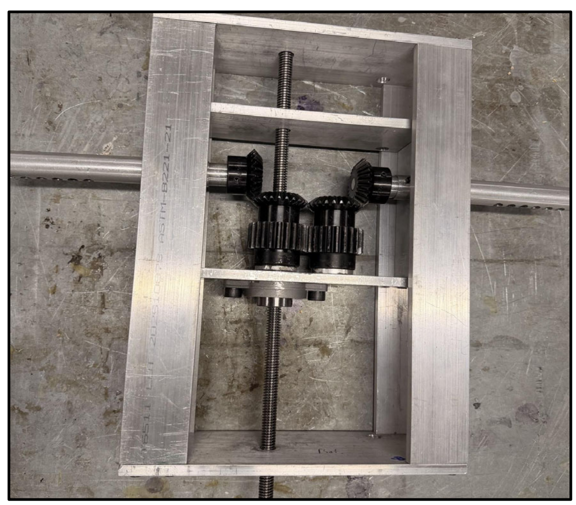


Fig. 3: Prototype of the center housing for the miter gears and spur gears connected to the ACM lead screw.

Overall, Team A's methodology leverages fundamental mechanical principles: gear-driven motion, threaded translation, and guided constraint to create a functional and reliable traction device that operates entirely through manual input.

C. Team B Methodology

Team B's methodology followed a structured engineering design process consisting of research, concept generation, evaluation, and iterative prototyping. The concepts were evaluated based on criteria such as safety, cost, portability, and effectiveness. Feedback from medical professionals and physical therapists were incorporated to refine the selected concept. Team B ultimately decided to design and test prototypes that utilized a pneumatic cylinder to provide traction to the user. Pneumatics were chosen as the mode of force application due to the simplicity of calculating the expected output force, controlling the output force, and implementing a failsafe to prevent injuries in the case of equipment malfunction.

Following concept selection, low and high-fidelity prototypes were developed to evaluate functionality, comfort, and feasibility.

(a) (b)

Fig. 4: An evolution of prototypes from a low-fidelity prototype used to evaluate the mechanical feasibility of the concept (a), and an overbuilt functional prototype designed to evaluate the medical feasibility of the concept (b). The latest prototype (Fig. 5) is a lighter, portable iteration designed to improve the usability of the concept.

The final design was refined based on the results of testing previous prototypes. Its pneumatic piston system generates controlled, adjustable spinal traction forces. The final prototype was designed to exert a maximum force of 623 Newtons to the user, and allow for the exerted force to be adjusted to lower amounts depending on the amount of force required to provide traction to users who weigh 113 Kilograms or less.

III. Results

A. Team A Results

The current prototype from Team A uses a 1:1 miter gear ratio as the main hub to supply both the needed vertical motion for the desired traction effect and adjustability with height for the user. The main housing of the gears provides a vertical range of motion of approximately 0.25 Meters. This range was not satisfactory for taller users, so a secondary attachment was added for the device to have an elevated rest to provide more height adjustment and contain a padded seat for comfort.

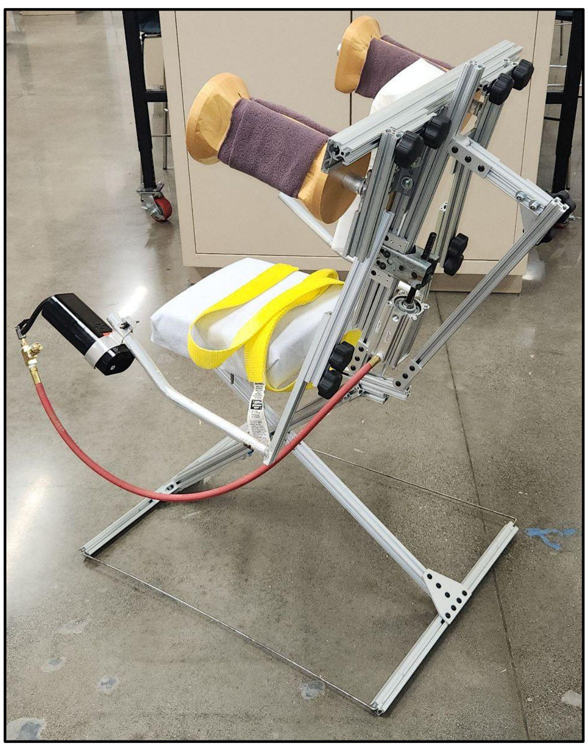
The intent of the design was to create a device that is able to provide traction forces within the acceptable range of lumbar decompression while also ensuring that the motion remains slow, controlled, and safe for the user. This design approach was selected because the main purpose of the device is not simply to create vertical movement, but to make sure that the decompression is applied gradually so that the user does not experience sudden or uncomfortable motion. During testing, the dual ratcheting handles were operated through their maximum effective crank range of approximately 90 Degrees per driving stroke. Each handle was connected through a synchronized 1:1 gear train consisting of identical 24-tooth bevel gears and 24-tooth spur gears, which allowed both sides of the system to rotate at the same speed while redirecting the user input by 90 Degrees. This rotational motion was then transferred directly to the centrally mounted 1/2 in -10 single-start Acme lifting nut attached to the fixed lead screw, allowing rotational motion to be converted into vertical linear displacement of the support box. Based on the measured lead of 2.54 Millimeters per full revolution, the system produced a vertical lift of approximately 0.635 Millimeters per crank stroke, which corresponds to 6.35 Millimeters after 10 strokes, 12.7 Millimeters after 20 strokes, and 25.4 Millimeters after 40 strokes. This small and controlled displacement was intentionally selected because the overall goal of the design was to provide slow and steady traction, allowing the user to gradually increase spinal decompression without sudden movement.

The traction force that the design needed to support was determined to be within the clinically acceptable range for lumbar decompression. The target force was set between 157 Newtons and 275 Newtons, which corresponds to approximately 20 to 35 percent of the body weight of a representative 80 Kilogram user. This range was selected because it falls within the level at which lower back traction can be effectively detected and provide relief. To ensure that the system could safely sustain this load, a 932 bearing bronze precision Acme round nut was used with a rated dynamic thrust capacity of 5782 Newtons. Based on the maximum design load, this resulted in a calculated factor of safety of approximately 21, confirming that the lifting assembly operates well within safe mechanical limits during testing. Ultimately, the final prototype was able to demonstrate a slow, controlled, and reliable traction mechanism that provides accurate user-controlled spinal decompression while maintaining a high margin of structural safety.

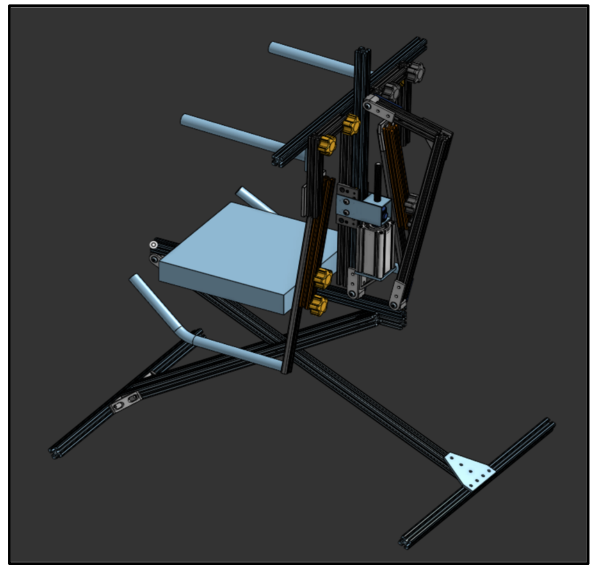
B. Team B Results

The latest iteration of the concept from Team B is designed with rough adjustments to account for varying body dimensions and a pneumatic piston to provide traction through the underarm supports. Heavier individuals received adequate traction in the second overbuilt prototype.

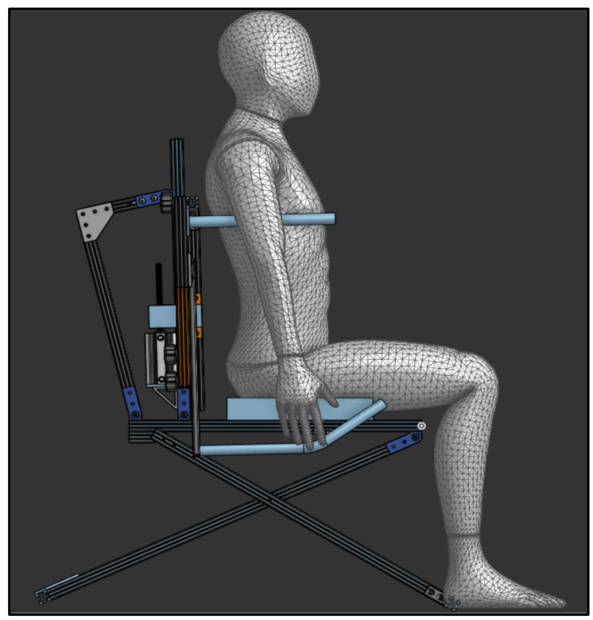
(a)



(b)



(c)



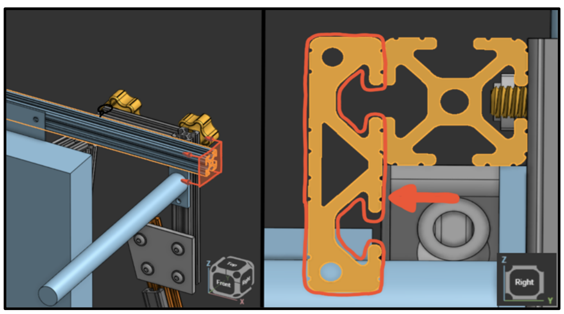
(d)

Fig. 5: Team B’s latest prototype. (a) Front side view featuring the air pump control system and the underarm supports. (b) Rear side view featuring the piston, rough adjustment bracket, and shoulder width adjustment knobs. (c) and (d) Initial CAD model of prototype.

Several challenges were overcome during the latest prototyping stage. One issue was that the base was unstable due to torsion in the base’s double legs. A solution was found by both installing a rigid plate between the members and by installing wire restraints to the ends of the base’s feet.

(a) (b)

Fig. 6: Chair base stability improvements. The rigid plate (a, top right) prevents torsion between the base members and the wire restraints (a, center left) resist base diagonal lengthening. The 3-hole nut with extra locknut and screw prevents the hinge from becoming dislodged from the end (b) at the front of the device.



(a) (b)

Fig. 7: Before (a) and after (b) CAD representations of the crossbar member that was modified to reduce torsion. The modification involved adding the outlined 1/2x2 Inch member to the top crossbar to increase its area moment of inertia.

Another issue was that the crossbar member was initially only designed to resist beam bending, but the controlling internal force was beam torsion due to the torque applied by the underarm supports (see Fig. 6). This oversight was discovered during prototype assembly and fixed in-situ by adding another crossbar member to increase the area moment of inertia. This improvement reduces the angular deflection caused by a 136 Kilogram individual from 3.8 Degrees to an acceptable 0.6 Degrees.

The current iteration continues to exhibit flexural instability due to the two-dimensional nature of the folding mechanism. A future design iteration will attempt to jointly counteract this design flaw and the issue with the maximum user weight by widening the central supports to a 3-Inch-wide member.

IV. DISCUSSION

A. Team A's Mechanical Design

Team A's fully mechanical design offers several advantages in terms of reliability, simplicity, and accessibility. By eliminating the need for pneumatic systems and electronic components, the device reduces potential failure points and minimizes maintenance requirements. This makes the system more practical for consistent, long-term use, particularly in home environments where ease of operation and durability are important. Additionally, the manual crank system allows the user to control the rate and extent of traction. This provides a level of intuitive control, as the user can adjust the applied force gradually based on comfort. The passive locking mechanism further enhances usability by allowing the system to maintain a fixed position without continuous effort. However, the design also presents certain limitations. One key challenge is the lack of precise force measurement and feedback. Because the system is entirely mechanical, there is no built-in method to quantify the exact amount of force being applied. This may lead to variability between users and could require additional training or guidance to ensure safe and effective operation.

B. Team B's Pneumatic Design

Team B's pneumatic design demonstrated the capabilities of an electronically controlled pneumatic device when providing traction to the back. Since the input pressure to the pneumatic cylinder is electronically controlled, the output force of the device is able to be calculated and displayed to users via a chart, allowing for traction to be input based on the user's body weight. The design still requires further work to solve issues of instability, in addition to force testing to properly gauge the recommended pressure input versus theoretical values.

V. CONCLUSION

The teams found that spinal traction was feasible using portable, stationary devices that have the potential to be low-cost and suitable for use in a home environment. The project produced several iterative prototypes, some of which demonstrated noticeable traction in the spine. The teams' prototypes are still proof-of-concepts which require further refinement using Design-for-Safety, Design-for-Manufacturing, and Design-for-cost principles. The nature of the project was exploratory prototyping; while medical studies were beyond the scope of this project, an effectiveness study across several demographics is the next step after prototype refinement. The teams wrestled with, and largely overcame, the challenges posed by competing design constraints.

ACKNOWLEDGMENTS

We would like to express our sincere gratitude to all those who contributed to the successful completion of this project. We especially wish to acknowledge our lab technicians, John Wild and Scott Weeks, for their invaluable time, effort, and technical assistance throughout the course of this work. We also extend our appreciation to the James Madison University Department of Engineering for its continued support throughout the implementation of this project. In addition, we are deeply grateful to Dr. Nando Visvalingam, MD, for his invaluable and continuous guidance and advice throughout the duration of this project.

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