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Enhancing Musculoskeletal Health: The Integration of the P.A.M. for Active Posture Correction

Hiyall Fitsum[1] and Elijah Almanzor[#]

[1]George Washington Carver Center for Arts and Technology, USA
[#]Advisor

ABSTRACT

Poor posture is a common issue causing musculoskeletal problems. Back braces are designed to improve spine alignment but can weaken back muscles and foster dependence on external support. This paper introduces an innovative approach, the Pneumatic Back Brace (PBB), which rectifies spine alignment for angles ≥ 60 degrees. The key component is the Pneumatic Artificial Muscle (PAM), a soft robotics element that expands and contracts via air inflation. PAM realigns the back and releases air to maintain proper posture. PBB activates muscles to counteract weakness and prevent poor posture habits from passive activities. This is a simulation study with a MATLAB model of the PBB which will help with the design in future work.

Introduction

Poor posture is prevalent and affects many individuals.[1] Poor posture is a static stance characterized by improper spinal alignment, causing muscle imbalance, muscular strain, and fatigue[2]. Individuals with weak abdominal muscles are susceptible to conditions like Lordosis, an evident curvature in the lower back.[3] (see Figure 1). Since the introduction of modern technology, many have chosen to participate in sedentary activities, contributing to poor posture. Research indicates that individuals who refrain from engaging in physical activities like sports or certain occupations face an increased risk of developing conditions such as protruding scapulae, lumbar abnormalities, and a rounded back[2].

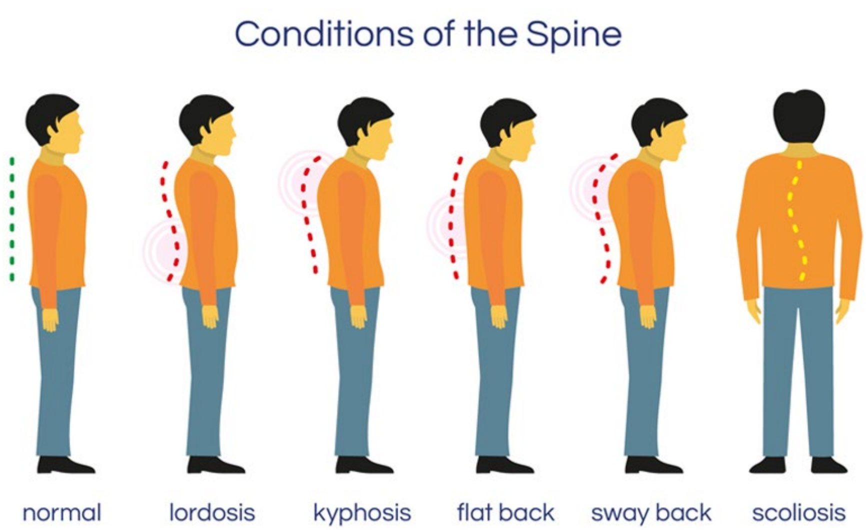

Figure 1. Illustration of the various spine conditions the human body may experience, it being the PBB's aim to avert the occurrence of any of these adverse conditions.

To combat this problem, many companies have developed various posture correctors. The most common type is a brace that uses its rigid mechanism to maintain one's stance, keeping the spine in alignment[4]. However, these braces are often constricting and uncomfortable. They are generic tools that cannot quickly adapt to your spine because they are not user centric. Additionally, these braces can increase your reliance on an external factor to improve your posture, weakening your back muscles and perpetuating those bad habits[5]. Those who exercise through sports and working out have a more assertive stance because they engage and strengthen their abdominal muscles, trapezius, deltoids, etc[2]. Stronger muscles offer better support to the shoulder and the upper and lower spine.

Instead of designing uncomfortable braces that weaken back muscles, emphasizing the problem, it would be more suitable to use compliant components that can easily adapt to your posture while engaging your back muscles and removing any uncomfortable feelings from the typical back brace. The Pneumatic Artificial Muscle (PAM) is a braided mesh containing an elastic material that expands and contracts depending on the air pressure applied. Developing a device that uses the softness of the PAM capacitates it to quickly acclimate to the shape of the spine and possibly correct posture more effectively. The Pneumatic Back Brace (PBB) is a prototype that attaches PAM from a strap on the lower back to the deltoids, resolving the issues mentioned. Rather than being used as support, its contraction mechanism would be used as a reminder, pulling patients back whenever they fall into a bad posture. This is a simulation study to help with future development of a physical model.

Related Literature

Beyond posture correction, the PAM has diverse applications. PAM can enhance assistive exoskeletons by amplifying human strength and mobility. Additionally, PAM can facilitate mobility rehabilitation, aiding individuals recovering from muscle-related impairments. Building upon the principles presented in this paper, collaborative research efforts have the potential to contribute to developing sophisticated machinery aimed at improving human capabilities.

Assistive Exoskeleton - PAM can exhibit a significant amount of power depending on the strength of the material and the maximum amount of air pressure that can be installed. This capacitates it to help humans surpass certain limitations. Whether it be increasing speed or strength, the PAM can act as an "extra muscle." (*Figure 2 ref.*) Figure 2 displays the Lower Limb Exoskeleton that utilizes the PAM to increase leg strength.

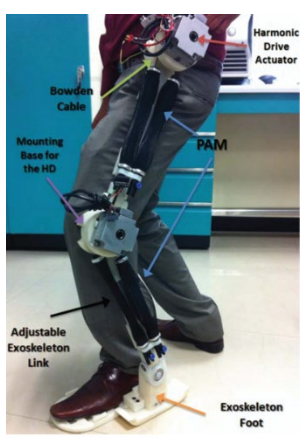

Figure 2. Assistive Exoskeleton developed to increase lower limb strength and facilitate movement using PAM.

Mobility Rehabilitation - PAM can help rehabilitate those who have lost mobility in almost any muscle. Depending on the structure of the mesh, when contracting, the PAM can bend in desirable directions. Pneuact is a hand rehabilitation machine developed by MIT that uses the PAM to close or open a subject's fingers. Their braided meshes force the PAM to bend vertically when inflated with air, thus bending the fingers. (*Figure 3 ref.*)

Figure 3. Pneuact developed by MIT which utilizes PAM to aid in finger rehabilitation.

Materials and Methods

Pneumatic Artificial Muscle

Developed in the 1950s by Joseph L. McKibben, the McKibben Pneumatic Artificial Muscle (PAM) has been frequently used to simulate the movement of human muscles due to its low cost and unique applications[6]. The PAM materials and design allow for the swift integration of novel inventions, such as exoskeletons or body rehabilitation. PAM is characterized by its flexibility and enabling enhanced safety in interactions between humans and robots[7].

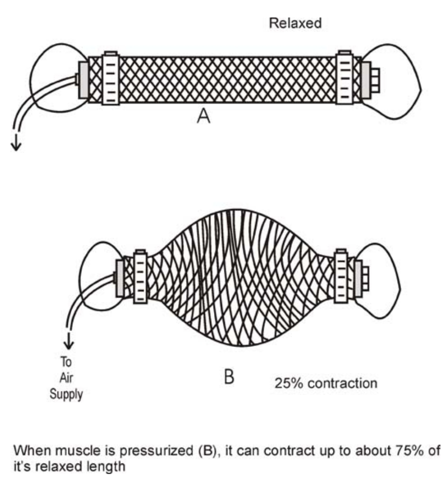

Figure 4. Illustration of the PAM and its contraction process.

The basic structure of the PAM is an elastic material that inhabits a mesh with a seal on one end to prevent air leakage.[6] The opposite side has a secure connection to an air pump. When the elastic material is inflated with air, it will expand and mesh with it. The PAM lengthens and contracts depending on the PSI installed and the angle of the mesh braiding. To maintain a congruent volume, the mesh forces its length to contract when the width increases, and vice versa. Others have harnessed this advantage, creating various devices that pull or push through contraction and growth e.g. *Vine Robot, and PneuAct.*

Equation 1: $\frac{b\sin\theta}{n\pi}$

Equation 2: $\frac{b}{n\pi}$

Equation 3: $F = \frac{\pi D_0^2 P}{4}(3\cos\theta - 1)$

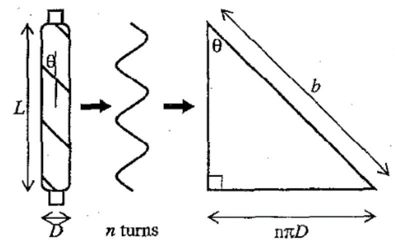

Figure 5. Illustration of the Chou and Hannaford model.

Equation 1, known as the Chou and Hannaford model determines the force (in newtons) exerted by the PAM depending on a variety of factors[8]. [(P) is the amount of air pressure applied to the PAM, typically measured in Pascals (Pa). (D) is the Diameter of the PAM (mesh or elastic component) before any installation of Air Pressure within it (see Equation 2). (D_0) is the Diameter of the PAM when θ is 90 degrees (see Equation 3). (b) is the length of each thread in the mesh. (n) is the number of turns in the mesh thread. (θ) is the angle between the braided thread and the cylinder's long axis (see Figure 5)][8]

The Force exerted by a PAM based on pressure. The parameters for this example of the *Chou and Hannaford Model* are $D_0 = 2$ and $\theta = 51.187$

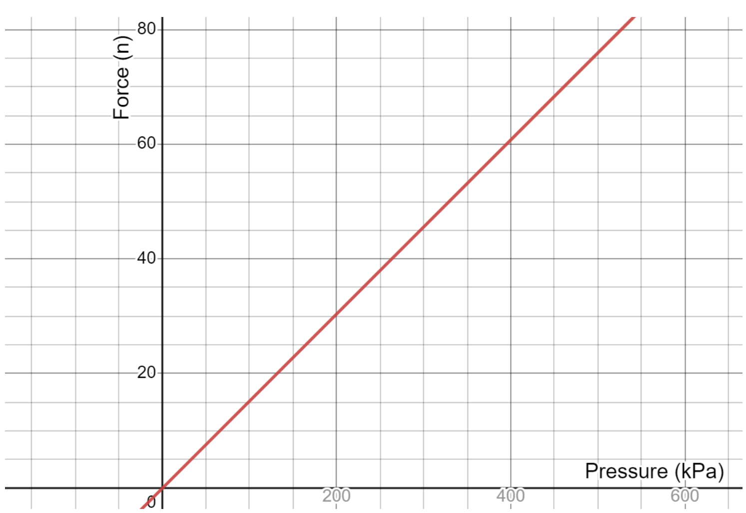

Figure 6. Desmos graph of relation between the input Pressure (kPA) and output Force (n) when implemented into the PAM using the Chou and Hannaford model.

Design

The PBB follows a Y-like format to ensure the force is distributed throughout the back muscles, such as the trapezius and erector spinae. This allows the prototype to fix the subject's posture accurately and effectively. With its design, two PAMs are placed on each side of the body strap, interconnected at both ends (see Figure 6). This is a preliminary design, however determining how many muscles to incorporate in the design is not trivial. Hence, a simulation is developed using MATLAB's simscape and simulink.

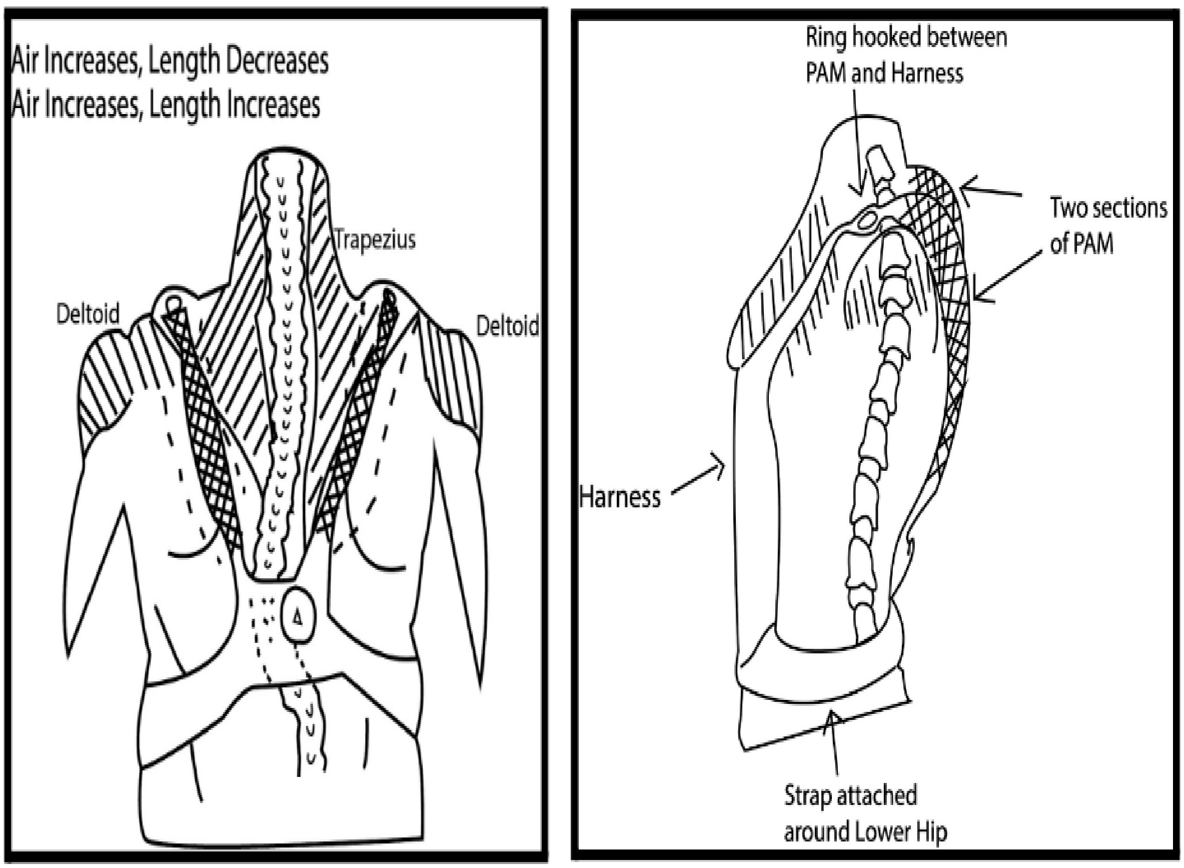

Figure 7. Blueprint of the PBB, illustrated by the author for reference.

The PAM can contract and detract through this, pulling the deltoids back and calibrating the remaining muscles. The PAM mechanism activates when the subject maintains a posture angle greater than or equal to 60 degrees for an extended duration, inflating the elastic component to induce contraction. 60 degrees was selected as the pivotal point because spinal curves exceeding this angle are associated with diminished pulmonary function and an increased risk of respiratory failure [9]. Thus, pulling the deltoids, eliminating hunched shoulders and lordosis. Once the participant's posture is fixed, the PAM will decrease their air pressure to release the strain on the back. The PAM makes for an inexpensive, practical, comfortable, and lightweight approach to improving posture.

The PBB serves as a reminder and reinforces practicing good posture, unlike other back braces that increase dependence and weaken back muscles. The synergy between real-time correction and active engagement distinguishes the PBB from conventional back braces, making it a dynamic and user-centric approach to addressing poor posture.

Experimentation and Modeling

To validate the PBB's potential effectiveness, MATLAB simulations were conducted. A simplified pulley system replicated PAM's contraction and expansion mechanism. The simulation depicted the spine's realignment process when subjected to PBB-like forces. The Chou and Hannaford model was integrated to quantify force exertion. Simulation results illustrated successful spine angle adjustments, suggesting the PBB's viability for real-world applications. These simulations offer valuable insights into the PBB's functionality and potential impact on posture correction.

Spine Pully MATLAB Simulation Model

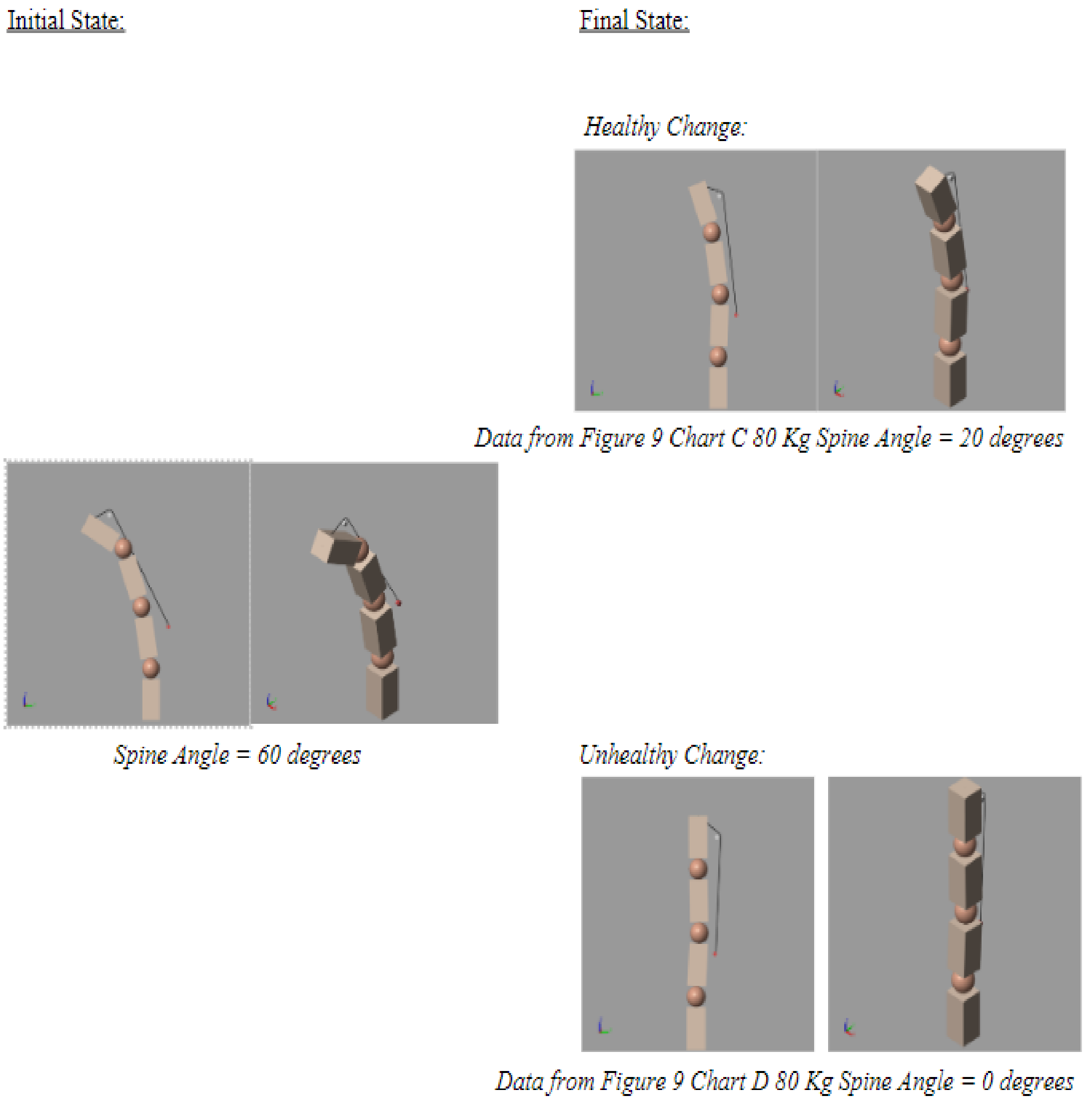

Figure 8. Display of MATLAB simulation of the PBB and Spine 3D models with proportionate parameters and force, measured from the x-axis.

The spine model comprises four solid bricks, which model the vertebrae, and three spheres, which model the facet joints, weighing about 3.5 kg or 7.7 lbs. The bottom facet joints are at an initial angle of 10 degrees, whereas the top facet joint is at an initial angle of 40 degrees, making a total Spine Angle of 60 degrees. The ultimate facet joint (also known as the cervical vertebrae) was given a larger angle because when in a sedentary position, the neck faces the most significant change in pitch due to the habits of looking down at an electronic device, slouching, etc. The simulation follows a one-line model in contrast to the Y-shape in the actual design to offer a more comprehensive perspective and streamline the approach. This allows for a fine examination of the spinal dynamics, especially accommodating variations in posture, such as a pronounced inclination of the cervical vertebrae influenced by modern habits.

Spine Pully MATLAB Facet Joint Angle Data

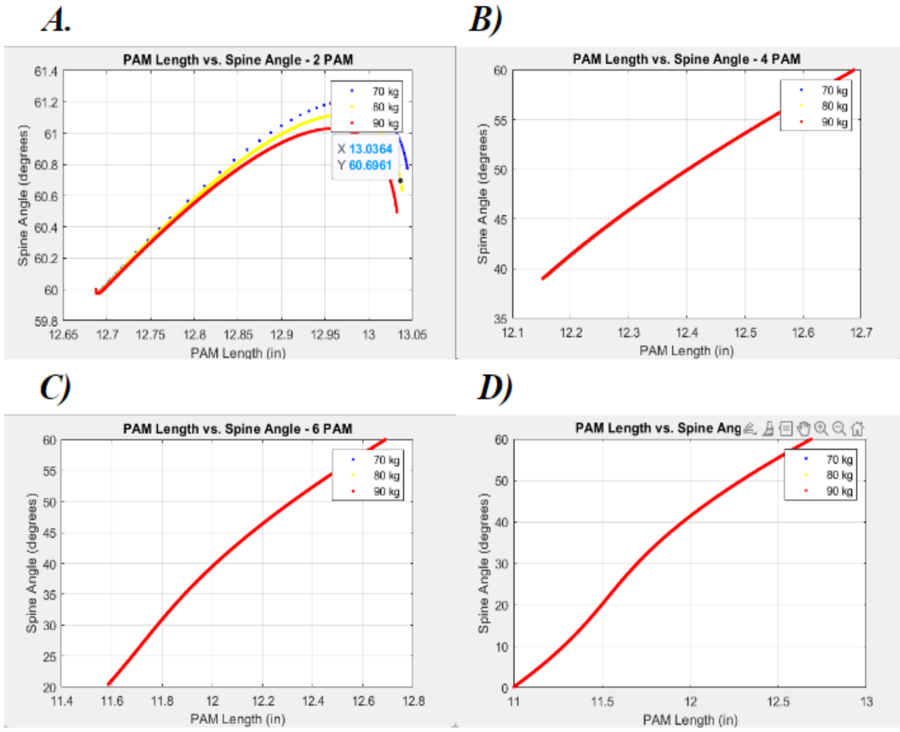

Figure 9. These graphs show the relationship between the Spine and Winch Angles. Results were gathered using the same parameters listed before (see Figure 6).

Each chart has three lines to represent three different torso weights. 70 kg - Average Female Torso Weight, 90 kg - Average Male Torso Weight, 80 kg - Average Torso Weight.

When interpreting these graphs, it is crucial to consider: (1) The Spine Angle (y) is influenced by decreases/contractions in PAM Length (x). (2) Note that in certain graphs, the data from the 90 kg spine may obscure the visibility of other lines.

Regarding Figure 9a when the simulation is initialized, the weight of the spine angle continues to fall into a worse posture with no actual support from the PAM, however, after a few seconds, the PAM causes a very insufficient correction to the subject's posture.

In Figure 9b all of the different spines end up with a cumulative spine angle of 39 degrees, a difference of 21 degrees with the PAMs contracting by 5%. The model does prove to have an effect however the spine angle difference might not be adequate to be classified as good posture.

Looking at Figure 9c 4 PAMs seem to provide ample posture correction leaving the subject with a cumulative spine angle of 20 degrees. Furthermore, the PAMs exhibit a change of an estimated 9.5% contraction. The data and model suggest that the muscles would not induce any spinal syndromes which indicates that 6 PAMs would be ideal for a real-life prototype.

In Figure 9d each piece of data reaches a spine angle of 0, such data suggests that 8 PAMs have the potential for inducing Flatback syndrome (see Figure 1). Meaning that the number of PAMs used to fix each spine posture is considered extreme.

The actuator must be able to contract a certain amount to pull the back to the correct posture. From the figures, it appears that it has to contract an estimated 20 inches in order to change the posture angle from 60 to 20 degrees.

Discussion and Conclusions

Posture is critical to overall health and wellness as more sedentary habits of slouching and leaning the neck become installed into our daily lives. Thus, leading to a variety of spinal syndromes that can affect participation in activities, completing simple tasks, and most importantly back pain.

As a solution to this problem, various companies have developed supportive back braces to maintain spinal alignment. However, these braces are uncomfortable, and rather than engaging muscles to cultivate muscle memory for correct posture, they create a dependence in which the spines require external support for proper posture. The Pneumatic Back Brace would address this problem by exerting force onto the subject's back to put it into an appropriate posture. Once the spine is in alignment, the PBB can release its strain leaving the participant the reminder to have good posture.

In terms of what lies ahead for the PBB, it is critical to obtain ethical approval. As the data gathered before proved that 6 PAMs are capable of aiding in posture correction, it is essential to experiment on physical subjects to determine whether or not the PBB does improve muscle memory and helps in long-term posture correction. These 6 PAMs would exert 1800 newtons of force and as provided by Data Chart C; the PAM would experience 9.5% contraction. Theoretically, these factors should offer sufficient posture correction. Accounting for this, during human experimentation, a gyroscope accelerometer will be attached to the subject's upper back and will track the pitch of the subject's movement to produce data on their spine angle. Data will be gathered and compared before and after the subjects use the PBB for a significant period. In the experimentation it is evident that only one cable is used for the design, differing from the Y-like design that was previously mentioned. This design was implemented during the simulation to simplify the preliminary study simulation, to see if the PAMs have enough contraction force to pull the whole back. This can have a completely different set of force vectors applied on the back, hence future work will change the simulation to have the Y-shape.

In conclusion, through MATLAB simulation PBB has proven to effectively correct posture through real-time correction. Given the persistence of sedentary habits, innovations like the PBB are pivotal in advancing posture and overall well-being.

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