Design for Continuous Passive Motion Lumbar Support Cushion

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Abstract:

Lower back pain affects the majority of the population in the United States. Existing lumbar support cushions attempt to support the lower back region by providing static support when sitting for a long time. A cushion that applies the principles of continuous passive motion would be more beneficial due to its potential to decrease the pain and discomfort an individual may be experiencing. Different designs for the delivery system and lumbar cushion that undergo continuous passive motion were developed. These were evaluated using a design matrix. A final design solution, a gel support cushion with a modified blood pressure pump, was proposed along with future development suggestions for the project.

Problem Statement: To design a pneumatic lumbar support cushion that will help alleviate lower back pain in patients through the use of continuous passive motion. The user will be in the sitting position, such as a car, while the cushion inflates and deflates through a range of motion for a specified duration of time determined by a user chosen setting.

Introduction:

Lower back pain has become a major issue effecting about 70% of the population of the United States (Hazard 1999). People with lower back pain find sitting in the same position for extended periods of time painful.

Continuous passive motion, CPM, has been proven to be effective in reducing muscle stiffness and promoting healing of joint tissue after major surgeries. Applying these same principles to the lumbar spine region, CPM could increase the range of motion, decrease stiffness, and allow for rehabilitation of lower back muscles (Center for Orthopedics, 1999). Another benefit of continuous passive motion would be the reduction of pain. Based on the pain gating theory, continuous movement of the cushion would stimulate fast conducting nerve fibers counteracting slow conducting nerve fibers responsible for transmitting pain sensory signals, thereby reducing a person's pain (John C. Liebeskind History of Pain Collection, 1996).

Based on the known benefits of continuous passive motion, the goal of this project is to design a lumbar support cushion that incorporates a continuous cyclic motion. An individual could reduce their lower back pain by using a continuous passive motion lumbar support cushion when sitting for long periods of time such as in an automobile.

During background research on design that incorporated continuous passive motion was found. OPTP introduced a device in 1999 called the Original McKenzie CPM Roll. This lumbar support roll cycles through an inflation/deflation cycle once every forty seconds motion (Orthopedic Technology Review, 2001).

Similarly, our client would like to provide support for the lumbar region with continuous passive motion. After talking to the client, this was understood to be a rotation of the lumbar region while also having a forward rotation of the pelvic region. This design also should have adjustable cycling settings to better accommodate the user's needs. Lastly, the device's noise level should be kept to a minimum (Sherry, 2001).

Alternative Design Solutions:

The overall design can be divided into specific components. A power supply is connected to a motor with variable control setting options. This powers a pneumatic pump that forces air through tubing in and out of the cushion (Figure 1). This divided our brainstorming to two distinct components: the delivery system and the support cushion.

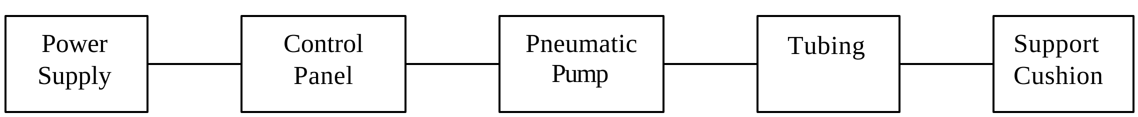

Figure 1: A schematic of the overall design system necessary to complete this design. A power supply drives a pneumatic pump that inflates and deflates a support cushion.

Delivery System Design Alternatives:

The delivery system includes a power supply, control panel and a pneumatic pump. The power source could either use batteries, or a car's cigarette lighter. Cycle settings should be able to be changed via a customer friendly control panel. Lastly, the pneumatic pump should deliver enough air at a pressure ranging from 50 – 90 mm Hg in the cushion. This whole system should be compact, durable, and lightweight, thereby facilitating easy transport. The following two designs were seriously considered during evaluation.

Delivery Design Option #1: Piston Driven Pump

In this design option, a closed system, spring-piston driven device pumps air into and out of the cushion. The piston is driven by microsensors that regulates compressions of springs within the piston. To inflate the cushion, a spring releases, pushing the piston and forcing air into the cushion. Upon reaching the maximum pressure, the microsensor will communicate back to the piston, initiating a sequence of events that will pull the piston back to its starting position, sucking the air back into the piston (Figure 2).

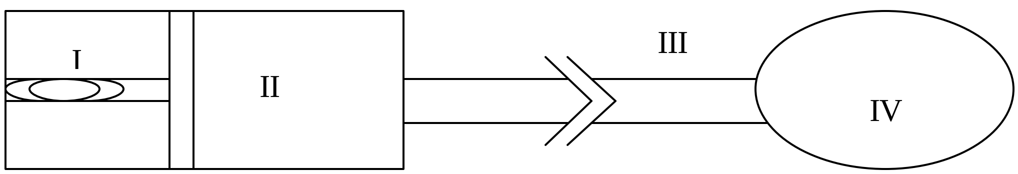

Figure 2: The pneumatic piston pump pictured delivers air within the chamber (II) through the tubing (III) into the cushion (IV). Within the cushion and piston are microsensors relaying information that directs inflation and deflation. The spring (I) releases, providing energy to drive air into the cushion, expanding it. Then, the air is then sucked back, recompressing the spring.

Delivery Design Option #2: Blood Pressure Pump

Another option would be to incorporate the motor system from an on-the-market automatic blood pressure device. These pumps automatically inflate to a desired pressure and then deflate afterwards. While it only undergoes one cycle, this pump could easily be modified for cycling.

Lumbar Cushion Design Alternatives:

The other component of our design, the lumbar support cushion, needs to incorporate the forward rotation of the pelvic region while also providing extension and flexion to the lumbar spine. Inflation should begin in the pelvic region moving up to the lumbar, while deflating from the lumbar to pelvic region. Materials used should have elastic properties, support a variable weight range, and provide friction to prevent undesired movement. Lastly, the increase in pressure should be lower enough where a seatbelt will effective restrain the user from undesired forward movement.

Support Cushion Design Alternative #1: Lateral and Vertical Support Beams

This cushion starts inflation via tubing on the side below the pelvis. Compartments divide the cushion into segments regulating airflow and providing structural support. An opening between each division allows for air to be moved upwards during inflation, and back out during deflation. The compartmental divisions are perpendicular to the surface of the cushion, thereby helping support the weight imposed on the cushion by the person (Figure 3).

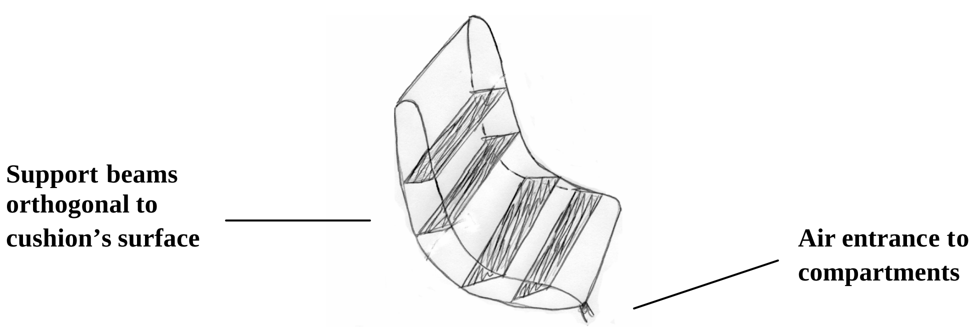

Figure 3: The divisions inside this cushion are at a 90-degree angle from the surface of the cushion. Air flows from the bottom of the cushion up during inflation, and vice versa during deflation.

Support Cushion Design Alternative #2: The Gel Cushion

In this cushion design, the cushion would consist of two layers: a gel filled compartment and an air compartment. The gel layer would provide better postural support for the patient while also providing a better ergonomic fit. Behind the gel would an air compartment that would inflate and deflate, thereby providing the user with continuous passive motion. The air compartment could be either one compartment or multi-compartmental.

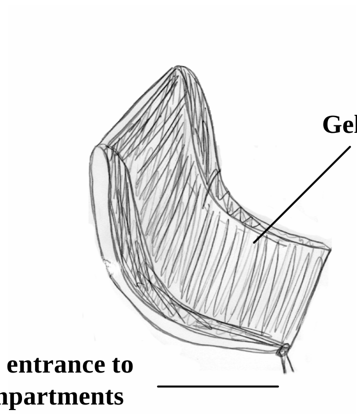

Figure 4: This cushion consists of a gel and air layer. The gel layer provides postural support. The air layer will deflate and inflate, thereby undergoing continuous passive motion.

Support Cushion Design Alternative #3: Timed Pneumatic Compartmental Release Cushion

Lastly, this cushion also has compartments dividing the air pocket. As air is pumped into the cushion, the compartments would fill from bottom up due to the presence of pressure sensitive valves between the different segments. When the pressure in a certain region reaches a designated pressure value, it would open, therefore allowing air to flow into the compartment above it. This would continue all the way up the lumbar cushion.

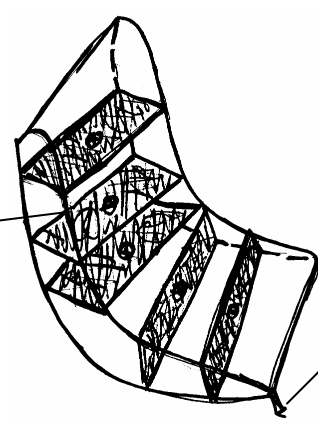

Figure 5: The cushion is divided into different air pockets that allow airflow through the use of valves. During inflation, when a cushion reaches a certain pressure value, the valve would release, allowing air to flow upward.

Evaluating Design Solutions:

When comparing the preliminary design solutions, criteria was established to determine which one was the final design solution. Most importantly, the cushion must provide the correct pelvic rotation. It should also provide good postural support throughout the cycle. The machine should be able to deliver enough pressure at a constant speed through the cycling process. It should also be able to consistently perform the cycle over a specified time interval determined by the user. The material of the lumbar support cushion should be sturdy and be able to withstand normal day-to-day usage wear. Lastly, simplicity and cost should also be considered with the final design solution.

When comparing the two modes of delivery systems, the automatic blood pressure system would be more ideal of a choice. Since this system is already on the market, it would be easy to obtain. Secondly, it performs a task very similar to the one desired for the overall design of the project. It is already known to provide the ideal pressure range consistently and accurately. Therefore, with a little modification, it could be programmed to cycle through as needed for continuous passive motion.

For the lumbar support cushion, a design matrix was developed (Figure 6) to accurately assess how each of the designs fit the criteria.

	Lateral and Vertical Supports	Gel and Air Compartments	Valve Compartments
Pelvic Position (x2)	++	++	++
Extra Postural Support	-	+	-
Ergonomic Fit	-	+	-
Controlled Air Flow	O	-	+
Reliability	+	+	+
Durability	+	+	-
Simplicity	+	+	-
Cost	+	+	O
Total:	**4**	**7**	**0**

Figure 6: The Design Matrix for evaluation of the lumber support cushion preliminary design options. A plus (+) indicates that the criteria were met well by the design, an O means it was indifferent, and a minus (-) means that it did not meet this criterion. The scores were then totaled (a 1 for each +, 0 for each O, and –1 for each -) with correct pelvic position being weighted twice as much as other criteria due to its utmost importance for the design.

Based on the design matrix evaluation, the gel and air compartment solution had the greatest potential. All three designs did provide good pelvic support for the user, but only the gel filled cushion provided extra postural support and a better ergonomic fit. It does lack a method of controlled airflow, which in the future could be modified to resemble that of the valve compartment design. The gel can easily be contained with a plastic encasement, making this a durable design. Cost should not be a big factor since all of the materials would be relatively cheap to obtain.

In the future, better design plans would definitely be needed. This design is just in the rough stages without specific dimensions and exact placement of the supports. Different plastics and gels should be researched to find a sturdy material that would best support the load, motion and strain. Lastly, looking at the system at a whole, the pump would need to be programmed to add cycling to the inflation and deflation cycle. It needs to have user specified settings that would change the frequency of cycling.

Appendix A: References

"*Continuous Passive Motion*" 2000. The Center for Orthopaedics & Sports Medicine http://www.arthroscopy.com/sp06001.htm Website. (September 28, 2001).

Hazard, R. G. *"Relief from an aching back"* 1999. http://orthopedics.about.com/gi/dynamic/offsite.htm?site=http%3A%2F%2Fwww.arthoscopy.com%2Fsp06004.htm. Website. (October 10, 2001).

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"*Relief of Pain and Suffering*" 1996. John C. Liebeskind History of Pain Collection, UCLA Louise M. Darling Biomedical Library. http://www.library.ucla.edu/libraries/biomed/his/PainExhibit/panel6.htm Website. (October 14, 2001).

Sherry, J. Personal Contact; September 14th, 2001.

Appendix B: Product Design Specification:

Product Design Constraints for a Continuous Passive Motion Support Cushion for the Lumbar and Pelvic Region

October 17, 2001

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Problem Statement: To design a pneumatic lumbar support cushion that will help alleviate lower back pain in patients through the use of continuous passive motion. The user will be in the sitting position, such as a car, while the cushion inflates and deflates through a range of motion for a specified duration of time determined by a setting chosen by the user.

Client Requirements:

- **Operational in a car**
- **Undergoes Continuous Passive Motion**
- **Different Cycle Settings**
- **Help Reduce Pain in Low Back by Pain Gating**

Design Requirements:

1. Physical and Operational Characteristics

a. Performance requirements: The device must complete cycles of inflation and deflation. These cycles should be able to continue for a time period of as little as thirty minutes to as long as half a day, 12 hours. Each cycle should last roughly a minute. Different time intervals should be chosen from a control panel. The cushion should support the pelvic and lumbar region, rotating from below the pelvis, pushing your butt into proper sitting posture. From there, it should complete the range of motion of the lumbar spine. Inflation should be applied bottom-up when inflating, and top-down when deflating.

b. Safety: Patient needs to stay stationary while device is in motion, allowing them to continue with normal functions such as driving uninhibited. The device should not move the person forward when inflating.

c. Accuracy and Reliability: The time between cycles should be kept consistent to the value chosen by the user. Pressure should remain within a few mm of Hg of the maximum pressure value (near 75-85 mm Hg) during each cycle.

d. Life in Service: The system should be able to continuously inflate and deflate the cushion for at least 12 hours. It can be used multiple times throughout the day. The device should be able to perform between 0-60 cycles per hours.

e. Shelf Life: Should be able to withstand wear and tear for a couple of years.

f. Operating Environment: Needs to be able to work in a temperature range and humidity range of outdoor environment. The cushion should be able to withstand up to 125 mm Hg of pressure. Noise level should be kept at a minimum so the user can go about activities as if the device was not running. Overall, the set up should be simplistic, so the user can easily assemble the device before driving.

g. Ergonomics: Should be well fit for the lumbar spine region as well as the pelvic region. Proper sitting position should be achieved.

h. Size: Should fit perfectly on the seat of the driver's seat of a car. This means that the cushion should at largest 1.5 feet wide, 1 foot on the back, and 1 foot below, supporting the pelvis. It should inflate no more than ½ foot.

i. Weight: Needs to be portable; approximately 1 lb.

j. Materials: Elastic, durable materials. Must be able to inflate to a desired shape. Also must be able to accommodate a pressure of up to 125 mm Hg.

k. Aesthetics, Appearance, and Finish: Needs to be a pleasant looking cushion since people will be displaying these in their car. Texture should be slightly rough to add friction, which will impede undesired movement.

2. Production Characteristics

a. Quantity: Right now 1, in the future, lots of them.

b. Target Product Cost: Total cost should be under $50.

3. Miscellaneous

a. Standards and Specifications: Would need to ultimately be FDA approved.

b. Customer: Customers would like a covering for the cushion to individualize the cushion. They would also like the option to increase or decrease the number of cycles.

c. Competition: One continuous passive system is available on the market by OPIC. This has one cycle setting that repeats for continuous passive motion. The design only supports the five lumbar vertebrates.