A Proposal for the Knee Brace Modification Project

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EXECUTIVE SUMMARY

This proposal recommends that Orthopedic Innovations design a device that will prevent people with injured or aging knees from falling when their knees buckle. A brace that already exists will be modified to include a system that could counteract the imminent buckling of a person's knee. If the leg motion falls within a normal range, such as for walking, the person can bend their knee freely; but if the velocity is above a certain threshold value, such as when the knee buckles, the brace will have a mechanism to lock and prevent the knee from bending further so the person does not fall.

After some initial research, four potential designs for this modified brace are being proposed. The idea behind a seat belt locking mechanism inspired one mechanical design. A mechanical system which uses a hydraulic chamber to sense the velocity and a spring system to lock the brace is also a potential solution. Another alternative is an electrical system that would contain an accelerometer, microcontroller, and a solenoid to lock the brace. Finally, a combination of mechanical and electrical systems could be implemented in which a hydraulic chamber is used, but this time with a pressure sensor to detect any change in velocity and a microcontroller to lock the brace. These alternatives will be described in detail later in the proposal and researched further pending the client's approval.

Orthopedic Innovations consists of four engineers with previous relevant experience. A design idea will be presented within three months time and, pending approval, a prototype will be built within eight months time. The estimated budget for the project has not yet been determined, but $300 is available for use from the client, as is the current brace that will be modified. This proposal contains an executive summary; introduction (background, requirements, company credibility); technical approach (resources, plan, contribution of technical advisor/client); and operations plan (criteria for success, division of labor, budget, timeline) which can be found on the pages as indicated in the Table of Contents. With your approval, we can begin the project on Wednesday, September 1st, 2004, and a detailed design can be presented by November 16th, 2004.
INTRODUCTION

Background on Opportunity
Tommy Williamson of the Forsyth Street Orthopedic Surgery and Rehabilitation Center has requested a device that will help prevent people with aging or injured knees from falling when their knees buckle. A brace already exists which ensures the patients' knees bend only in the sagittal plane, so he has requested that this brace be modified to include a device which would allow for movement of the knee so long as the motion is in the normal range of speed required for walking. It must have a means of detecting imminent buckling and lock the brace in place to prevent the knee from bending further and causing the user to fall.

Requirements
There are certain requirements that the design must meet and other criteria that would be preferable but are not mandatory. The device must prevent people from falling when their knees buckle. The modifications must not impede their normal gait and should also be as small as possible. The system should be durable; it must withstand the daily rigors of walking as well as the wear and tear of putting on the brace and removing it each day. It should be as lightweight as possible, and aesthetically pleasing. We would like to keep all costs as low as possible; it is imperative that the project be completed under budget.

Company Credibility
Orthopedic Innovations is a company with previous relevant experience that has all the tools and resources necessary to modify a knee brace that will prevent people from falling when their knees buckle. Orthopedic Innovations consists of four team members: Travis Blackburn, biomedical engineer, Christal Garner, biomedical engineer, Stacie Hamel, biomedical engineer, and Jon Stanton, mechanical engineer. We all have experience that will be beneficial in the completion of this project, including technical communications skills which enable us to efficiently write professional technical documents. In addition to the descriptions below, please see attached pages 11-14 for complete resumes.

Biomedical Experience. Mr. Blackburn, Ms. Hamel, and Ms. Garner each have a Bachelor of Science in Engineering with a specialization in Biomedical Engineering from Mercer University. While at Mercer, they excelled in courses such as Statics, Dynamics, and Biomechanics, which will assist them in examining various stresses and strains involved in the design of the brace as well as those placed on the knees. Also, they have taken multiple courses in Electrical Engineering, which have provided them with valuable insight into electric circuits and sensor mechanisms. They are currently enrolled in a course on microcontrollers, which will be especially useful if a microcontroller is chosen to implement the locking mechanism for this brace. They have successfully completed previous design projects and have experience in problem solving.
Mechanical Experience. Mr. Stanton has a Bachelor of Science in Engineering with a specialization in Mechanical Engineering from Mercer University. During his career at Mercer, he attended classes in Statics, Dynamics, Solid Mechanics, and Machine Design, all of which will give him valuable methods useful for examining stresses on the components in the components used in the team's design. Also, he attended Manufacturing Practices while at Mercer, giving him experience with welding and machine metals, which may be necessary for implementation of the team's design. His experience in Visualization and Graphics has provided him with proficiency in AutoCAD and Pro Engineer; useful software packages for conveying engineering designs to others. In addition, his experience on the Mercer Formula SAE team has given him real-world experience with engineering design.

Background on Knee Braces

General Description. Knee braces are useful in the treatment of knee ligament injuries, primarily anterior cruciate ligament injuries. They may be used by the patients who have not had surgical treatment and also in post surgical patients.

Major Components. Knee braces consist of three components: a superstructure (usually a rigid shell), a hinge, and a strap system. The superstructure extends proximally and distally to a hinge centered around the knee axis of motion. The strapping system secures the brace to the limb.

Four Categories of Braces. Prophylactic braces attempt to prevent or reduce the severity of knee ligament injuries. Rehabilitation braces are designed to allow protected motion of injured knees that have been treated operatively or non-operatively. They are usually purchased off the shelf and used for 6-12 weeks after injury. Functional braces are designed to assist or provide stability for unstable knees during activities of daily living or sports. Functional knee braces can be divided into two categories; (1) Off the shelf braces and (2) Custom fabricated braces. The "Off the shelf" functional brace comes in various sizes and fit most patients reasonably well. The custom fabricated brace, however, requires either a cast mold or extensive measurements, which are provided to the manufacturer so that the brace can be fabricated. Unloader knee braces are specifically designed to reduce the pain and disability associated with severe osteoarthritis.

(Taken from: http://www.wellmark.com/e_business/provider/medical/policies/kneebrace.htm)
TECHNICAL APPROACH

Availability of Resources
The textbooks used by the team at Mercer University contain a plethora of information on many engineering topics. Also, The Tarver Library at Mercer University contains technical journals, relevant books, and access to the Galileo database, which contains many more technical journals. The laboratories at Mercer University will also be useful when the design is implemented, since they contain sufficient machining, welding, and electrical equipment for this project. The technical advisors also possess books that are more detailed than those used by most students.

Plan/Alternatives
Mechanical Alternatives. Our team is currently considering two possible mechanical mechanisms intended to halt movement of the knee brace and prevent the user from falling. The first possible alternative is inspired by the mechanism used in seat belts. It uses a gear that turns in one direction as the leg bends, and the other during extension. At normal walking speeds, the gear moves relatively slowly, but if the leg suddenly buckles, the gear rapidly accelerates causing the centrifugal force to move a pin inside the gear, which locks the gear in place, preventing a fall of the user.

The other mechanism uses hydraulic fluid within a cylinder that is forced out through a small valve in the cylinder during motion of the knee. The cylinder pressure remains relatively low during walking, but the rapid motion of a fall would cause pressure inside the cylinder to increase, which would actuate a locking mechanism to hold the brace stationary, stabilizing the user. The mechanical mechanism tentatively consists of a spring-loaded pressure switch in the cylinder that locks the cylinder valve in place, preventing fluid flow and holding the brace stationary.

Electrical Alternatives. Our team is also considering two different mostly electrical mechanisms that can be used to halt movement of the knee brace, upon buckling, to prevent the user from falling. The third possible alternative is a system that involves an interlocking gear system, an accelerometer, a filter, a microcontroller, a solenoid, and a locking mechanism. The accelerometer is a sensor that can be used to detect relative acceleration of the interlocking gear system. The most important aspect to consider when choosing the specific sensor would be response time because to be able to prevent the user from falling, the mechanism would need to sense the buckling very quickly. The filter would be used so that only the high frequency outputs of the sensor will trigger the microcontroller to flip the solenoid, which will enable the locking mechanism to lock the brace. A feedback loop will need to be in place so that after a buckling occurrence, the knee brace can return to regular unhindered motion.
The fourth and final mechanism under consideration consists of a compressible fluid chamber, a pressure sensor, and similar to alternative three, a filter, a microcontroller, a solenoid, and a locking mechanism. The pressure sensor could be used to detect changes in pressure of the fluid chamber. Using the same mechanism as in alternative three, the pressure information would be filtered, then processed to evaluate if the solenoid should be switched to lock the brace.

Contribution of Technical Advisors and Client

*Technical Advisors.* The team has two technical advisors; Dr. Hodge Jenkins will specialize in the mechanical aspect of the design, and Dr. Edward O’Brien will specialize in the biomedical and electrical aspects. Dr. Jenkins specializes in design of machines and structures and will help us find the most important components of the design to analyze. His experience will also help the team eliminate ideas that are not feasible. Dr. O’Brien will contribute his electrical experience to assist us in the design and implementation of the sensors, filters, and microcontrollers to ensure the concepts are fleshed out properly and that they are physically possible.

*Client.* The client, Tommy Williamson, will review our progress periodically throughout the design process, as well as supply the funds necessary to complete the project. Since the client works as a physical therapist, he can assist us in ergonomic details by perhaps using his patients as test subjects for the modified knee brace and/or by offering details about his past successes and failures with various knee braces.
OPERATIONS PLAN

Criteria for Success
The goal for every project that Orthopedic Innovations designs is to give the client a product that satisfies his needs and exceeds his expectations. In this case, we have been asked to design a knee brace that will lock if the knee buckles. Just like every project that our company has worked on, we plan to complete this design to the full satisfaction of the client to the best of our ability. If the client thinks that something in the design should be different, we will re-evaluate it in order to suit those concerns. We are not happy with the project until the customer is happy.

Another goal is to perform first-rate work within budget constraints. We will perform research on the costs of parts so that the cheapest price for each part is found. Our company also promises to discuss the costs in the budget throughout the project so that everyone involved is aware of items that need to be purchased and that there are no surprises.

Division of Labor
Although most of the initial brainstorming and design selection will be done all together, each member will serve as an expert in one particular aspect of the design. At this point, the final design has yet to be selected, therefore the exact jobs of each member are only tentative.

*Travis Blackburn.* Travis will tentatively be in charge of the microcontroller aspect of the project. He will be in charge of developing the code, as well as the selection of the proper microcontroller for this project along with its test plan.

*Christal Garner.* Christal will tentatively be in charge of the sensing aspect of the project. She will be in charge of selecting the appropriate sensor, as well as researching the possible values to be obtained and the related test plan.

*Stacie Hamel.* Stacie will tentatively be in charge of what happens to the output of the microcontroller, specifically the possible use of a solenoid and the locking mechanism. She will be in charge of selecting the appropriate output device, as well as researching possibilities and the related test plan.

*Jon Stanton.* Jon will tentatively be in charge of the fabrication and hydraulic aspects of the project. He will be in charge of making sure that designs are feasible for fabrication and will research possible mounting options, as well as contribute hydraulic, stress, and strain calculations and insight when needed.
Deliverables
The client will receive several deliverables from Orthopedic Innovations during the course of this project. We will provide extensive mechanical and electrical analyses of our feasible alternatives. We will supply detailed drawings of our final designs, as well as any circuit drawings that are necessary to explain internal processes. At the end of next semester, we will provide a brace that has been modified to sense when the knee is buckling and have a catch mechanism so the user has time to regain his balance before falling.

Budget
Orthopedic Innovations has discussed the budget with the client, Tommy Williamson, and it is understood that up to 300 dollars has been allotted for this project. Due to the close proximity of the client, there will be no charge for transportation costs, so the majority of the money will be used for parts. Since the designs have not been fully developed, there is no way to know exactly which parts are going to be used. However, the company has contemplated the idea of having mechanical designs and electrical ones, with the greatest possibility being that the final design will contain both mechanical and electrical parts. Parts could include devices such as hydraulic cables, accelerometers, sensors, and microcontrollers. From the preliminary research that has been performed, Orthopedic Innovations is certain that all these parts can be purchased with the money that has been allotted.

Timeline
To successfully accomplish what we have set out to do, we have developed a timeline, see Table 1 on the following page. The work has been divided over a period of 13 weeks.