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Low Cost Shear and Pressure Sensor

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LOW COST SHEAR AND PRESSURE SENSOR

BME Design Project



APRIL 17, 2015
DIABETIC INNOVATION
Kyle Rohrig

Abstract

Elevated pressure and shearing stresses at the foot-shoe interface are believed to play a role in diabetic foot ulceration. The main goal of this project was to design a simple insole that could distinguish between sites of high pressure and sites of excessive shearing stresses at the foot-shoe interface. Wear patterns that relate specifically to shear and pressure acting on the plantar surface of a patient's foot also needed to be exhibited. The team used reflective tape that was applied to the surface to various types of insoles to look for visible wear patterns. These wear patterns were identified by the use of a MATLAB code. Pressure sensitive Fujifilm Prescale was used to detect sites of excessive shear stresses at the skin-shoe interface, by being inserted into slits in an insole. Based on the color and color-density of the Fujifilm sites, high and low shear stresses can be identified. Areas of excessive wear from the reflective tape and the Fujifilm results can be correlated to the control sample step we obtained from Dr. Davis's shear detection machine.

INTRODUCTION

Problem Statement

Elevated pressure and shear stresses at the foot-shoe interface are believed to play a role in diabetic foot ulcer formation. What is needed is a simple insole that can distinguish between sites of high pressure and sites of excessive shear stresses. Wear patterns that relate specifically to shear and pressure, acting on the plantar surface of a patient's foot, must also be exhibited. There is currently no design on the market for an insole that can detect shear, while there are ones that can detect pressure. This design will focus primarily on being able to accurately assess shear stresses on the skin-shoe interface.

Customer Information

Dr. Brian L. Davis

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Our customer who assigned us this project is Dr. Brian L. Davis, a Biomedical Engineering professor and department chair at the University of Akron. One of Dr. Davis's primary areas of research is diabetic foot ulceration, to which he has more than 10 years of experience and several research articles published. Dr. Davis assigned this project in order to see if it was possible to inexpensively design an insole that could show wear patterns that could distinguish areas of excessive shear stresses at the foot-shoe interface.

Purpose of Doing the Project

The purpose of this project is to create a simple and affordable insole that can detect sites of excessive shear stresses on the plantar surface of the foot through material wear patterns; as well as to see if these sites of excessive shear can be correlated to the formation of diabetic foot ulcerations. Currently, there is no such insole on the market that can detect the sites of shear stresses on the foot's plantar surface. The insole also needs to be inexpensive; thus, allowing it to be affordable to patients in poorer areas and be distributed to a large market. The insole should not contain any objects that can cause any damage to the foot because it will be used by diabetic patients who may not feel any pain that occurs in their feet. Thus, the procedure of detecting the shear stresses will be noninvasive.

BACKGROUND INFORMATION

Many pressure mats and insoles currently exist on the market. Companies such as Tekscan, Novel GmbH, Vista Medical, and Parotec have insole pressure measuring products. However, no insole currently exists on the market to measure shear forces. A very common sensor type that is typically used is piezoelectric/resistive. Another type of sensor that is currently being used is capacitive that exist in Novel GmbH's insoles. Capacitive sensors are more sensitive and accurate than piezoelectric/resistive sensors, but take a longer time to process data that are recorded from 100's of sensors at rates up to 200 Hz. Piezoelectric sensors also have a multitude of problems including the need for constant recalibration due to degradation of the material. All these products also have problems with hysteresis, as much as 7% for Novel GmbH and 24% for Tekscan [9]. These products are only capable of measuring pressure forces. The problem with this is that foot ulcer formation only occurs in the locations of high pressure about one-third of the time. Being able to distinguish shear, pressure, and frictional forces should give more reliable results for early foot ulcer detection.

Another sensor type we thought to use was strain gauges but their application here is limited. Multiple or biaxial strain gauges can measure shear force on a plane however the contours of the insole and foot are ever changing. Changing the angle of multi-axial strain gauges gives inaccurate results due to the fact that the gauges lose their orientation with each other. Thus the strain gauge measures strain on an ever changing plane. Also, strain gauges can only measure strain at a single point and would then require an enormous number of sensors if they were to be used in an insole.

It is important to note that these devices measure forces in real time and wirelessly. A wired system is troublesome when trying to monitor a patient. The wired system tends to be more bulky and awkward for the patient to carry when replicating daily scenarios and can also be a tripping hazard. This is where a wireless system would be more preferred. However, data transferred wirelessly can result in a loss of data. There can be as much as 10% discrepancy between a wired and wireless system.

These systems also tend to be expensive as well. Most systems, including software, can cost over \$10,000 dollars. This is unacceptable if we market the product to any part of the world, specifically targeting regions of underdeveloped nations where diabetes is a rampant problem.

PROJECT OBJECTIVES AND GOALS

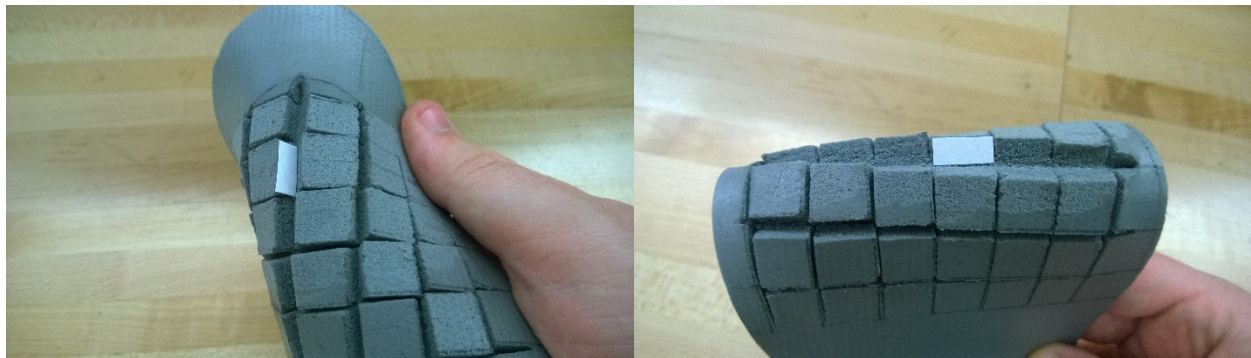
The goal of our project is create an insole that can be used to aid diabetic patients in the early detection of potential sites for diabetic foot ulcer formation. The insole is meant to be an inexpensive solution for detecting shear stress at the foot-shoe interface. We wish to create a product that is affordable and can be readily available to any part of the world. Our goal for the price of our insole is to be between \$1 and \$2. As a direct result of the low market cost of the insole, we wish to measure shear forces without directly implementing real time data collection, electrical components, or electrical interfaces directly into the design of the insole itself.

METHODS/PROCEDURES/MANUFACTURING

Multiple paths were pursued for this project. The complexity of the task and the constraint on production cost required us to explore multiple ways and materials to measure shear. The group tried to steer away from using electronic sensors in the insole due to the large cost and the number we would need. The materials that we initially focused on using for our insole were an Ossur Replacement Insole and an insole made out of reflective material.

For the hexagonal Ossur Replacement Insole, we originally tried to insert materials in between the hexagons that would produce wear on the adjacent hexagons in the pattern. We did this by inserting a piece of a paperclip through one of the hexagons near the center of the insole. We quickly abandoned this initial design idea though because we did not want to have an object in the insole that could potentially damage a patient's foot if the object came loose. Under no circumstance can we risk causing injury to the patient.

We then decided to use Fujifilm that could be placed within the insole, perpendicular to the base of the foot. Fujifilm is a type of pressure sensitive film that changes color from white to different intensities of red under compression. The film would be cut into strips that would be placed in a vertical orientation inside an insole, by cutting small slits in the insole for the film to be placed. The film could also be arranged in a grid array within the foam



insert of the insole.

Figure 1: Fujifilm vertically oriented inside the insole

Figure 2: Fujifilm horizontally oriented inside the insole

As the patient walks, shear forces should cause the slits within the insole to apply shear pressure on the film. The intensity of the shear pressure would be recorded by the change in coloration of the Fujifilm. The film would be sealed inside the slits of the insole to prevent water, dust, or oils from altering the results. The material we use for the insole would have to be strong enough to not compress or crinkle the film from the normal force of the foot; however, it also has to be flexible enough to allow the patient to walk normally. After the insole has been used, the film will then be carefully removed and scanned onto a computer. MATLAB would then be used to determine and measure the pressure applied to the film. After analyzing the film it should be possible to determine how much shear occurs at different parts of the insole.

We took controlled pressure readings of the Fujifilm in order to be able to successfully analyze the Fujifilm in MATLAB as well as to determine and measure the pressure applied to the film in the insole. These controlled readings were taken by using an ASTM Flat and a set of ASTM certified calibration weights, both supplied by Mr. Stephen Paterson, the Senior Engineering Technician for the Biomedical Engineering department. In order to preserve the Fujifilm, a 0.75 inch diameter weight was set on a piece of Fujifilm that was sized to fit the diameter. By using the equation $\text{Pressure} = \text{Force} / \text{Area}$, we were able to calculate the amount of weight that we needed to apply to the 0.75 inch diameter weight in order to get the corresponding psi pressure that we needed. Our psi scale for the Fujifilm started at 8 psi and ended at 28 psi, with a scale that increased by increments of 1 psi. These readings were then scanned on an Epson Stylus Photo RX620 at 1000 dpi into a computer and saved as our pressure reference scale.



Figure 3: The set up that was used for creating the 8 to 28psi scale. A 0.75 inch diameter weight was used for the area our force was applied over. A flat was used for a level testing surface.

Three materials were selected to be used as an insole to test the Fujifilm. These materials were a rubber mat material, R49 insulating foam, and the hexagonal Ossur Replacement Insole. A grid consisting of a series of horizontal and vertical slits were cut into these materials in order to insert strips of Fujifilm, except for the Ossur Replacement Insole that was already pre-cut. Once the Fujifilm strips were inserted into the different insole materials, the insole materials were then stood on for time periods ranging from 5 to 20 minutes, in order to see how much compression occurred to the material and how it affected the Fujifilm. The insole materials were then walked on. The rubber mat material was inserted into a shoe and walked on for 400 meters, to simulate normal walking patterns over the insole. This allowed us to see if pressure due to shear could be detected accurately using the Fujifilm. All three materials showed changes in coloration for this walking trail.

The hexagonal Ossur Replacement Insole being used along with the Fujifilm was eventually abandoned, due to the edges of the hexagons applying undistributed pressure loads to areas of the Fujifilm that inaccurately skewed the data. In place of the hexagonal insole, an insole from a rubber mat was cut out, as well as an insole from R49 insulating foam. A series of grids were cut into the insulating foam and the rubber mat to insert the Fujifilm into. The rubber mat insole became our main insole to test the Fujifilm in, due to its quarter-inch thickness, flexibility, and ability to be easily inserted into a shoe for testing. Due to the size of the mat that we purchased, there was enough material to create multiple insoles that were able to be cut to the appropriate sizes for all of our team members to be able to wear.

Another material we tested was reflective tape. A crude test was done first to see if there could be wear at all on the insole. The test included one of the members applying the tape directly to his shoe and sock before three 50 minute soccer games. The tape was examined after each game for any type of wear. The tape looked worn after the first game and progressively became more deteriorated. It showed promise so the group continued working with it. The reflective tape is rather thin, only a few millimeters

at most, and flexible, so we wrapped it around a standard Dr. Scholl's AllTopBargains insole, believing that it would not interfere with the patient's normal movement.

One insole was wrapped horizontally, and the other was wrapped vertically. A basic stand was then created to take pictures from any desired height. Pictures were taken of the insole at a standard height at 9 $\frac{3}{8}$ inches with a Nokia Lumia 920 phone. A LED light from a Droid Ultra was placed next to the Nokia, further away from the pole of the stand, in order to get a constant light flooding. A picture was taken before use, and after a 10 minute first trial and a 30 minute second trial. These pictures were then uploaded to MATLAB to be processed. It is important to note that phones might not be the best scanning system, however they are easily accessible and most people have smartphones with a camera quality greater or equal to 5 mega pixels.

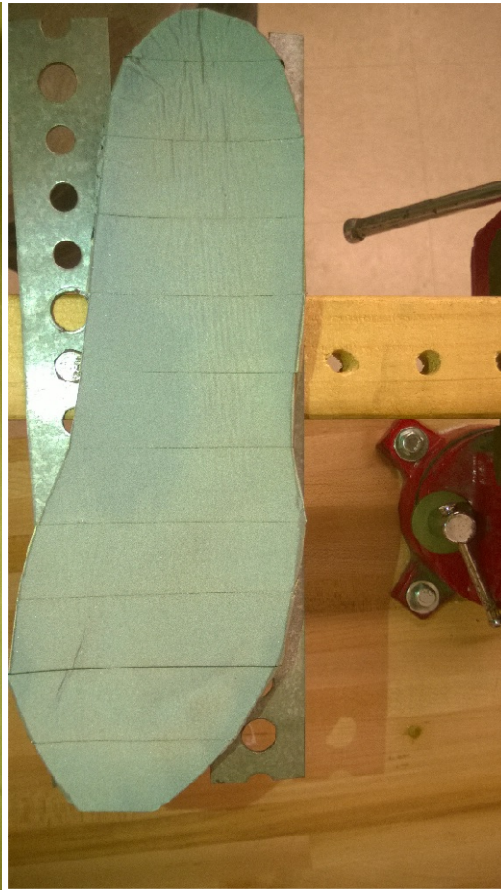


Figure 4: Reflective insole wrapped vertically Figure 5: Reflective insole wrapped Horizontally

Smartphones are becoming ever more popular and increase the potential of this insole to reach a greater amount of people. The pictures obtained from the Nokia were processed using a MATLAB code that was developed earlier in the semester. The code functions by converting both the before and after images of the insole into gray scale. A point selection code was then run, and a grid was assigned to the before and after image, allowing them to be aligned together. The before and after image were then overlaid. The before image would then “shine through” the after image to show where the most wear had occurred. The wear patterns were then studied after each trial to determine what wear was occurring in what locations. The wear is currently being compared to our standard test which involves pulling and spinning a simple weight, covered in a sock, over the material. This test is designed not to give exactly how much force was exerted on the material, but rather the visual baseline to what type of wear (rotational, linear). For a numerical comparison to the type of wear, please see the performance testing section of this paper.

PERFORMANCE TESTING

Images of the reference Fujifilm scale and results of the worn Fujifilm will be uploaded into MATLAB as .jpeg files. By converting the images to grayscale and cell counting, a MATLAB code will be constructed that will be able to compare the Fujifilm from our saved pressure reference scale to the Fujifilm that was inserted into the different insole materials. By reading the images of the reference scale as matrices, numerical results can be displayed in the matrices that will correspond to the different psi readings. From here, the numerical results given by our tested Fujifilm will be compared to the numerical psi reading from our scale. This will allow us to determine where different psi intensities occurred on our tested material with the Fujifilm inside it. This will allow us to see where areas of high and low shear stresses occurred on the foot from normal walking patterns.

In order to make sure our device is correctly displaying where sites of shear stresses are occurring, a meeting with Dr. Davis will be set up in order to use the shear sensor in his lab. This sensor is able to give accurate readings of areas of high and low shear stresses by having a patient stand on the sensor and take a step. By having a team member take a step on the sensor, we will be able to gather accurate data that would be compared to the Fujifilm compression readings from the tested insole materials. The material that showed the most accurate correlation with Dr. Davis's shear sensor would then be selected as the material to be used for the insole base. This process should be done at least 5 times for that person or until results are shown to be consistent. It would be preferable to repeat this process at least 20 times for more individuals for comparison purposes.

Top layer material testing will begin after we find our desired insole base. The purpose of the top layer would be to acquire a second material that could show the distinct wear patterns we are looking for. The second layer would have to be thin and securely fastened to the base. The combined base-to-top prototype should be less than .25 inches as directed by Dr. Davis. To test for how much force is needed to create the wear patterns, the original Fujifilm test would be repeated with the added top layer. The Fujifilm results should remain the same as the original test even though there is the new top layer. If the results cannot be accurately correlated to the original test, then a new top layer material must be found. This process must be repeated until results are consistent and repeatable. As much detail should be recorded and should include but not limited to: time worn, weight of patient, activity done (ex: Walking), speed of activity, humidity/temperature at foot, etc.

The top-layer material that shows the most preferred wear patterns will be selected to cover the surface our non-Fujifilm base. The hope is that the insole should be able to show the same wear patterns as the prototype test without the Fujifilm. This would then allow us to reach our required budget set by our customer.

All mechanical properties including Young's modulus, yield strength, ultimate strength, and failure point for the materials can be determined with simple tension testing machine. This machine can be accessible from Dr. Marnie Saunders, an Associate Professor in the Biomedical Engineering Department, or by sending the materials to a certified testing company. The wear patterns however are difficult to replicate with a mechanical walking machine, because the machine must replicate how a foot touches down and pushes off of the surface. This includes the replicating rotational and linear shear accurately. Therefore, the previous Fujifilm testing method would be preferred.

FUTURE DIRECTIONS

After our initial prototype construction, the next step we would take would be to continue to test our prototype to see if the prototype has any flaws or inaccuracies that need to be corrected. Upon identifying any existing problems with our initial prototype, our prototype design will be refined in order to correct these problems. This might include redesigning our current prototype model, in order to get a more efficient design that would yield more accurate results. Some design iterations could include varying the thickness of the insole, changing how the top-layer of the insole is applied, or altering the material that the base of the insole is made of.

Although a high resolution scanner gives better quality pictures of the insole, smartphone cameras seem to have sufficient pixel density for pictures. For visual analysis of the insole, this was believed to be more than sufficient when compared to the high definition scanner we used for the Fujifilm. Higher density images would be better at determining forces of interest on smaller areas of the insole. For this project, we believe that we don't have to go to this intensity to find the results we are looking for. Higher density images would contain more pixels and would have better quality than our smartphone images and could be used to get more precise data. Using high definition scanners would be preferred over our smartphones, but the accessibility of smartphones might prove to be a crucial

factor in the distribution of the insole worldwide. Patients could potentially wear the insole at home and send the images to their doctor. This method seems more cost effective for poorer areas.

We would also conduct more extensive material testing and product testing on our prototype and the materials that went into making it. With a larger budget, we could construct an apparatus that replicates normal walking patterns. With our current budget this apparatus seems unlikely, since a large amount of our budget went into the purchase of Fujifilm. With our remaining budget, a construction of such an apparatus is not very feasible. Designing an apparatus that reliably replicates normal walking would allow us to test a variety of insole materials and their material coverings to see how they behave under normal movement. This would include compression testing of the insole material, testing for material slippage, and testing for surface wear. Determining the Modulus of Elasticity of the prototype would allow us to simulate accurate testing through FEM software on a computer.

A gait analysis could also be performed to get the range of motion that occurs for the individual taking the test. Further analysis would have to be done of the foot area of this individual during gait to get the comparison of wear to range of motion. This study might allow us to see the type of movement that may cause excessive shear.

APPENDICES

FUNCTIONAL REQUIREMENTS

1. The insole is lightweight.

It was necessary for the insole to be lightweight to insure normal movement for the diabetic patient. If the insole is too thick or too heavy then normal movement is impaired. Any insole or insert can impede normal movement. Movement can be impaired by the insole itself, and or by the peculiar setting that flusters the patient. The key is to make the insole is unnoticeable as possible to insure accurate results. Our goal was to make the weight of each insole to be a quarter of a pound or less.

2. The insole is flexible.

A flexible insole is required for multiple reasons. The insole has to be able to undergo all motion that the foot makes. If the material is not flexible then it will surely break under multiple zones that undergo severe bending, specifically the region behind the toes and balls of the feet. Also it is important for the insole to be flexible for comfort-ability. A rigid insole tends to hurt the feet, as founded out through testing.

3. The insole is thin.

Like previously stated for the lightweight requirement, the insole cannot significantly impede normal movement. An excessively thick insole can significantly impede normal movement for a patient. As recommended by our customer, Dr. Davis, the insole should be no more than a quarter inch thick but the thinner the better.

4. The insole readings are reliable.

The insole should show accurate results that distinguish between the multiple forces. The insole has to be able to distinguish between what type of shear is occurring and where it is occurring. This is the purpose of the project.

5. The insole will not shift in the shoe.

Regular insoles will shift in a shoe. The amount of shift has to be small in order for the same regions to be compared. However shear force across a face will cause the insole to move and cause wear. We decided that as long as the insole fits well in the shoe, then the amount of shift that occurs will be acceptable. If the shifting proves to be too severe, then we will adjust for the situation.

6. The insole material will not bunch up.

The material should not bunch up unless intended. If the material bunches up too much, it could tear more easily. Also when a material bunches up it pulls the material from other areas of the insole. This results in the wear patterns being stretched or destroyed over there actually occurring area.

7. The insole material will not dry out.

The material properties of the insole can change due to humidity changes at the foot shoe interface. Diabetics can sometimes have reduced sweating due to neuropathy because the nerves that control the sweat glands do not work properly. The material should be able to work properly under these conditions for the necessary duration.

8. The insole material will not cause microbial growth.

The material cannot cause microbial growth. Ulcers can get infected quickly if opened and for patients with already high risk cannot be exposed to these risks. However, hopefully with low humidity and the small duration these insoles are worn, this risk can be averted.

9. The insole material will not bond to or strip the skin.

If any adhesive was applied to the patient's foot, the adhesive material could not be painful to remove, strip the skin, or bond to the skin. This is because diabetic patients at risk of foot ulcer

formation tend to be numbed to pain on the foot. This mean that if any skin damage is occurring that the diabetic patient will not be able to feel it and the damage could worsen.

10. The insole material will not bond to or strip the sock, if not intended.

The sock is an element that we have to pay attention to. We are trying to detect what is occurring at the foot-insole interface of a diabetic patient. We have to try and keep as much normality as possible to accurately detect what happens in a standard day of a patient. If the sock does not behave the same way as it would normally, then it might lead to unwanted results. However this is an ongoing process for all studies, not just this one, on how much the sock effects what happens. For now we will ignore the sock as long as it is not excessively worn (thinning, holes).

11. The surface texture of the insole will not irritate the foot.

If the insole is uncomfortable to wear, the patient may walk differently in order compensate for the uncomfortableness. This will cause a different weight distribution on the insole than normal, which will cause areas of high shear stress to show up in areas where they would not normally be present. This would lead to inaccurate results.

12. The insole will not cause further damage, pinch, or irritate the foot.

Diabetic patients at risk of foot ulcer formation tend to be numbed to pain on the foot. This means that if any skin damage is occurring that the diabetic patient will not be able to feel it, and the damage could worsen.

13. The insole material will not cause an allergic skin reaction or a chemical skin reaction.

The skin-insole reaction is one of our biggest concerns. The material we chose cannot hurt the patient in any manner. Safety is our main priority and in no way can be neglected.

14. The insole will not deform due to compression (minimal).

Compression due to pressure cannot be avoided with any material; it can only become minimal depending on the strength of the material. Forces become harder to detect and distinguish when a material is able to deform excessively. Although a material with greater compressive strength might be better at detecting wear patterns, it would be more efficient of our time to choose a material that compresses very little.

15. The insole material will show wear as a result of shear forces.

This is the part of the concept we are meant to find. We want to be able to distinguish shear wear from other types of wear.

16. The insole material will show different wear as a result of pressure and can differentiate between sites of high shear and high pressure, if intended.

Shear forces are what this project is concerned with. It is important that we be able to distinguish between shear and pressure. Either we have to have no pressure wear or we have to be able to clearly see the difference.

17. The insole will be able to work appropriately at the pressure ranges at the foot shoe interface.

The insole has to have enough strength to be able to handle a wide range of weight applied to it and cannot be destroyed unless intended. This is important for application purposes.

18. The insole will be able to collect sufficient data within 2 to 3 hours or less of wearing.

The insole is meant to be used in a controlled testing environment or while the patient is at home, so long period tests are inconvenient for both the patient and the physician. A longer test is more prone to human factor errors because there is an increased chance of the patient doing activities that exceed the recommended testing conditions.

CONSTRAINTS AND LIMITATIONS

The insole needed to be inexpensive, at a preferable price range between one and three dollars, at market cost. Our client wanted our product to be in this cost range so that it could be readily available and easily affordable in poorer areas. Our team goal was to have our final prototype meet this price range, with the assumption that the insole or its image would then be sent to a facility where the appropriate scanning and software equipment would be used to collect the data. It was suggested that the insole be reproducible through 3D printing. The low market cost for the insole means that the constructed insole would most likely not be able to incorporate any type of electrical components or electrical interface.

The insole needed to be able to sufficiently show shear wear while being relatively thin, preferable 1/16th of an inch. If the insole was too thick it would not be able to comfortably fit inside a patient's shoe. If the insole material could not reliably show shear wear, conclusive data would not be able to be drawn from our tests, and the design would be a failure.

The insole needed to show enough prominent and reliable data to only need to be worn for up to two to three hours. The insole is meant to be used in a controlled testing environment or while the patient is at home, so long period tests are inconvenient for both the patient and the physician. A longer test is more prone to human factor errors because there is an increased chance of the patient doing activities that exceed the recommended testing conditions.

The insole is meant for activities no more strenuous than walking. The insole design is meant to find reliable, correlating, data on how shear stresses and pressure affect foot ulcer formation for a patient who is walking. Strenuous activities, such as running, can cause abnormal amounts of shear stresses and pressure, compared to what is normal in a patient's daily life. If these results are taken into account, without knowledge of the strenuous activities, then the results for areas of shear stresses and pressure will most likely be incorrect.

The material used for the insole needed to be flexible, lightweight, and comfortable enough to not impede normal movement. If the patient is not able to walk like they normally would, without the modified insole, then false data would likely be collected. This is because the patient will favor one foot over the other while walking with the insole or will put their weight on different areas of the foot, in order to be able to walk comfortably. This will cause increased shear stresses and pressure in areas where it would not normally be present and inaccurate data will be collected.

Any and all materials used for the design of the insole must not cause a chemical or skin reaction. For instance, there are people who have latex allergies, so heavily incorporating latex into the design would be a poor decision. This would alienate an area of potential patients who could benefit from the insole. We do not want the materials in our design to reduce the potential number of patients who could benefit from the device.

If any adhesive was applied to the patient's foot, the adhesive material could not be painful to remove, strip the skin, or bond to the skin. This is because diabetic patients at risk of foot ulcer formation tend to be numbed to pain on the foot. This means that if any skin damage is occurring that the diabetic patient will not be able to feel it, and the damage could worsen.

The budget for the design project was five hundred dollars. This budget meant that there were certain, more expensive, materials and testing devices that were impractical for the design to use or incorporate. We did not know how many of the materials that were being used for design testing would be incorporated into our final design, so we could not spend our entire budget on just one type of material or idea, in case it did not show results. Compromises had to be made for practicality versus quality, in some instances of the design.

Time was our biggest limitation. The entire project needed to be completed by April 17th 2015, at the latest. This deadline meant that, regardless of setbacks, the project needed to be done by this date. There were many times where three to four weeks were put into a design concept just to have it

scrapped because it would not work. This was time that we could not get back. With this in mind, the team's free time and group meetings were optimized for maximum time efficiency. Meetings were held almost every day following the first Progress Report for the spring semester.

TIMELINE

See the attached Gantt chart files for a full timeline for the design project

BUDGET

The budget limit for this project was \$500. The following table demonstrates the expenses:

Project Materials	Date of Purchase	Place of Purchase	Cost
Reflective Tape	N/A	The reflective tape was given to us by Dr. Verstraete	N/A
Red Spray Paint	1/25/2015	Ace Hardware	\$1.99
Gasket Cork	1/25/2015	Ace Hardware	\$3.99
Outdoor Traction Tape	1/25/2015	Ace Hardware	\$5.98
Wallbase Vinyl and Tax	1/25/2015	Ace Hardware	\$3.34
12 Pair Lot Unisex Memory Foam Insoles Shoe Pad Comfort Cushion Feet Heel Shock (AllTopBargains)	1/26/2015	AllTopBargains at Amazon.com	\$19.26

Ossur Replacement Insole For DH Walker (Large Size)	1/26/2015	The Brace Shop at Amazon.com	\$44.95
Ossur Replacement Insole For DH Walker (Medium Size)	3/3/2015	The Brace Shop at Amazon.com	\$44.95
Fujifilm Prescale by the Foot Extreme Low	3/3/2015	Sensor Products, Inc. at Amazon.com	\$124.40
5" X 48" GUTTER FOAM FILTER	3/13/2015	Home Depot	\$6.97
SB HOUSEHOLD SCRUB SPONGE	3/13/2015	Home Depot	\$2.88
Weatherstrip RUBBER	3/13/2015	Home Depot	\$3.98
PAINTERS TOUCH 2X MEADOW GREEN	3/13/2015	Home Depot	\$3.44
PAINTERS TOUCH 2X GLOSS BRILLIANT BL	3/13/2015	Home Depot	\$3.44
PICTURE BAG	3/13/2015	Home Depot	\$7.47
SANDPAPER	3/13/2015	Home Depot	\$3.97
SOFT FOOT CUSHION MAT - GRAY	3/13/2015	Home Depot	\$1.98
Tax	3/13/2015	Home Depot	\$2.98
Total Cost of Materials			\$295.95

If our design were to be prototyped in the “real world” by a company or university, the cost would vary depending whether or not the materials were bought in bulk. By buying in bulk, our cheapest

prototype would cost roughly \$136.38, to gather the materials required to assemble it. This would include the 24" by 12" sheet of Fujifilm, the 24" by 24" Soft Foot Cushion mat, and a \$10.00 roll of reflective tape.

By using a 12" by 4" area of the mat for each insole, it is possible to get twelve insole molds from the mat. These insoles are then lined with 0.25 inch strips of Fujifilm and covered with reflective tape. Each insole uses roughly a 0.25" by 12" strip of Fujifilm that is cut and inserted into the slits in the insole. Each 24" by 12" sheet of Fujifilm can be used to test 96 insoles. For each sheet of Fujifilm a total of eight Soft Foot Cushion mats will be used.

With this in mind the cost of each individual insole for prototyping comes down to:

$$(\$124.40 + \$1.98 \times 8 + \$10)/96 = \$1.57$$

It should be noted that the total amount of reflective tape rolls for this total is still unknown at this time, so the final cost will vary some.

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