The Effect of Transtibial Prosthesis Suspension on Residual Limb Pistoning

Austin Balogh

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Hello slide

Background

- Goal of prosthetic suspension is to minimize residual limb motion within prosthesis
- Poor suspension can cause: [Carroll 2006, Edwards 2000, Michael 2004]
  - Skin breakdown
  - Loss of control
  - Discomfort
  - Compliance issues

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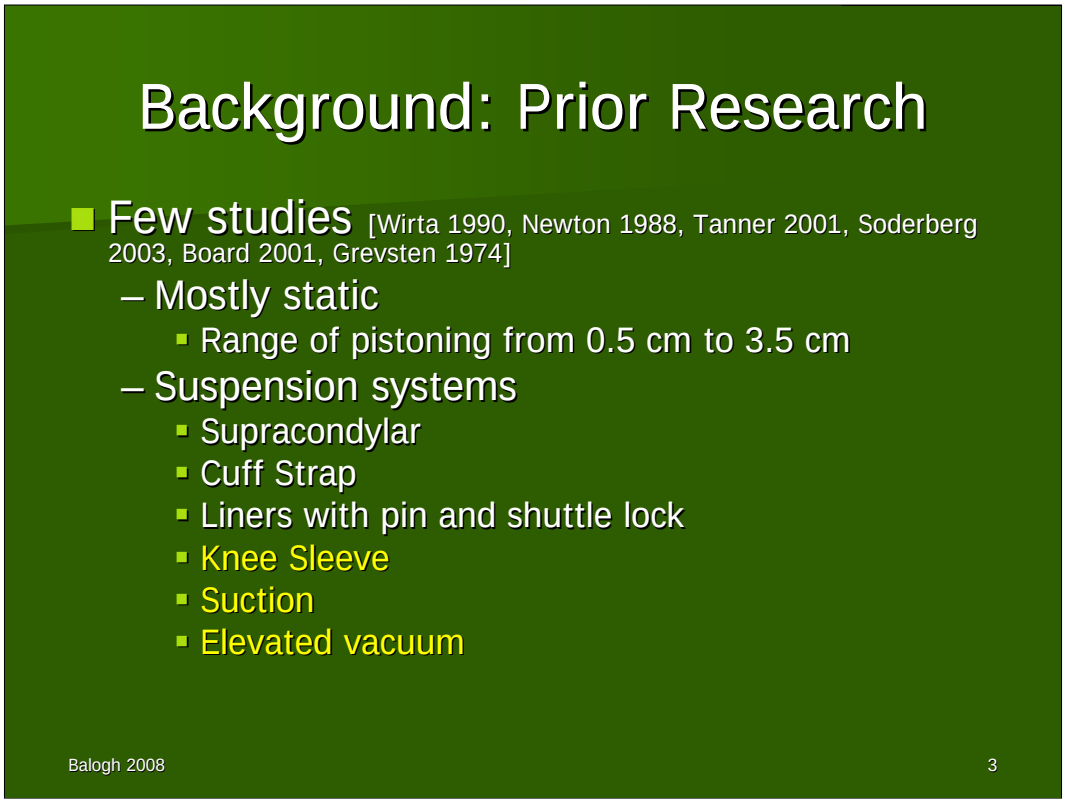
There are several methods by which a transtibial prosthesis may be suspended, or held onto the residual limb of a person with an amputation. The common goal of all suspension methods is to minimize the amount of motion that occurs between the residual limb and the prosthesis, otherwise known as pistoning. Excessive motion at this interface can lead to troubling issues for the prosthesis user including skin breakdown, loss of control, general discomfort, and compliance issues. If the prosthesis is causing discomfort and skin breakdown, this in turn limits the mobility of amputee and can have a negative impact on the quality of life.



There has been prior research conducted specifically examining the motion of the transtibial residual limb within a prosthesis. Most of these studies analyzed the motion which occurred statically in positions of simulated gait. Pistoning was determined by measuring the distance from the distal end of the tibia to a reference point on the prosthesis, typically the distal end of the socket. Reported values of pistoning in the literature ranged from 0.5 cm to 3.5 cm. Nearly all available suspension methods have been tested previously, but recent developments in elevated vacuum applications have only been investigated on a limited basis.

Purpose

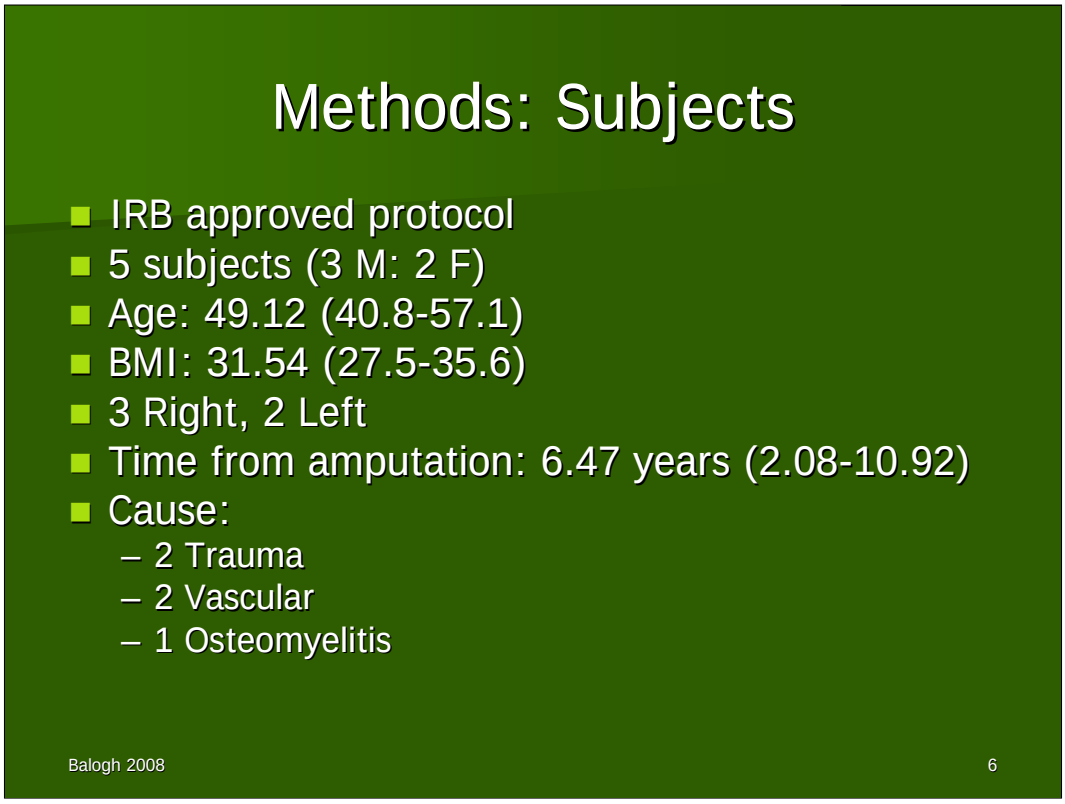
- Describe the effects of three suspension systems on the residual limb motion (pistoning)
  - Static simulation
  - Dynamic motion capture

The purpose of this study is to determine the effects of suspension on residual limb pistoning. For this study, three suspension methods were compared using static simulation and dynamic motion capture. The comparison of static simulation was accomplished using radiographic images of the residual limb and prosthesis under loading patterns which mimic forces on the limb during walking. The second method of dynamic evaluation was conducted in a gait lab using a Vicon motion capture system. For the purpose of this presentation, the focus will be on the static method of evaluation.

Hypothesis

- Elevated vacuum suspension will significantly reduce the amount of pistoning when compared to suction and knee sleeve suspension methods

The hypothesis is that an elevated vacuum suspension will significantly reduce the amount of pistoning within the prosthesis when compared to both suction and knee sleeve suspensions.



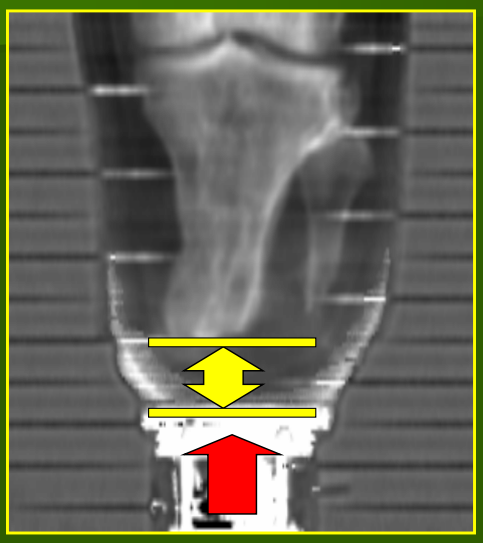
All five subjects who participated in this study had unilateral transtibial amputations. The average age was 49 years, and the BMI was 31.54 on average. Three subjects had amputations on the right leg, while the other two subjects had the left leg amputated. The average time since amputation occurred was 6 and a half years. Two amputations were due to trauma, two were caused by vascular issues, and the final one was caused by osteomyelitis.

Methods: Protocol

- Fabricate and fit prosthesis
- Dual energy x-ray absorptiometry (DEXA) scans of limb for 3 conditions for each suspension
  - No loading
  - Loaded to half body weight
  - 44.5 N distraction force [Board 2001]
- Total of 9 images per subject

For the purpose of the study a new prosthesis was fabricated for each subject using a model of the subject's residual limb. The prosthesis was fabricated using the first diagnostic socket, which allowed the subjects to walk comfortably enough to complete this study. The prosthesis was fit and aligned by a certified prosthetist. DEXA scans of the residual limb within the prosthesis were taken under three different conditions for each suspension method. First a image with no loading on the prosthesis was taken. The second and third images were taken in a random order. The prosthesis was then loaded to half body weight by the subject and a second image was taken. This image was intended to mimic standing with equal weight bearing on each leg. A third image was taken with a 44.5 N distraction force applied to the prosthesis. This force was determined by Board and colleagues to be the average distraction force of the prosthesis while walking. A total of nine images were collected per subject.

Methods: Pistoning



- Limb imaged at load of half body weight (HBW) for each suspension
- Distance from tibia to prosthesis measured five times
- Average value calculated

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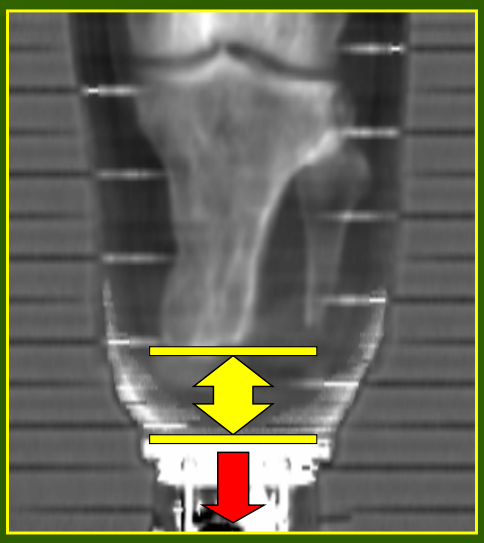
Here is an example image of one DEXA scan. You can see the underlying anatomy as well as the prosthetic components. In this image the prosthetic suspension method was elevated vacuum and the limb was loaded to half of the subject's body weight. The distal end of the tibia and the bottom of the prosthetic socket are marked, and a measurement was taken. This measurement was repeated five times on each image, each time with the previous measurement hidden in attempt to eliminate bias. An average value of distance between the tibia and prosthesis was calculated for the half body weight condition.

Methods: Pistoning

- Limb imaged at 44.5 N distraction force for each suspension
- Distance from tibia to prosthesis measured five times
- Average value calculated



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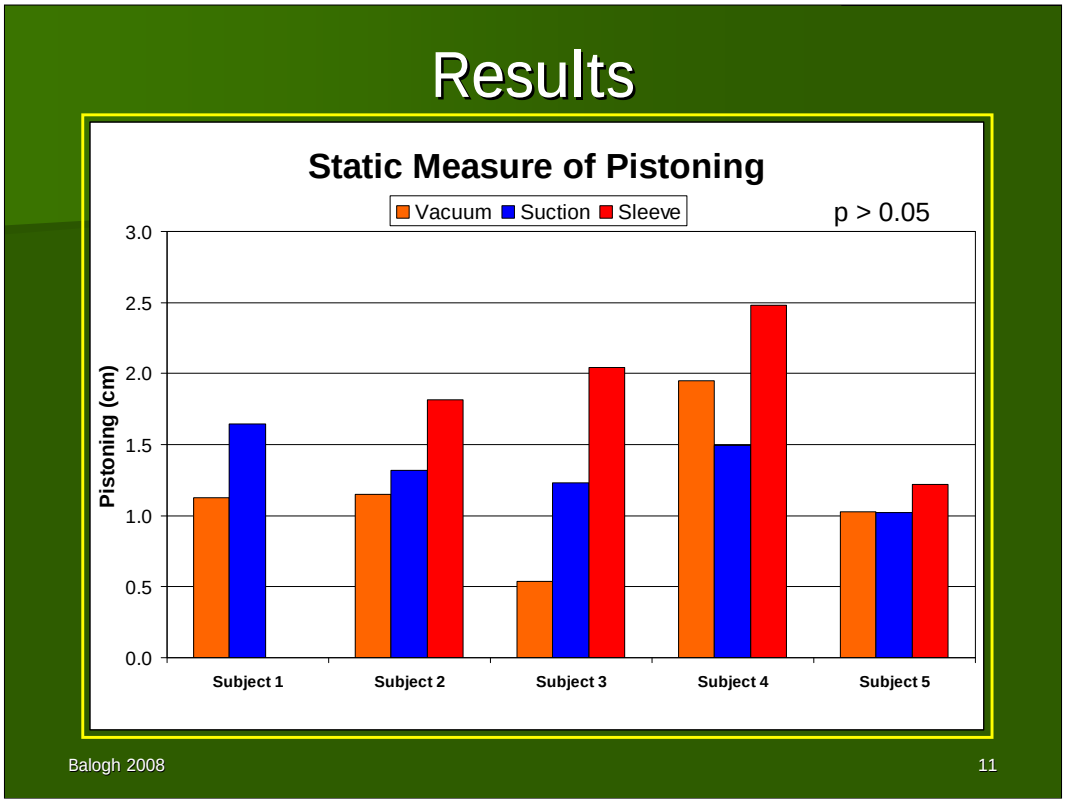
Here is an image of the same subject and suspension, only the prosthesis is distracted with a 44.5 N force. Similar to the half body weight condition, the distance from the distal tibia to the prosthesis is measured five times and an average value is calculated.

Methods: Pistoning

Pistoning $_{vacuum}$ =

Avg (44.5 N $_{vacuum}$) - Avg (HBW $_{vacuum}$)

Here is an example equation which demonstrates how the pistoning was calculated for each suspension. The average value of the five measurements from the half body weight condition is subtracted from the average value of the five measurements in the distraction condition. This result is then the calculated value of pistoning for each suspension. This process was similar for all subjects and suspensions.



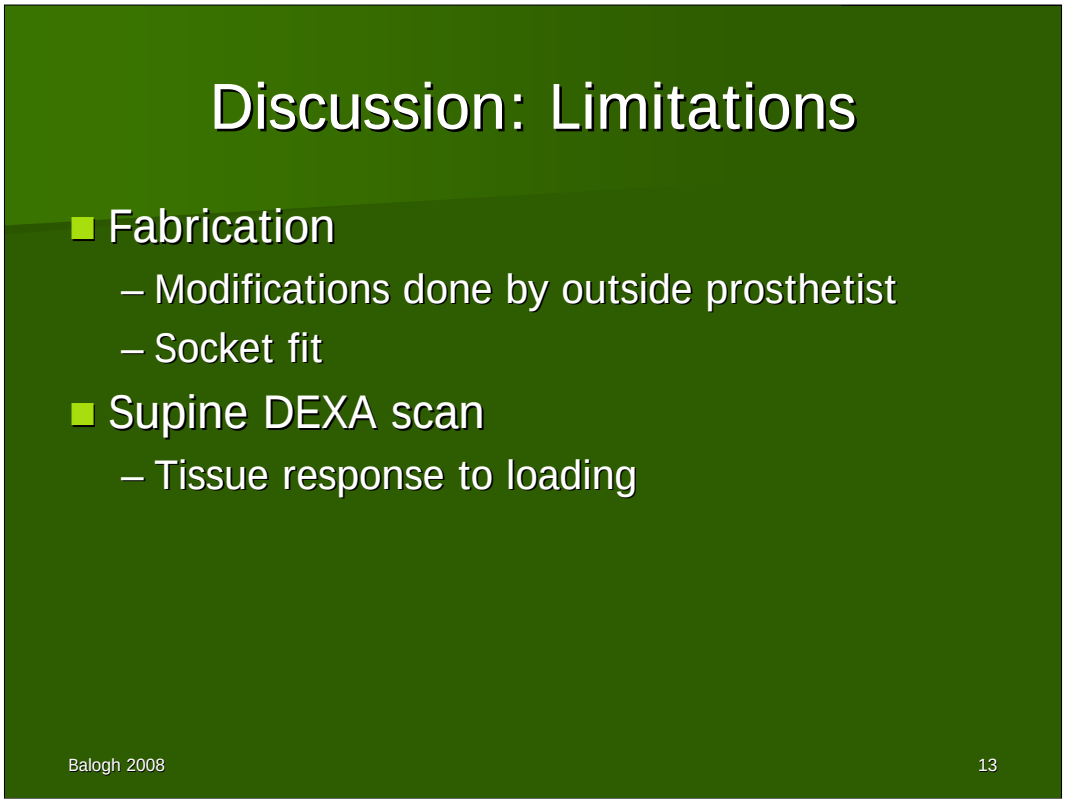
The bar graph shown here illustrates the results of the pistoning calculations. Each group of bars represents one subject. The y-axis is the measure of pistoning in units of cm. The orange bars represent the elevated vacuum suspension. Blue indicates suction, while red refers to the sleeve suspension. First you may notice that subject 1 had an incomplete data set, which didn't allow for a full comparison across all subjects. A repeated measures within subject ANOVA determined a p value of 0.060, and thus these results are not statistically significant. The general trend which is shown by the data indicates that for 3 of 5 subjects, the elevated vacuum had the least amount of pistoning. Subject 5 had nearly equal amounts in both the elevated vacuum and the suction suspension systems. Subject 4 is the main outlier, and a plausible explanation may be that subject 4 had the worst fit of all subjects. He was a 10 ply fit while all other subjects were 5 ply or less.

Discussion: Pistoning

- Average amount of pistoning
  - Elevated vacuum: 0.99 cm (± 0.68 cm)
  - Suction: 1.34 cm (± 0.24 cm)
  - Sleeve: 1.92 cm (± 0.48 cm)
- Pistoning falls within the ranges found in literature (0.5 cm – 3.5 cm)

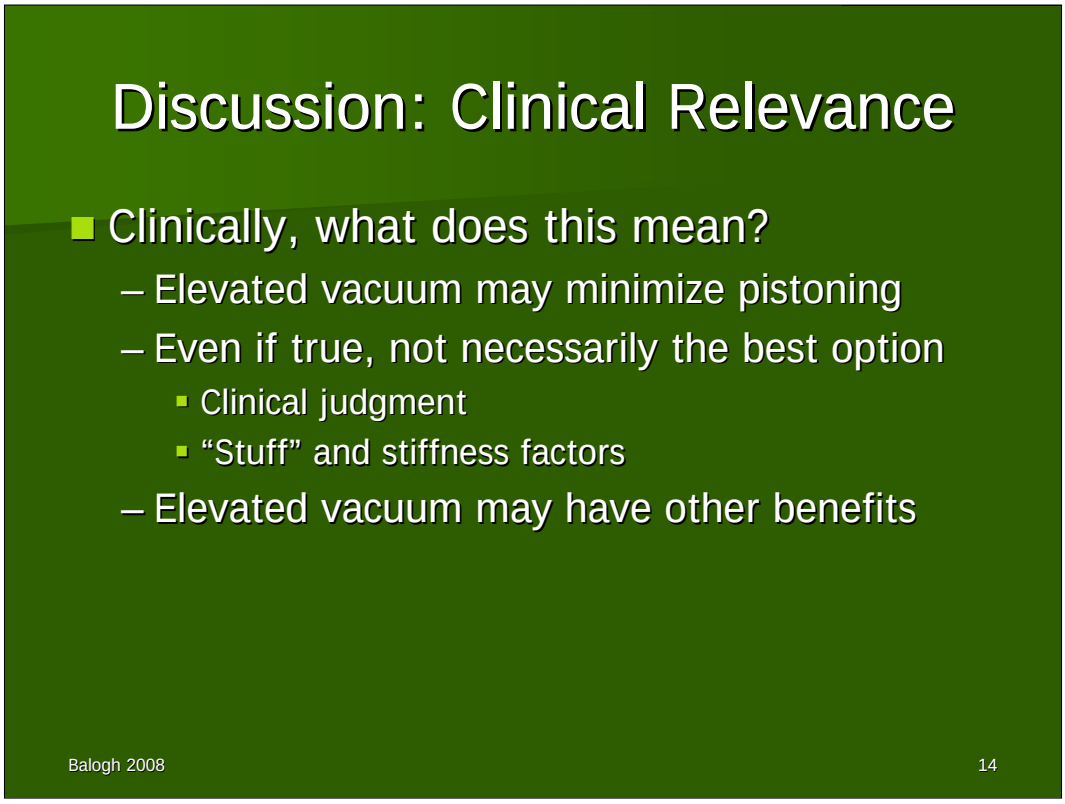
The average amount of pistoning across all five subjects is listed here. Elevated vacuum allowed about 1 cm of pistoning while the suction and sleeve allowed 1.34 and 1.92 cm respectively. Again, the results were inconclusive because there was no statistical significance. The trend suggests however that elevated vacuum performs better than both suction and knee sleeve suspension. An explanation for the variation with each suspension system could be the fit of the prosthesis. Each subject had a different fit and all subjects would be fit with another diagnostic socket in clinical practice to best utilize the elevated vacuum suspension.

It is also important to note that the values of pistoning determined in this study fall within the range of the data previously reported.



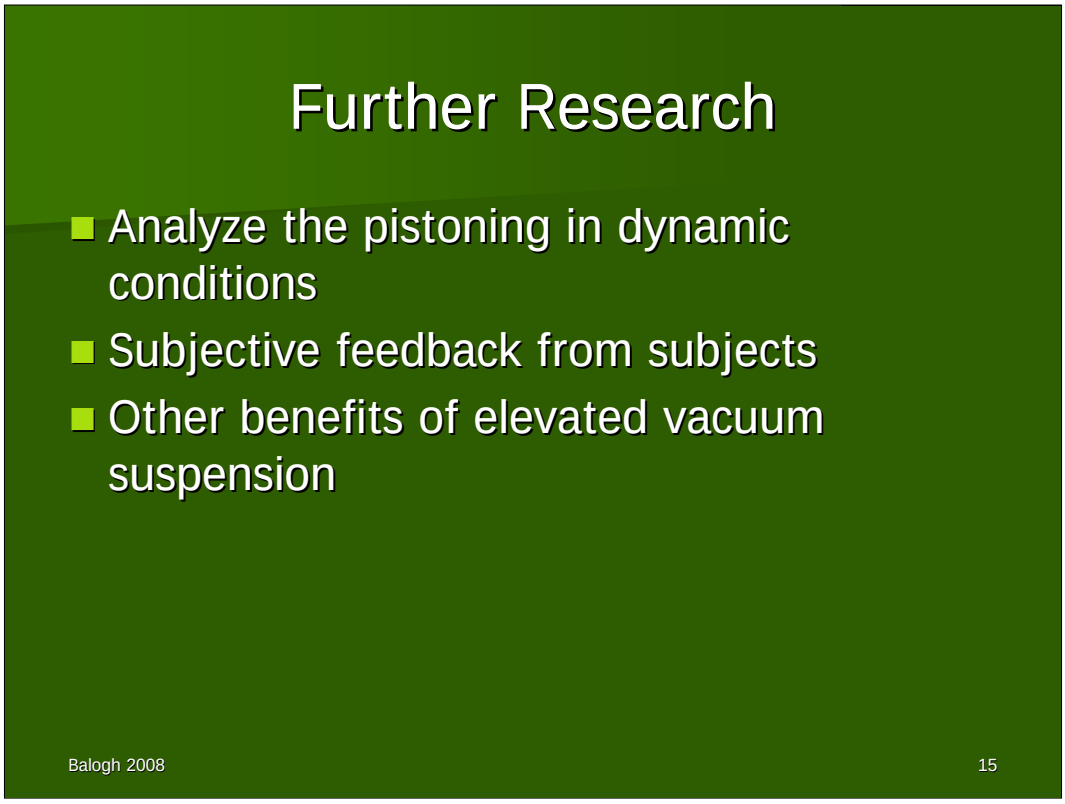
This study had several limitations. The fabrication of a prosthesis is not a simple task and for this study only one attempt was planned. The modifications to the model were done by an outside prosthetist whom had never seen the subjects, so his modifications were likely less than ideal. Because only one socket was used, the socket fit may have been a contributor to the variance of the data. Ideally for a elevated vacuum suspension, there will be no prosthetic socks between the liner and the prosthesis. For this study, most of the subjects had at least a 3 ply fit, while subject 4 had a 10 ply fit.

The data may also have been affected by supine position of the limb and prosthesis during imaging. An image taken with the subject standing and gravitational forces acting in distraction on the prosthesis may more realistically mimicked a walking gait cycle. Another thought is that a standard radiograph may have been a cleaner image of the several interfaces within a prosthesis. This may have allowed evaluation of the distance between the liner and the prosthesis as well as the tibia and the prosthesis to allow for a determinant of where the pistoning occurs.



The elevated vacuum suspension method may minimize pistoning when compared to the other methods in this study. The difference exhibited was less than half a centimeter, which may not have much clinical significance. However, elevated vacuum is not the best suspension option for every patient. It is **important to remember** that clinical judgment of the prosthetist ensures the best outcome for the patient. The elevated vacuum systems themselves have limiting factors. The system involves both a liner and a knee sleeve which can contribute to the amputee feeling knee stiffness and loss of range in knee flexion. A patient who is accustomed to another system may find that there is too much “stuff” when dealing with the liners, sleeves, controls, ect in using an elevated vacuum system.

Elevated vacuum may provide benefits other than minimizing pistoning. Anecdotal reports from elevated vacuum users indicate that the suspension method may improve proprioception and the prosthesis just “feels like it is part of the patient’s leg”. Prosthetist's have reported that wound healing is improved in those patients with delicate or chronically damaged skin who use an elevated vacuum system.



Further research in this study should include analysis of the pistoning data collected in the gait lab. This study was designed to be continued for a second year to improve both in subject number and the methods of analysis. Research should also be directed towards the other anecdotal benefits of elevated vacuum suspension.

Thank You!

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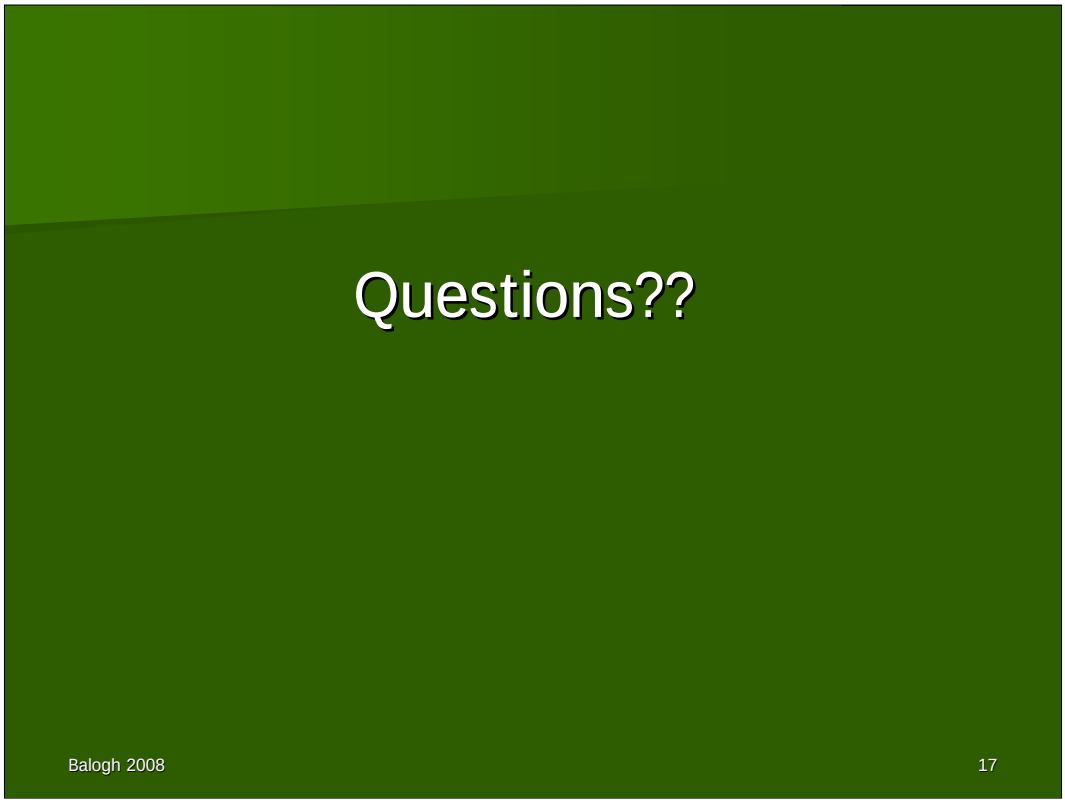
- Jim Colvin
- Rob Kistenberg
- Arick Auyang
- Dr. Young-Hui Chang
- Natalia Estrada

Finally, I would like to thank all those involved in this project.



Any questions??

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Transtibial Suspension Methods

[Michael 2004]

- Atmospheric Pressure
  - Roll-on locking liners, vacuum assisted suction, knee sleeves, hypobaric seal with suction
- Anatomic
  - Supracondylar wedge, supracondylar with suprapatellar extension
- Straps
  - Cuff strap, waist belts
- Hinges
  - Thigh corset

Atmospheric Pressure Suspension [1-4]

- Indications
  - Whenever clinically possible
- Advantages
  - Minimize pistoning
  - Proprioception
  - Best ROM
- Limitations
  - Consistent donning necessary
  - Best used with mature limb

Ohio Willow Wood Alpha Max Liners [11]

Inclusion/Exclusion

- Inclusion
  - Unilateral
  - 18+ years old
  - Liner user
  - Amputation for > 1 year
  - Able to walk at variable speed
  - Current socket is less than 5 ply sock fit
- Exclusion
  - Dementia or inability to give consent
  - Knee flexion contracture > 15°
  - Pregnant or think they might be pregnant

Dynamic Study

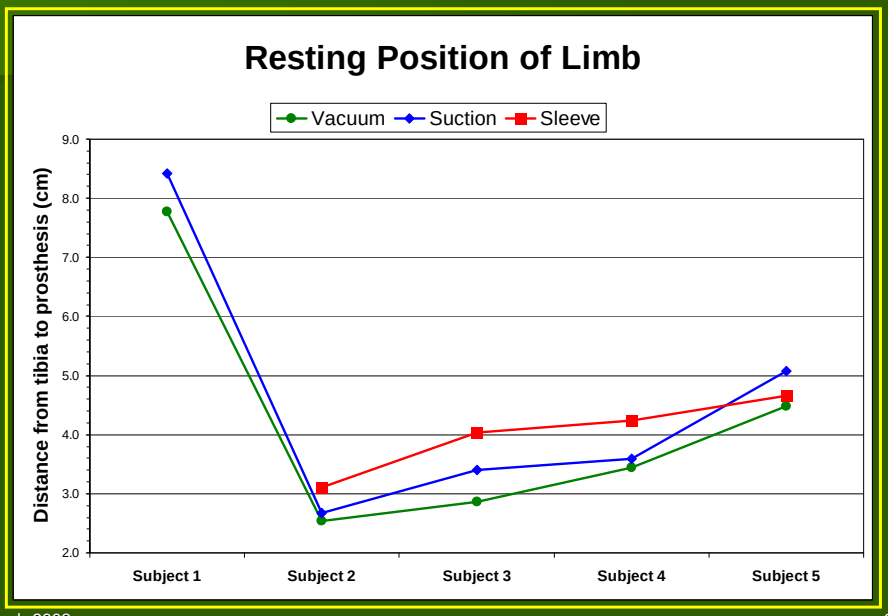
[Wirta et al 1990]

- Studied 7 different PTB suspension systems on 20 adult, unilateral TT amputees
- Walked at three speeds
  - 0.76 m/s, 0.98 m/s, 1.23 m/s
- Measured pistoning of limb to be 1.91 cm (0.6-3.1 cm)

Gait Lab

- Instrumented gait lab
- Reflective markers placed on lower body
- Walk under four conditions:
  - Current prosthesis
  - Elevated vacuum suspension
  - Suction suspension
  - Sleeve suspension
- Walk at two speeds in each suspension
  - 1.2 m/s
  - 1.4 m/s

Results



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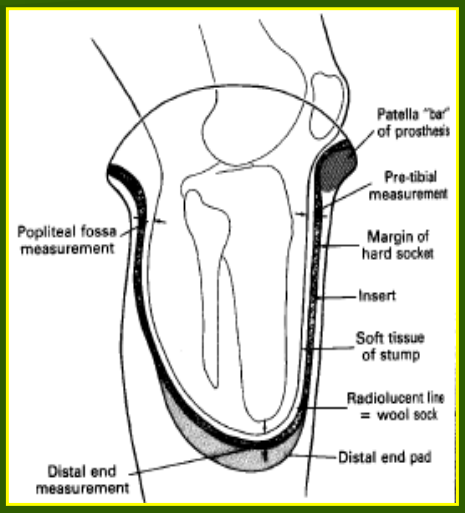
Also of note is the result of the no load condition. Again, the subjects are grouped along the x-axis. The y-axis is the distance between the tibia and the prosthesis. The color scheme is similar to the previous graph. The image was captured while the subject sit with the limb and prosthesis laying on the table, with no load applied. For all cases the limb was seated further into the socket in the elevated vacuum condition. This data may suggest that the limb under an unstressed condition is already seated further into the socket, thus minimizing the amount of excursion possible during walking.


Patella "bar" of prosthesis
Pre-tibial measurement
Popliteal fossa measurement
Margin of hard socket
Insert
Soft tissue of stump
Radiolucent line = wool sock
Distal end pad
Distal end measurement