Joint Forces within The Ankle During Level Walking.

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Abstract. Total Ankle Replacement (TAR) has been shown to lack the long term reliability of other implants. Many efforts have been made to improve the design. These have included simply exploiting more anatomically shaped prosthesis; however understanding the fundamental mechanics of the joint based upon robust experimental data is perhaps a more promising approach.

Current data describing ankle joint forces have been calculated based on questionable assumptions from a very limited number of investigations dating back to the 1970s. The purpose of this study is to develop a more sophisticated computer simulation of the ankle joint to provide data more reliable than that currently exist.

The foot has been modelled as a rigid segment while the ankle is modelled as two independent revolute joints: one for the ankle and one for the subtalar joint. Plantar flexion originates from the Achilles tendon forces which are determined completely by the ground reaction force and they are largely statically determinate in AnyBody Technology simulation software.

Gait data were collected with a custom model marker placement set with
extra markers on the medial ankle, 1st and 5th metatarsals. Data were then processed in the AnyBody Technology simulation software to investigate the reaction forces within the ankle joint. Forces acting on the Achilles tendon as well as forces from the tibialis anterior, tibialis posterior and peroneus muscles were also determined.

There was a good agreement between the forces predicted by the model and force data reported from studies using other methodologies. Forces predicted by our simulation could now be used in FEM studies to investigate pressure and stress on the ankle prosthesis and provide better understanding of the reasons why these prostheses are so prone to failure.
Joint Forces Within the Ankle During Level Walking

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Purpose of the Project

“Virtual Assessment of the Latest Generation of the Total Ankle Replacement Using Motion Analysis“

• Investigate the reasons for ankle joint replacement failure and possibly optimise ankle prosthesis design.
Brief Summary of the Talk

- Total Ankle replacement (TAR) has a lack of reliability over the long term as a result of few number of investigations compared to THR and TKR
- Few Ankle Joint Forces data is available through literature and go back to the 1970s
- New model design for Collecting MoCap Data and investigate the resultant musculoskeletal and ankle joint forces in AnyBody®
Introduction: Why TAR?

- Treatment of ankle joint diseases, Osteoarthritis
- TAR maintains normal motion of the joint and distribution of loads on the surrounding structures
Intro: Drawbacks of TARs

• Small size of the joint
• High resultant Moment
• High Stress
• Disregard for anatomic component shape and physiological ankle biomechanics
• Poor reproduction of the normal mechanics of the ankle
Intro: Available Data on Ankle Joint Forces

“Forces and Motion Analysis of the Normal, Diseased and Prosthetic Ankle Joint”

Richard N Stauffer 1977

2D!
Intro: Current Ankle Joint Forces
Intro: Current Ankle Joint Forces
Intro: Current Ankle Joint Forces
Intro: Aim of this Study

- Lack of knowledge on ankle joint internal forces
- Knowledge important because TAR not so reliable

Improve Data and hence Design!
Methodology

Gait Experimental: Vicon   Model Simulation: AnyBody
Methodology: Gait Experimental

- Methodology being adopted
  - Gait Data Collection using Vicon®
- Custom Model definition with 22 markers
  - LASI, RASI, LPSI, RPSI
  - LTHI, RTHI, LKNEE, RKNEE
  - LTIB, RTIB
  - LANK, RANK, LMANK, RMANK
  - LHEE, RHEE, LTOE, RTOE
  - L1MEH, R1MEH, L5MEH, R5MEH
Methodology: Gait Experimental

• Methodology being adopted
  – Gait Data Collection using Vicon System®
    ➢ Vicon Cameras MxF40
      ✓ 8 Cameras used
      ✓ 4 Megapixel
      ✓ Data taken at 50 Hz
Methodology: Gait Experimental

• Methodology being adapted
  – Gait Data Collection using Vicon System®
    ➢ KISTLER FORCE PLATES
    ➢ 8 Channels: 4 on Z-D, 2 on X-D and 2 on Y-D
    ➢ Analogue Data at 1000 Hz
Methodology: AnyBody™ Model

• Methodology being adapted
  
  - Purpose of AnyBody™ Gait Model
    
    ❖ Construct a musculoskeletal body computer stimulation of the ankle joint. The model will then be employed to predict the forces transmitted through the joint and surrounding tissues.
Methodology: AnyBody™ Model

Description of Gait Model

- Anybody Musculoskeletal Model with no Muscles on the Trunk
- Anybody TLEM Model of the Leg:
  - More Sophisticated Muscles
  - More Muscles around the ankle Joint
- Ankle with 2 separate REVOLUTE joints:
  - Subtalar Joint
  - Ankle Joint
Methodology: AnyBody™ Model

Muscle Recruitment Solver:
- MinMax Solver
- Quadratic Solver

Forces Collected:
- GRF Ankle Joint
- Forces Acting on Achilles Tendon
- Tibialis Anterior/Posterior
- Peroneus
Results: GRF Ankle Joint

• Right Ankle Forces Component
  ➢ Comparison between Quadratic and Simple Solution
Results: GRF Ankle Joint

- Right Ankle Total Forces Vector
  - Comparison between Quadratic and Simple Solution
Results: GRF Ankle Joint

![Graph showing GRF Ankle Joint results with Force (N) on the y-axis and Time (S) on the x-axis. The graph compares Quadratic and MinMax models.]
Results: Forces Acting on the Achilles
Results: Tibialis Anterior Forces
Results: Tibialis Posterior Forces
Results: Peroenus Forces
Results: Muscle Activity
Discussion

Achilles Tendon Forces

Plantar Flexion of the Ankle

GRF Data

Plantar Flexion of the Ankle
Discussion

Robust Data

Reliable Forces

Plantar Flexion of the Ankle

GRF Data

Achilles Tendon Forces
Discussion

• Forces Computed **DO NOT** depend on the recruitment solver in AnyBody®
• More interesting ! …
• Importance of the Muscle
• Not a problem in AnyBody : more muscles than degrees of freedom.
Summary

• Present TARs are among the joints replacement that don’t have reliable results
• Further Joint Data needed for investigation
• Data Collected in Vicon® and Processed in AnyBody®
• Results lie in an acceptable range
  • Therefore …
Current/Future Work

- Use an FE Model to investigate forces and stresses on the bones and stresses on the Prosthesis
- Collect data from a defined Normal and Diseased population
- Process Data and Compare!
Thank You ...