Award Number: DAMD17-00-1-0515

TITLE: Biomechanical Factors In Tibial Stress Fracture

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Fort Detrick, Maryland 21702-5012

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INTRODUCTION

Stress fractures can be extremely costly to the military in terms of both time and medical expenses. The tibia is a common site for such injuries and has been most often associated with running, an activity common to all military training. Stress fractures are among the top 5 cited to account for 50% of all injuries sustained by runners (Kowal, 1980; Reinker et al., 1979; Jones et al., 1983; James et al., 1978; Clement et al., 1981; Pagliano et al., 1980). They are among the most serious of running-related overuse injuries as they take long to heal and if untreated, can progress to a macrofracture. Females, a growing military contingency, appear to be particularly susceptible, as it has been noted that they are twice as likely to experience a stress fracture than their male counterparts (Brudvig et al, 1983; Pester & Smith, 1992; Reinker et al, 1979). The tibia is a common site for such injuries and has been most often associated with running. Structural and biomechanical factors have been suggested in the cause of stress fractures. However, these mechanisms are not well understood. Therefore, the purposes of this study are 1) to compare the structure mechanics of runners who have sustained a tibial stress fracture to those who have not, 2) to gain an understanding of which combination of factors (structural and/or biomechanical) are predictive of tibial stress fractures, and 3) to assess whether mechanics are altered following a tibial stress fracture. Once the parameters associated with stress fractures are identified, future work will focus on formation and testing of a simple screening tool to facilitate identification of those at risk.

The study began on September 1, 2001 after funding was received from the Department of Defense and has been under investigation for 12 months. This Annual Report will focus on preliminary results after the first year of the study.

BODY

Summary of Methodology

The overall aim of this research is to gain insight into the etiology of tibial stress fractures. Three dimensional motion analysis data along with structural data will be collected from 400 subjects (200 at each site) over a 3-year period. 30 of the subjects will have sustained a tibial stress fracture prior to the study and the other 370 will have not. Subjects will be recruited primarily from track teams, running clubs, and physicians local to the University of Delaware and University of Massachusetts. All subjects will be females between the ages of 18 and 45 and will be free of lower extremity injury at the time of testing. Lower extremity kinematics and kinetics will be collected during running. In addition, radiographs of both tibia will be taken as well as clinical measures of lower extremity alignment. Subjects will then report their exposure data (mileage, intensity, terrain) as well as any injuries they have sustained each month via a custom developed webpage which will serve as a database for this information. If a subject reports a tibial stress fracture/reaction, the site coordinator will be notified automatically...
and the subject will be asked to return for a second running analysis once the fracture has healed and they are cleared to run by their physician. The structural and biomechanical factors leading up to a tibial stress fracture will be assessed. In addition, comparisons will be made of mechanics before and after the stress fracture to determine whether subjects revert back to their pre-injury mechanics.

**Statement of Work**

Between the two data collection sites, the following objectives were outlined in the approved Statement of Work for the first year. These objectives included:

1. Recruitment of 50 subjects per site.
2. Collection and reduction of kinematic, kinetic, and structural data (radiographs, and lower quarter evaluations).
3. Design, development and refinement of web page database to store and retrieve data from both sites.
4. Begin follow-up procedures on subjects.

**Adherence to Work Objectives**

1) Recruitment of Subjects

To date, data on 20 subjects have been collected at the University of Delaware and 23 subjects have been collected at the University of Massachusetts. Several local coaches and track teams have been recruited to recruit subjects and establish relationships for injury tracking. Additional contacts will continue to be made to recruit the necessary subjects.

Although these numbers do not reflect what was proposed, several circumstances exist to explain the discrepancy. We were notified of our award in September of 1999 and were hoping to begin work on the web page database in the spring of 2000. However, the funds did not become available until July 2000. Therefore, work on the database did not begin until September, 2000. The first subject was collected in December, 2000 so we missed collecting the fall cross country teams. The bulk of the remainder subjects being collected in Jan-Feb, 2001. We believe that we will have the remaining 30 subjects at each site collected by Dec. 2001, putting us 3 months behind on our schedule. All universities having women’s track and cross country teams within a 60 mile radius of each site (16 for the University of Delaware and 8 for the University of Massachusetts) have been identified (Appendix A) and these will continue to be the primary recruitment locations.

2) Collection of Data

All kinematic, kinetic, and structural data have been collected for the 43 subjects. Preliminary results will be presented in the Reportable Outcomes section. All radiographs have been digitized and a custom program has been developed to determine the area moment of inertia parameters needed for the analysis.

Local physicians have been contacted and a working relationship has been established at Papastavros’ Associated Medical Imaging in Newark, DE and University
Health Services Radiology Department in Amherst, MA for the purpose of taking x-rays of each subject.

3) Development of Database

A web-based injury tracking and reporting system was to be developed and be ready for use by September 1, 2001. Within this program, subject injury and training history, monthly exposure, and monthly injuries are documented. It is then possible to compile all information into a database for statistical analysis. Furthermore, subjects are automatically sent a monthly e-mail reminder to login to the web site and record their monthly exposure and injury status. If any subject reports a stress injury/fracture of the lower extremity or any injury to the tibia, an e-mail notification is sent to the program coordinator.

The programmer who began the development of the database was unable to implement the automatic function of reminding the subjects to log in each month and notifying the site coordinator of any potential tibial stress fractures that were reported. He worked on this for months and then left the University of Delaware to take a position elsewhere. We therefore had to hire a new programmer who has recently produced a fully functioning web-based program that meets all of our needs and specifications. Examples of the user interface are found in Appendix B.

4) Follow-up procedures

Since the web-based injury tracking and reporting system has not been implemented as of yet, follow-up procedures have been conducted via telephone and e-mail for the 43 subjects. All subjects have been tracking their monthly running exposure and injuries since their initial visit and these data will be input into the database.

KEY RESEARCH ACCOMPLISHMENTS

Data collection and analysis of this 5-year project is still in the early stages. As defined by the Technical Reporting Requirements guidelines, there are no Key Research Accomplishments to report, nor were any expected at this stage of the project.
REPORTABLE OUTCOMES

Preliminary Data Analysis

A summary of all of the subjects as well as a small group of subjects who have sustained a tibial stress fracture prior to entering the study will be presented.

Of the 43 subjects who have participated in this investigation, 5 have had previous tibial stress fractures (PrTSF). It was hypothesized that these subjects, in comparison to the non-injured limb and as compared to runners who have never sustained a tibial stress fracture, would exhibit:

1. greater vertical loading rates
2. greater peak vertical ground reaction forces (GRF)
3. greater peak positive tibial acceleration
4. greater stiffness
5. greater tibial varum
6. decreased tibial area moment of inertia
7. decreased ankle dorsiflexion excursion
8. decreased knee flexion excursion

With the relatively small number of participants who have suffered previous tibial stress fractures, statistical analyses of the preliminary results have not been performed. Results for each of these variables will be discussed individually with respect to trends observed in the data. A summary of results for the respective hypotheses is presented in Table 1.

TABLE 1. Mean Scores for Preliminary Results of Selected Hypotheses

<table>
<thead>
<tr>
<th>Variable</th>
<th>Uninjured Group</th>
<th>PrTSF Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Both Limbs</td>
<td>Injured Limb</td>
</tr>
<tr>
<td>Vertical Loading Rates</td>
<td>108.81</td>
<td>110.85</td>
</tr>
<tr>
<td>Peak GRF</td>
<td>2.52</td>
<td>2.54</td>
</tr>
<tr>
<td>Peak Positive Tibial Acceleration</td>
<td>7.52</td>
<td>8.18</td>
</tr>
<tr>
<td>Stiffness</td>
<td>8.70</td>
<td>9.68</td>
</tr>
<tr>
<td>Tibia Varum</td>
<td>5.25</td>
<td>5.29</td>
</tr>
<tr>
<td>Moment of Inertia (M/L level 1)</td>
<td>21748.79</td>
<td>15894.06</td>
</tr>
<tr>
<td>Moment of Inertia (M/L level 2)</td>
<td>20322.50</td>
<td>18453.61</td>
</tr>
<tr>
<td>Moment of Inertia (A/P level 1)</td>
<td>12874.78</td>
<td>11319.31</td>
</tr>
<tr>
<td>Moment of Inertia (A/P level 2)</td>
<td>13297.36</td>
<td>12550.97</td>
</tr>
</tbody>
</table>
Vertical Loading Rates

Analysis of vertical GRF data (Fig 1) supports the hypothesis that the injured limb of the PrTSF group exhibited a greater rate of loading as compared to the non-injured limb. No differences can be observed as compared to the Uninjured group.

![Figure 1. Vertical loading rate for the Uninjured and Previous Tibial Stress Fracture Groups.](image)

Peak vertical ground reaction forces

In partial support of the hypothesis, the injured limb of the PrTSF exhibited a reduced peak vertical ground reaction forces (GRF) as compared to the non-injured limb but greater peak vertical GRF as compared to the Uninjured group (Fig 2).

![Figure 2. Peak vertical ground reaction force for the Uninjured and Previous Tibial Stress Fracture Groups.](image)
Peak positive tibial acceleration

Analysis of peak positive tibial acceleration (Fig 3) supports the hypothesis that the injured limb of the PrTSF group exhibited greater acceleration at heel contact as compared to the non-injured limb and as compared to the Uninjured group.

![Peak Positive Tibial Acceleration](image)

Figure 3. Peak positive tibial acceleration force for the Uninjured and Previous Tibial Stress Fracture Groups.

Stiffness

In partial support of the hypothesis, the injured limb of the PrTSF group exhibited less stiffness as compared to the non-injured limb but greater stiffness as compared to the Uninjured group (Fig 4).

![Stiffness](image)

Figure 4. Stiffness for the Uninjured and Previous Tibial Stress Fracture Groups.
Tibial varum

Analysis of tibial alignment (Fig 5) supports the hypothesis that the injured limb of the PrTSF group exhibited greater tibial varum as compared to the non-injured limb. However, no differences were observed as compared to the Uninjured group.

Figure 5. Tibial Varum for the Uninjured and Previous Tibial Stress Fracture Groups.

Decreased tibial area moment of inertia

The moment of inertia was calculated at two levels and for both the medial/lateral and anterior/posterior aspects of the tibia as described by Milgrom et al. (1989). It was hypothesized that the injured limb of the PrTSF group would exhibit a reduced moment of inertia as compared to the non-injured limb and Uninjured group. This hypothesis is supported in the preliminary analysis of the data for both views and for both tibial levels (Fig 6, 7, 8, & 9).

Figure 6. Level 1 Medial/Lateral Moment of Inertia for the Uninjured and Previous Tibial Stress Fracture Groups.
Figure 7. Level 2 Medial/Lateral Moment of Inertia for the Uninjured and Previous Tibial Stress Fracture Groups.

Figure 8. Level 1 Anterior/Posterior Moment of Inertia for the Uninjured and Previous Tibial Stress Fracture Groups.
Figure 9. Level 2 Anterior/Posterior Moment of Inertia for the Uninjured and Previous Tibial Stress Fracture Groups.
Decreased ankle dorsiflexion excursion

It was hypothesized that the injured limb of the PrTSF group would exhibit decreased ankle dorsiflexion excursion during the first portion of stance (0-20%). Figure 10 demonstrates that this hypothesis was not supported by the preliminary analysis as the injured limb of the PrTSF subjects exhibited greater ankle plantarflexion excursion as compared to the non-injured limb and the Uninjured subjects (Fig 10).

Fig 10. Ankle Angle During the Stance Phase of Gait for the Uninjured and Previous Tibial Stress Fracture Groups. Greater values represent ankle dorsiflexion.
Decreased knee flexion excursion

It was hypothesized that the injured limb of the PrTSF group would exhibit decreased knee flexion excursion during the first portion of stance (0-10%). This hypothesis was supported by the preliminary analysis as the injured limb of the PrTSF subjects exhibited greater knee flexion excursion as compared to the non-injured limb and the Uninjured subjects (Fig 11).

Fig 11. Knee Angle During the Stance Phase of Gait for the Uninjured and Previous Tibial Stress Fracture Groups. Positive values represent knee extension.
Publications

From data collected on the 43 subjects, one abstract has been submitted and was presented at the American Physical Therapists’ Association Combined Sections Meeting in Boston, Massachusetts. The reference is provided below and the complete abstract is included in the Appendix C.


Additional 3-D Lower Extremity Variables

The overall aim of this research is to gain insight into the etiology of tibial stress fractures using three dimensional motion analysis and structural data. 3-D data of all other lower extremity variables for the 43 subjects has been collected and are presented in Appendix C. The Motion Analysis equipment at each University are working properly as are the computer programs used for data analysis. The data presented in Appendix E are similar to previously reported data.
CONCLUSIONS

The overall aim of this research is to gain insight into the etiology of tibial stress fractures using 3-D motion analysis and structural data. Data from 400 subjects will be collected at the University of Delaware and University of Massachusetts (200 at each site) over a 3-year period. 30 of the subjects will have sustained a tibial stress fracture prior to the study and the other 370 will have not. The structural and biomechanical factors leading up to a tibial stress fracture will be assessed. In addition, comparisons will be made of mechanics before and after the stress fracture to determine whether subjects revert back to their pre-injury mechanics.

This Annual Report focused on the one-year status of this investigation. Four specific work objectives were approved and discussed with respect to adherence and methods to meet all objectives in a timely manner. We are confident that by December of 2001, we will be very close to achieving all work objectives.

To date, data on 43 subjects were collected and a preliminary analysis was performed. Overall, the primary hypotheses are supported by the data after subjective analysis. These are encouraging results. We are confident that additional data will provide valuable information regarding mechanics and etiology of tibial stress fractures.
REFERENCES


APPENDICES

Appendix A: Universities having women’s track and cross country teams within a 60 mile radius of each site
Here is the list of (8) schools that match your search criteria. Click on a school name for information on everything from financial aid to admissions to campus life, or return to the search page to modify your search criteria.

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<thead>
<tr>
<th>School</th>
<th>State</th>
<th>Sports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trinity College</td>
<td>CT</td>
<td>cross-country, track (indoor), track (outdoor), track and field</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(indoor), track and field (outdoor)</td>
</tr>
<tr>
<td>Amherst College</td>
<td>MA</td>
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</tr>
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<td></td>
<td></td>
<td>(indoor), track and field (outdoor)</td>
</tr>
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<td>Fitchburg State College</td>
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<tr>
<td></td>
<td></td>
<td>(indoor), track and field (outdoor)</td>
</tr>
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<td>MA</td>
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<td></td>
<td></td>
<td>(indoor), track and field (outdoor)</td>
</tr>
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<tr>
<td></td>
<td></td>
<td>(indoor), track and field (outdoor)</td>
</tr>
<tr>
<td>Westfield State College</td>
<td>MA</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(indoor), track and field (outdoor)</td>
</tr>
<tr>
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<td></td>
<td>(indoor), track and field (outdoor)</td>
</tr>
<tr>
<td>Keene State College</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(indoor), track and field (outdoor)</td>
</tr>
</tbody>
</table>
Here is the list of (16) schools that match your search criteria. Click on a school name for information on everything from financial aid to admissions to campus life, or return to the search page to modify your search criteria.

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</tr>
<tr>
<td>West Chester University of Pennsylvania</td>
<td>PA</td>
<td>cross-country, track (indoor), track (outdoor), track and field (indoor), track and field (outdoor)</td>
</tr>
</tbody>
</table>
Appendix B: Web-based injury tracking and reporting system

User Interface

This section specifies conceptual user interface as wire frame templates. Note that the templates are for illustration only and do not represent the look and feel of the final system.

Subject ID Form

Stress Fracture Study

Please enter your Participant ID number:
The ID number should look like this: UD_JY001.

Continue

21
Subject Demographic Form

<table>
<thead>
<tr>
<th>Your Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name: Jie Yang</td>
</tr>
<tr>
<td>Subject ID#: UD_op900</td>
</tr>
<tr>
<td>Date of Birth: 1/1/1981</td>
</tr>
<tr>
<td>Height: 5'10&quot;</td>
</tr>
<tr>
<td>Weight: 110 lb.</td>
</tr>
<tr>
<td>Physician: nobody</td>
</tr>
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</table>

<table>
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<tr>
<td>City: lkh; lkh</td>
</tr>
<tr>
<td>State: AK</td>
</tr>
<tr>
<td>Zipcode: 11111</td>
</tr>
<tr>
<td>Email Address: arsdas2o.com</td>
</tr>
<tr>
<td>Phone Number:</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Away from School or Permanent Address:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home Address:</td>
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<tr>
<td>City:</td>
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<tr>
<td>State:</td>
</tr>
<tr>
<td>Zipcode:</td>
</tr>
<tr>
<td>Email Address:</td>
</tr>
<tr>
<td>Home Phone:</td>
</tr>
</tbody>
</table>

< Done > Internet >
Subject Questionnaire Form

Runner Information

How many years have you been running? ____________________________ Years

Do you wear orthotics? 

- Yes  
- No

If yes, what were they prescribed for?

Which events do you run?

- Miles/Min.

What is your average training pace?

- Miles/Min.

What is your average racing pace?

Enter
Mileage/Exposure History Information

Please answer the following questions for the past 6 months.

Total Mileage for the Past 6 Months: ____________ Miles
Average Weekly Mileage: ____________ Miles
Sessions per Week: ____________ Sessions
Minutes per Session: ____________ Min.
Surface Percentage:
- Hills: ____________ %
- Track: ____________ %
- Road: ____________ %
- Trail: ____________ %

Enter [ ]

[ ] Done

[ ] Internet
Subject Monthly Injury Form

Monthly Injury Report

Please report all injuries you had in the last month, one form per injury.

1. Please specify the injury, select one entry only.
   - Back Injury: none
   - Hip/Groin Injury: none
   - Thigh Injury: none
   - Knee Injury: none
   - Lower Leg Injury: none
   - Ankle Injury: none
   - Foot Injury: none
   - Lower Leg Injury:
     - If metatarsal injury, specify which ones:
       - 1
       - 2
       - 3
       - 4
       - 5

2. Please indicate the injury side.
   Injury side: [unspecified]

3. Please indicate the date of injury.
   Injury date: [JAN] [O1] [2001]

4. Number of days lost due to injury:

5. This injury required treatment at hospital:

6. This injury required surgery:

7. This injury required rehabilitation:

8. Please check all the diagnostic tests performed:
   - X-Ray
   - MRI
   - Bonescan
   - Compartment Test
   - Other, please specify:

9. Injury required attention by: (Please check all that apply)
   - ATC
   - MD
   - PT

10. Diagnosis was made by: (Please check all that apply)
    - ATC
    - MD
    - PT
    - Self
    - Coach

11. Injury occurred during: Please select:

12. Additional comments regarding training or injuries:

13. Do you need to report another injury for this month?  Yes  No

Continue
Injury Alert

If a subject reports a stress injury/fracture of the lower extremity, or any injury to the tibia, an email notification is sent to responsible program coordinator. Included in the email is a link to the subject lookup page so that the recipient can click on the URL link to access the user information directly.
Appendix C: Abstract

MULTIPLE LOWER EXTREMITY STRESS FRACTURES IN A FEMALE DIVISION I CROSS COUNTRY RUNNER: A CASE STUDY. Pollard C. D., McClay I. S., Hamill J. Biomechanics Laboratory, University of Massachusetts, Amherst, MA.

Background and Purpose. A stress fracture in the high performance collegiate athlete presents a difficult problem. The tibia is the most common site of stress fractures in runners accounting for between 32-56% of total stress fractures reported. The purpose of this case report is to describe a case of multiple lower extremity stress fractures over time. Case Description. The patient is a 20-year-old female Division I collegiate cross-country runner who reported a history of five lower extremity stress fractures over the past three years. The stress fractures were located at bilateral tibias, bilateral first metatarsals, and the right third metatarsal. The right tibial stress fracture was diagnosed during the cross-country season, while the others were diagnosed during the off-season. The patient reported complying with the recommended rest period of 6-10 weeks following each stress fracture diagnosis. The patient has trained and competed in custom orthotics since recovery from the first stress fracture. The patient has been evaluated by a registered dietitian and determined to have adequate nutrition and eating habits. The patient is eumenorrhoeic and had two separate DEXA bone density scans over the past two years that demonstrated normal bone density. Area moments of inertia were measured for the distal third of both tibias and were 30% lower than average values. Bilateral peak tibial accelerations were measured during running (3.70 m/s) and were also within normal range (5-8 g's). However, the right peak tibial acceleration was on the high end of normal values (8.3 g's). Upon a recent physical therapy evaluation, the patient presented with significant bilateral static genu varum and excessive bilateral static calcaneal inversion (right: rearfoot angle 18°, tibial varum 11°; left: rearfoot angle 15°, tibial varum 10°). Over the past three years, the patient has been followed by a sports medicine physician and has participated in numerous physical therapy treatment progressions. Outcome. Although this patient has attempted to do everything indicated to prevent the reoccurrence of a lower extremity stress fracture, she has not been successful. Discussion. It is thought that overuse injuries occur when tissues do not adapt normally to repetitive stress. There can be numerous underlying reasons that these tissues do not adapt normally and result in a stress fracture. Anatomic malalignment has been implicated in the etiology of stress fractures. Matheson et al. (1987) noted that varus malalignment (genu & tibial) was often present in athletes with stress fractures. This patient exhibits significant lower extremity malalignment. Bone structure is thought to contribute significantly to the overall risk of stress fractures. Milgrom et al. (1989) has suggested that stress fractures may occur in regions where high bending loads are found. This patient exhibits lower than average tibial area moments of inertia (resistance to bending). In an attempt to prevent future stress fractures, following her first stress fracture, this patient made multiple adaptations in her training, strengthening, and flexibility programs and implemented the use of orthotics. These adaptations did not result in the avoidance of further stress fractures. Even though this patient has followed all recommendations, she seems to have bilateral anatomic alignment and structural limitations that may not allow her tissues to tolerate the training demands of a Division I cross country runner. References.
Appendix D: Group Data for 3-D Joint (Ankle, Knee, and Hip) Angle, Moment, Power, and Ground Reaction Force Data

Figure 1. Ankle Angle in X (sagittal plane), Y (coronal plane), and Z (transverse plane) axes. Positive values indicate dorsiflexion (top), abduction (middle), and eversion (bottom).
Figure 2. Ankle Moment in X (sagittal plane), Y (coronal plane), and Z (transverse plane) axes. Positive values indicate dorsiflexor moment (top), abduction moment (middle), and eversion moment (bottom).
Figure 3. Ankle Power in X (sagittal plane), Y (coronal plane), and Z (transverse plane) axes. Positive values indicate energy generation, negative values indicate energy absorption.
Figure 4. Knee Angle in X (sagittal plane), Y (coronal plane), and Z (transverse plane) axes. Positive values indicate extension (top), abduction (middle), and internal rotation (bottom).
Figure 5. Knee Moment in X (sagittal plane), Y (coronal plane), and Z (transverse plane) axes. Positive values indicate extensor moment (top), abductor moment (middle), and internal rotation moment (bottom).
Figure 6. Knee Power in X (sagittal plane), Y (coronal plane), and Z (transverse plane) axes. Positive values indicate energy generation, negative values indicate energy absorption.
Figure 7. Hip Angle in X (sagittal plane), Y (coronal plane), and Z (transverse plane) axes. Positive values indicate extension (top), abduction (middle), and internal rotation (bottom).
Figure 8. Hip Moment in X (sagittal plane), Y (coronal plane), and Z (transverse plane) axes. Positive values indicate extensor moment (top), abductor moment (middle), and internal rotation moment (bottom).
Figure 9. Hip Power in X (sagittal plane), Y (coronal plane), and Z (transverse plane) axes. Positive values indicate energy generation, negative values indicate energy absorption.
Figure 10. Ground Reaction Force for X (sagittal plane), Y (coronal plane), and Z (transverse plane) axes.
Appendix E: Curriculum Vitae for Irene S. McClay

Irene Sprague McClay
Curriculum Vitae

PERSONAL

EDUCATION

<table>
<thead>
<tr>
<th>Degree</th>
<th>Year</th>
<th>Institution</th>
<th>Major</th>
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<tbody>
<tr>
<td>PhD</td>
<td>1990</td>
<td>Pennsylvania State University</td>
<td>Biomechanics</td>
</tr>
<tr>
<td>MEd</td>
<td>1984</td>
<td>University of Virginia</td>
<td>Biomechanics</td>
</tr>
<tr>
<td>BS</td>
<td>1978</td>
<td>University of Florida</td>
<td>Physical Therapy</td>
</tr>
<tr>
<td>BS</td>
<td>1977</td>
<td>University of Mass.</td>
<td>Exercise Science</td>
</tr>
</tbody>
</table>

EMPLOYMENT

Director of Research, Joyner Sportsmedicine Institute, (6/97 - present)
Development of research within the Joyner Sportsmedicine Institute aimed at advancing the science of sportsmedicine and improving prevention, diagnosis and treatment of sports-related injuries.

Associate Professor, Program in Physical Therapy, University of Delaware. (5/97 - present)

Assistant Professor, Program in Physical Therapy, University of Delaware. (9/89 - 5/97)
Instruction of graduate students in physical therapy. Research in clinical biomechanics with specific interest in lower extremity mechanics and injury. Director, Running Injury Clinic.

Research Assistant, Pennsylvania State University, Center for Locomotion Studies. (8/85 - 6/89)
Responsible for the development and coordination of the Running Injury Clinic and Orthopedic Clinic. Research activities in locomotor biomechanics. Consultant to the Distance Runner's Camp at US Olympic Training Center.

Research and Teaching Assistant, University of Virginia, Rehabilitation Engineering Center. (8/82-8/85)
Research activities in wheelchair ergonomics. Instructor of graduate courses in biomechanics and human dissection. Co-coordinator of the Arts and Science of Sports Medicine Conference held annually at the University of Virginia (6/84, 6/85)

**Physical Therapist**, Blue Ridge Rehabilitation Associates, Charlottesville, VA (1/83 - 7/85)
Part time home health and private practice physical therapy.

**Physical Therapist**, Woodrow Wilson Rehabilitation Center, Fishersville, VA (2/79 - 6/82)
Patient treatment, supervision of physical therapy students, inservice training and Coordinator of the Amputee Clinic. Instructor in continuing education course in Management of the Spinal Cord Injured Patient.

**GRANTS**

---

**In Review**

The Biomechanics behind Successful Orthotic Intervention in Patients with Patellofemoral Pain Syndrome. Submitted to the Pauline Marshall Research and Education Foundation. $35,000 for 1 year. Preliminary proposal accepted - Invited to submit full application.

The Effect of Wedged Foot Orthoses on Lower Extremity Mechanics and Function in Patients with Knee Osteoarthritis. Submitted to the National Institutes of Health (COBRE Grant) $125,000/yr for 5 years (in review)

The Effect of a Training Program on Lower Extremity Injuries and Functional Performance in Collegiate Female Basketball Players. Submitted to the Orthopedic Research and Education Foundation. $150,000 for 3 yr. grant period (in review)

**Funded**

Biomechanical Factors Associated with the Etiology of Stress Fractures in Runners. The Department of the Army. $1.05 million for 5 yr grant period beginning 9/2000.


A Comparison of Four Methods to Obtain a Negative Impression of the Foot, $3,250, Foot Management, Inc, 1998-1999


The Effect of the Protonics System on Patellar Aligment and Gait in Patients with Patellofemoral Joint Pain. $18,000. Funded by Inverse Technology, 1998-1999
Clinical Efficacy of the Protonics System in Patients with Patellofemoral Joint Pain. $3,000. Funded by Inverse Technology, 1998-1999

A Comparison of Strengthening vs. Orthotics on Pronation and Pronation Velocity. Funded by the Physical Therapy Foundation $60,000, 1993-1995


The Relationship between Subtalar Joint Axis Orientation, Joint Motion and Injuries in Runners. Funded by the Biomedical Research Support Grant. $2550, 1992

The Relationship between Subtalar Joint and Knee Joint Motion in Runners. Funded by the University of Delaware Research Foundation. $16,000, 1990.


PUBLICATIONS


In Press


In Review


ABSTRACTS

Laughton, CA, McClay, IS, Hamill, J. Effect of Orthotic Intervention and Strike Pattern on Tibial Shock in Runners. Presented at the International Society of Biomechanics, Zurich, Switzerland, July, 2001


Laughton, CA and McClay, IS. Relationship between Loading Rates and Tibial Accelerometry in Forefoot Strike Runners. Presented at the Annual American Society of Biomechanics Mtg, Chicago, IL, July, 2000


Williams, DS and McClay, IS. Injury Patterns in Runners with Pes Cavus and Pes Planus. Presented at the ACSM National Mtg in Indianapolis, IN, 6/00.

Sahte, V, Ireland, ML, Ballantyne BT and McClay, IS. Acute Effect of the Protonics System on Patellofemoral Alignment. Presented at the ACSM National Mtg in Indianapolis, IN, 6/00.

Ott, S, Ireland, ML, Ballantyne, BT and McClay, IS. Gender Differences in Functional Outcomes following ACL Reconstruction. Presented at the ACSM National Mtg in Indianapolis, IN, 6/00.

Williams, DS, McClay, IS & Laughton, CA. A Comparison of between day Reliability of Different Types of Lower Extremity Kinematic Variables in Runners. Presented at the American Society of Biomechanics, 10/99, Pittsburgh, PA.

McClay, IS, Williams, DS & Laughton, CA. Can Gait be Retrained to Prevent Injury in Runners? Presented at the American Society of Biomechanics, 10/99, Pittsburgh, PA.

McClay, IS, Williams, DS and Baitch, S. The Effect of the Inverted Orthotic on Lower Extremity Mechanics. Presented at the International Society of Biomechanics Mtg, 8/99, Calgary, Canada


McClay, IS The Relationship between Lower Extremity Mechanics and Injury in Runners to be presented at the Whitaker Conference, Utah, August, 1996.


McClay, IS & Manal, KT Lower Extremity Kinematic Comparisons between Forefoot and Rearfoot Strikers. Presented at the American Society of Biomechanics Meeting, Stanford, CA 8/95.

McClay, IS & Manal, KT Lower Extremity Kinetic Comparisons between Forefoot and Rearfoot Strikers. Presented at the American Society of Biomechanics Meeting, Stanford, CA 8/95.

McClay, IS & Manal, KT Coupling Parameters in Runners who Pronate and Normals. Presented at the American Society of Biomechanics Meeting, Columbus, Ohio, 11/94.


McClay, IS, Cavanagh, PR, Sommer, HJ, & Kalenak, A: "Three-Dimensional Kinematics of the Patellofemoral Joint during Running". Proceedings of the American Society of Biomechanics Meeting, 10/91, Tempe, AZ.


SELECTED INVITED PRESENTATIONS


"Developing Standards in Epidemiological Research" Presented at the National ACSM Mtg in Indianapolis, June, 2000

"Lower Extremity Mechanics and Injury Patterns in High and Low Arch Runners". Keynote Presented at the Foot and Ankle Research Retreat, Annapolis, MD, May, 2000


"Visual Gait Analysis in Runners" Presented at the Arts and Science of Sports Medicine, Charlottesville, VA, June, 2000.
“Injury Mechanisms in Runners” Keynote speaker at the Fifth IOC Congress on Sport Sciences, Sydney, Australia, November, 1999.

“Clinical Gait Analysis” Keynote speaker at the Fifth IOC Congress on Sport Sciences, Sydney, Australia, November, 1999.


“Coupling between the Foot and the Knee in Runners” Presented at Joyner Sportsmedicine Institute National Conference, Hilton Head, SC, 10/99.


Eugene Michels Research Forum - “Instrumented versus Visual Gait Analysis in Clinical Assessments” Presented at the Combined Sections Meeting in Dallas, TX, 2/97.


"The Use of Motion Analysis in Physical Therapy". University of PA, Philadelphia, 10/95.

"The Patellofemoral Joint - Implications of the study of three-dimensional kinematics". Grand Rounds, Dept. of Orthopedic Surgery, Hershey Medical Center, 1/95.

"What is Clinical Research". Keynote Address at Research Symposium, Shenandoah University, 4/94.

"Research in Foot and Ankle Biomechanics". Presented at the Combined Sections Meeting of the American Physical Therapy Association, New Orleans, LA, 2/94.


"Closed Kinetic Chain Activities for the Foot and Ankle" Presented at the Foot and Ankle Seminar for HealthSouth in Orlando, FL, 2/93, Phoenix, AZ, 3/93, St. Louis, MO, 4/93 and for Foot Mgt, Inc in Ocean City, MD in 10/94 and 4/96.
"Normal Structure and Gait". Presented at the Arts and Science of Sports Medicine Conference, Charlottesville, Va., 6/92, and at the Symposium on the Biomechanics of the Lower Extremity, NATA, Denver, CO, 2/92.


"Biomechanics of the Foot and Ankle". Presented at the Arts and Science of Sports Medicine Conference, Charlottesville, Va., 6/91.


"Anatomy and Biomechanics of the Patellofemoral Joint". Presented at the Sports Physical Therapy Meeting, Orlando, Fla. 12/90.


"Biomechanical Perspective of Stress Fractures in Professional Basketball Players". Presented at the Annual Meeting of the NBA Physicians, West Palm Beach, Fl, 11/88.


"Biomechanical Profile of Elite Woman Distance Runners". Presented at the Dogwood Festival Pre-race Conference, Atlanta, GA, 7/88.

**HONORS**

<table>
<thead>
<tr>
<th>Physical Therapy Foundation Scholar</th>
<th>1988</th>
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<tbody>
<tr>
<td>Recipient of Zipser Scholarship, The Penn State University</td>
<td>1988</td>
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<tr>
<td>Outstanding Masters Student Award, University of Virginia</td>
<td>1984</td>
</tr>
<tr>
<td>Nominee for Mary McMillan Scholarship Award, APTA</td>
<td>1978</td>
</tr>
<tr>
<td>Magna Cum Laude Graduate, University of Florida</td>
<td>1978</td>
</tr>
<tr>
<td>Magna Cum Laude Graduate, University of Massachusetts</td>
<td>1977</td>
</tr>
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</table>
PROFESSIONAL ACTIVITIES

Societies

American Society of Biomechanics
Organizing Committee, Annual ASB Mtg, Chicago, IL, July 2000
Membership Committee (1997-present)

American College of Sports Medicine
American Physical Therapy Association (APTA)
Orthopedic and Research Sections Member
Chairperson of Research Committee of the Foot and Ankle Special Interest Group (1997-present)

International Society of Biomechanics

Advisory

Invited Participant to the “Working Conference on Gait Analysis in Rehabilitation Medicine” National Institutes for Health, September, 1996
Medical Consultant for Runners World (1995-present)

Ed. Board

Clinical Biomechanics (1999-present)

Reviewer

Journal of Biomechanics
Medicine and Science in Sports and Exercise
Foot and Ankle, International
Journal of the American Podiatric Medical Association
Journal of Applied Biomechanics

Other

Organizing Chair for Research Retreat - Static and Dynamic Classification of the Foot. Annapolis, MD, May, 2000.

Licensure

Licensed Physical Therapist, State of Delaware
Appendix F: Curriculum Vitae for Joseph Hamill

CURRICULUM VITAE

Joseph Hamill

[Address information]

Professor and Chair
Department of Exercise Science
Director, Biomechanics Laboratory
University of Massachusetts Amherst

and

Adjunct Professor
Department of Medicine
University of Massachusetts Medical Center

BUSINESS ADDRESS:
Biomechanics Laboratory
Department of Exercise Science
University of Massachusetts
Amherst, MA 01003
(413) 545-2245
(413) 545-2906 Fax
JHAMILL@EXCSCI.UMASS.EDU

EDUCATION

1967 Teaching Certificate Lakeshore Teacher's College, Toronto, Canada
1972 B.A. York University, Toronto, Canada
1977 B.S. (magna cum laude) Concordia University, Montreal, Canada
1978 M.S. University of Oregon, Eugene, Oregon
1981 Ph.D. University of Oregon, Eugene, Oregon

Undergraduate Areas of Study: Political Science
General Science
Graduate Area of Study: Biomechanics

RESEARCH INTERESTS

Mechanics of lower extremity function
Analysis of normal and pathological gait.
Modeling the lower extremity in gait.
Optimality criteria in human locomotion
Biomedical measurement technology
EMPLOYMENT EXPERIENCE

1977-1979  Graduate Teaching Fellow
Biomechanics Laboratory, University of Oregon

1979-1981  Graduate Research Fellow
Biomechanics Laboratory, University of Oregon

1981-1982  Post-doctoral Fellow
Biomechanics Laboratory, University of Oregon

1982-1985  Assistant Professor (Biomechanics)
Department of Physical Education, Southern Illinois University

1985-1986  Assistant Professor (Biomechanics) and Graduate Program Director
Department of Physical Education, Southern Illinois University

1986-1988  Assistant Professor (Biomechanics)
Department of Exercise Science, University of Massachusetts

1989-1995  Associate Professor (Biomechanics) and Graduate Program Director
Department of Exercise Science, University of Massachusetts

1990-  Adjunct Professor
Department of Medicine, University of Massachusetts Medical Center

1995-1996  Associate Professor (Biomechanics) and Department Chair
Department of Exercise Science, University of Massachusetts

1996-  Professor (Biomechanics) and Department Chair
Department of Exercise Science, University of Massachusetts

RESPONSIBILITIES OF PRESENT POSITION

Department Chair
Director of the Biomechanics Laboratory
Teach graduate and undergraduate courses in Biomechanics
Advise undergraduate and graduate students
Chair graduate theses and dissertations in the Department
Conduct research in the area of Biomechanics
Secure external funding for the Biomechanics Laboratory

TEACHING RESPONSIBILITIES

At Southern Illinois University

P.E. 511  Mechanical Analysis
P.E. 512  Biomechanics of Sport
P.E. 505A  Biomechanics Instrumentation
P.E. 505B  Computer Applications
P.E. 505C  Biomechanics of the Musculo-skeletal System
P.E. 561  Doctoral Seminar
P.E. 302  Kinesiology for Physical Therapy
P.E. 370  Tests and Measurement
At University of Massachusetts
Ex Sc 300  Writing Seminar for Exercise Science
Ex Sc 305  Kinesiology
Ex Sc 304  Human Anatomy
Ex Sc 311  Anatomy of Human Motion
Ex Sc 531  Mechanical Analysis of Human Motion
Ex Sc 611  Introduction to Research
Ex Sc 732  Advanced Biomechanics
Ex Sc 892  Doctoral Seminar
Ex Sc 895  Clinical Biomechanics Seminar

UNIVERSITY SERVICE

Department Committees
Master's Thesis Review Committee, 1982-1983
Comprehensive Examination Review Committee, 1983-1984
Chair, Graduate Faculty, 1982-1986
Chair, Search Committee for Department Chairperson, 1986
Graduate Committee, 1986-
Telecommunications Committee, 1988-1990
Chair, Department Personnel Committee, 1994-1995
Chair, Motor Control Search Committee, 1994-1995

College Committees
College Computer Advisory Committee, 1982-1986
School Personnel Committee, 1994-1995
School Executive Committee, 1995-
Member, School Development Officer Search Committee, 1997.

University Committees
Graduate Council, 1991
Recruitment and Retention Committee, 1991-92
Research Council, 1992-1995

PROFESSIONAL ORGANIZATIONS

American Alliance for Health, Physical Education, Recreation and Dance
Biomechanics Academy of the Research Consortium
International Society of Biomechanics
Canadian Society of Biomechanics
American College of Sports Medicine
New England College of Sports Medicine
American Society of Biomechanics
International Society of Biomechanics in Sport
ASTM

RESEARCH AFFILIATIONS

Scientific Advisory Board, LifeFitness, Inc., 1993-
Scientific Advisory Board, USA Field Hockey, 1995-1998
ACADEMIC HONORS

Fellow, Research Consortium of the AAHPERD, 1984
Fellow, American College of Sports Medicine, 1986
Fellow, American Academy of Kinesiology and Physical Education, 1997

OFFICES IN PROFESSIONAL ORGANIZATIONS

1. Chair-elect, Kinesiology Academy, 1990-91.
3. Chair, Biomechanics Interest Group of the American College of Sports Medicine, 1996-97.
4. Member-at-large, Executive Committee of the New England Chapter of the American College of Sports Medicine, 1995-
6. Member, Credentials Committee, American College of Sports Medicine, 2000-
7. Member-at-Large, Executive Board of Canadian Society of Biomechanics, 2000-

PROFESSIONAL SERVICE

Review Committees For Professional Meetings


External Reviewer for Theses and Dissertations

External Grant Reviewer
1. External Reviewer for internal grants at University of Texas at Tyler, 1991.

Committee Member

EDITORIAL BOARD OF PROFESSIONAL JOURNALS

Member, Editorial Review Board, Pediatric Exercise Science, 1988-
Member, Editorial Review Board, Medicine, Exercise, Nutrition, and Health, 1991-1995
Section Editor, Biomechanics, Research Quarterly for Exercise and Sport, 1993-96
Member, Research Quarterly for Exercise and Sport Editorial Board, 1998-
Associate Editor, Medicine and Science in Sports and Exercise, 2000-
Member, Editorial Review Board, Sports Biomechanics, 2000-
Member, Advisory Editorial Board, Journal of Sports Sciences, 2001-

REVIEWER FOR PROFESSIONAL JOURNALS

Reviewer, Medicine and Science in Sports and Exercise, 1985-
Reviewer, International Journal of Sports Biomechanics, 1986-
Reviewer, Research Quarterly for Exercise and Sport, 1989-
Reviewer, Sports Medicine, 1991-
Reviewer, Journal of Gerontology, 1991-
Reviewer, Journal of Orthopaedic and Sports Physical Therapy, 1991-
Reviewer, Journal of Applied Biomechanics, 1993-
Reviewer, Journal of Applied Physiology, 1993-
Reviewer, Journal of Biomechanics, 1993-
Reviewer, Clinical Journal of Sports Medicine, 1996-
Reviewer, British Journal of Sports Medicine, 1996-
Reviewer, Clinical Biomechanics, 1999-
Reviewer, Exercise and Sports Science Review, 2000-
Reviewer, European Journal of Applied Physiology, 2000-
PUBLICATIONS


MANUSCRIPTS UNDER REVIEW


MANUSCRIPTS IN PREPARATION


Hamill, J., Derrick, T. R.: Co-contraction of lower extremity muscles under varying stride frequency conditions.


PROCEEDINGS


PUBLISHED ABSTRACTS


Stewart, D., Hamill, J., Adrian, M. Effect of prolonged work bouts on ground reaction forces during running. Medicine and Science in Sports and Exercise. 16:2, S185, April, 1984.


Holt, K. G., Hamill, J., Greer, N. L., Andres, R. O. Effects of stride length, stride frequency and velocity on ground reaction forces in walking. Medicine and Science in Sports and Exercise. 19:2, S17, April, 1987


BOOKS


BOOK CHAPTERS


NON-REFEREED PUBLICATIONS


PUBLISHED RESEARCH REPORTS


PUBLISHED BOOK REVIEWS


PRESENTATIONS

International:


National:


Regional, State, and Local:


KEYNOTE PRESENTATIONS


INVITED PRESENTATIONS


Medio-lateral foot function during locomotion. University of Illinois Graduate Faculty and students, Champaign, IL, February, 1983.


If the shoe fits: A biomechanical analysis of locomotion. Sigma Xi Society, University of Massachusetts, Amherst, MA, November 16, 1988.


Biomechanical implications of the design of running shoes. Physical Therapy Department, Boston University, April 18, 1990.

Biomechanics of running. Physical Therapy Department, Boston University, November 6, 1990.


Biomechanical considerations for equipment design in children's sports. Seminar on Children's Activities, United Hospital Medical Center, Port Chester, NY, March 28, 1992.


A force-driven harmonic oscillator model of human locomotion. German Sports University, Cologne, Germany, February 29, 1996.

If the shoe fits: the biomechanics of running shoes. American Medical Athletic Association, Boston, MA, April 12, 1996.


An oscillator model of locomotion. University of Massachusetts Physics Department Seminar, Amherst, MA, May 1, 1996.


From a Pendulum to a Spring. Department of Kinesiology, Louisiana State University, Baton Rouge, LA, October 24, 2000.


GRANTS AND GIFTS


2. Dynamics of platform diving, United States Diving Association, $3,000, 1/84 - 12/84.

3. Effects of anatomically variant foot-types on walking gait, ORDA, Southern Illinois University, $6,000, 9/85 - 6/86.

4. Ergonomics of lower extremity function, KangaROOS, USA, $58,000, 9/86 - 9/89.

5. Effect of orthotic inserts on walkers with rearfoot and forefoot dysfunctions. Biomedical Research Support Grant, $6,000, 1/87 - 1/89.


10. Lower extremity action during exercise, Life-Fitness Group, $6,000, 7/90 - 7/92.


12. Lower extremity mechanics, Hyde Athletic Shoe Company, $279,000, 1/89 - 1/97.


