ABSTRACT

MUSCLE WORK DISCREPANCY DURING INCLINE AND DECLINE RUNNING AT THREE SPEEDS

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April, 2009
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Introduction: Previous research has explored muscle function during gait and this work has shown that more positive mechanical muscle work is produced in gait tasks that primarily raise the center of mass (incline gait tasks) compared to the amount of negative mechanical muscle work dissipated in gait tasks that primarily lower the center of mass (decline gait tasks). This has led to the hypothesis that skeletal muscles generate more mechanical energy in gait tasks that raise the center of mass compared to mechanical energy dissipated by muscles in gait tasks that lower the center of mass. The purpose of this study was to compare the positive and negative muscle work produced during incline and decline running at three speeds in healthy young adults.

Methods: Three-dimensional gait analysis was performed to compare the kinetic and energetic differences between incline and decline running on 20 healthy runners (mean age 20.5 years) at speeds of 2.68 m/s, 3.35 m/s, and 4.47 m/s. Positive and negative muscle work in all three planes during the stance phase were derived from the power curves and compared across speeds. Muscle work from both the incline and decline running conditions were analyzed using a two-factor analysis of variance (ANOVA). Mean differences with alpha levels below 0.05 were considered significant.

Results: Incline running had 36% more net muscle work compared to decline running ($p<0.001$). A significant interaction effect between gait direction and running speed was found such that the difference between positive and negative work increased with running speed ($p<0.001$).

Discussion: The results of this work show that muscles produce and dissipate work differently during incline and decline running. Several reasons for the difference in muscle work have been identified which include: increased vibrational motion of soft tissues, poorer mechanical advantage in incline compared to decline running, and longer stride lengths in decline vs. incline running. The data of the present study support the hypothesis that skeletal muscles generate more mechanical energy in gait tasks that raise the center of mass compared to mechanical energy dissipated by muscles in gait tasks that lower the center of mass.

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A Thesis

Presented to the Faculty of

The Department of Exercise and Sport Science

East Carolina University

In Partial Fulfillment

of the Requirements for the Degree of

Masters of Science in Exercise and Sport Science

Biomechanics Option

By

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April, 2009

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Introduction

Human locomotion is only possible because of the many different physiological and mechanical processes that work together to produce this skillful movement. Skeletal muscle contractions are one important element of these processes. In locomotion both shortening and lengthening muscle contractions occur to either generate or dissipate energy to the body. Therefore, understanding how the body generates and dissipates energy is important when trying to understand skillful human movement.

In level gait tasks of constant average velocity the body's center of mass is both raised and lowered an equal amount during an average gait cycle. This causes the total amount of mechanical energy of the body to increase and decrease equally (Laursen, 2000; Minetti, 1993). Minetti et al. (1993) explained that in level gait tasks there is an equivalent amount of both positive and negative work produced and dissipated, respectively. This is due to the fact that the body's center of mass is both raised and lowered an equal amount. So, the positive mechanical work produced by raising the center of mass must be counterbalanced by an equal amount of negative mechanical work produced when lowering the center of mass (Minetti, 1993).

In incline gait conditions the body's center of mass is both raised and lowered but there is a bias toward raising the center of mass. This bias in raising the center of mass in incline gait conditions produces more positive mechanical work (Laursen, 2000, DeVita, 2007). The body's center of mass is also raised and lowered in decline gait conditions with a bias towards lowering the center of mass. This bias in lowering the body's center of mass in decline gait causes more negative mechanical work to be dissipated during the decline conditions (Laursen, 2000, DeVita, 2007).

Determining the mechanical work due to muscle function is essential when describing the mechanics of how humans perform locomotion. Muscles produce mechanical energy through concentric (shortening) contractions and dissipate mechanical energy through eccentric (lengthening) contractions (Elftman, 1966). Positive mechanical work is done by muscles that exert force on the skeleton through their attachments and when the muscles shorten (Elftman, 1966). Negative work is produced by these same muscles when a force is exerted on the muscles and when the muscles' lengthen (Elftman, 1966).

DeVita et al. showed that the positive mechanical work produced by muscles in level walking exceeded the amount of negative mechanical work dissipated by muscles in level walking (DeVita, 2007). This showed that there was a discrepancy in the amount and type of work produced by skeletal muscles. DeVita and colleagues further showed that more positive mechanical work by muscles is produced in gait tasks that primarily raise the center of mass (incline gait tasks) vs negative mechanical work dissipated by muscles in gait tasks that primarily lower the center of mass (decline gait tasks) (DeVita, 2007).

Hypothesis

The work by DeVita and colleagues have led to a global biomechanical hypothesis that skeletal muscles generate more mechanical energy in gait tasks that raise the center of mass compared to mechanical energy dissipated by muscles in gait tasks that lower the center of mass, despite equivalent changes in total mechanical energy.

Purpose

The purpose of this study is to compare the positive and negative muscle work produced during incline and decline running at three speeds in healthy young adults.

Expectations

DeVita et al. conjectured that the bias towards positive vs. negative muscle work was due to larger ground reaction forces in descending vs. ascending gaits (DeVita, 2007). Therefore, it is expected that gaits with larger ground reaction forces, such as running compared to walking, or faster compared to slower running (Belli, 2002), would have larger biases in positive compared to negative muscle work. This thesis will further explore the hypothesis by manipulating gait velocity in incline and decline running.

Delimitations and Limitations

The following delimitations and limitations were incorporated and identified for this experimental design:

1) Only subjects considered healthy with no previous history of lower extremity injury or disease were included.

2) Subjects were between the ages of 18-25 years.

3) Subjects had Body Mass Index (BMI) values of less than 30 kg/m^2.

4) Only three running speeds, 2.68, 3.35, and 4.47 m/s, and one incline and decline ramp angle of 10 degrees were examined.

5) Upper extremity mechanics were not taken into account.

6) Data limited to accuracy of instruments which has been determined to be acceptable for the purposes of this research.

Assumptions

The following assumptions were made for this experimental design:

1) Laboratory equipment did not interfere with any part of the subject's performance.

2) Any information given by the subject was considered to be true.

3) Appropriate approximation of anthropometric measures and equations were made for each subject.

4) Muscle function was considered to be symmetrical between the right and left legs.

Operational Definitions

The following operational definitions were used for this experimental design:

1) Positive muscle work- Total energy generated through shortening or concentric muscle contractions.
2) Negative muscle work- Total energy dissipated through lengthening or eccentric muscle contractions.
3) Inverse Dynamics- Biomechanical process of determining joint reaction forces and joint torques from kinematic and ground reaction force data.

Review of Literature

The purpose of this study is to compare the positive and negative muscle work produced during incline and decline running at three speeds in healthy young adults. A review of existing literature on the topics of non-level locomotion and muscle work is necessary to accurately examine the effects of various speeds on non-level running. In this chapter, the existing literature will be discussed in the following sections: 1) Kinematic and kinetic changes due to speed in running, 2) Changes in kinematics and kinetics from level to non-level running, 3) Positive and negative work in level and non-level locomotion 4) and Conclusions.

Kinematic and Kinetic Changes due to speed in Running

It is well understood that in order to achieve faster running speeds certain biomechanical processes within running must be altered. A runner can increase stride frequency by decreasing stride length, or for that matter, decrease stride frequency with an increase in stride length, to increase the overall running speed. Belli et al. observed increases in step frequency with decreases in the amount of contact time on the ground as running speed increased (Belli, 2002). It has been reported, however, that the primary kinematic changes in faster running speeds were not due to changes in stride frequency, but instead were due to changes in stride length (Mercer, 2002).

As changes occur in kinematics due to increases in running speed certain kinetic variables must change as well. Weyand et al. found that a runner's fastest running speeds were not due to the runner's ability to reposition the legs or from the length of each stride but instead were due to the amount of support force the runner applied to the ground (Weyand, 2000). So, as running speeds increase the major kinematic change is stride

length, but when the runner wants to run at top speed, the amount of support force applied to the ground increases. It has also been found that with increases in running speed the amount of time the force is applied to the ground decreases (Kyrolainen, 1999, Belli, 2002).

Hip extensor torque increases as speed increases in the initial part of the contact period of the stance phase (Belli, 2002). Greater hip flexor torques are also found with increases in speed during the entire contact phase of running (Belli, 2002). Running has three hip power phases during the stance portion of running and the greatest hip power output occurs at maximal running speeds (Belli, 2002). The initial stage is a positive extensor power phase (concentric contractions) followed by a negative flexor power phase (eccentric contractions) and positive flexor power phase (Belli, 2002). Belli et al.(2002) consider the hip as the prime forward mover of the body as increases in speed are made in running.

When heel contact is made in running, knee extensor muscles contract eccentrically to counter balance the effects of gravity (Belli, 2002). With increases in speed the peak knee extensor torque also increases (Arampatzis, 1999, Belli, 2002). More energy absorption at the knee was found in running compared to energy generation during the stance phase (Roberts, 2005). As running speed increases the amount of energy absorption at the knee was also found to increase (Arampatzis, 1999).

As the foot pushes off in running, a plantar-flexor torque is generated to help propel the runner upward and forward. As running speeds increase, an increase in peak and average plantar-flexor torque can be seen (Arampatzis, 1999). The plantar-flexor torque found in running causes a bias for positive energy production compared to

negative energy absorption (Arampatzis, 1999; Belli, 2002). Arampatzis et al. (1999), also found that with increases in running speed the difference between energy generation and energy absorption at the ankle increased until the two highest speeds examined, 4.5 m/s and 5.5 m/s, where energy generation and absorption were found to be about the same.

From these articles it has been established that certain biomechanical variables do indeed change as running speed is increased. The review of this existing literature has provided part of the foundation for the purpose and has also provided justification for testing the studies' hypothesis.

Changes in Kinematics and Kinetics from Level to Non-Level Running

As running changes from level to non-level, certain kinematic changes occur. It has been reported that the knee is less flexed at heel contact but the knee flexes more throughout the stance phase in decline compared to level and incline running (Buczek, 1990). Dorsi-flexion of the ankle at heel strike was found to be higher but maximum dorsi-flexion during the entire stance phase was relatively unchanged in decline running compared to incline running?(Buczek, 1990). Roberts et al. found differences at the knee and ankle angular position during incline running with no changes in hip angles compared to level and decline conditions (Roberts, 2005).

Kinetic changes have also been seen in runners when running on decline and incline surfaces. Normal, or perpendicular to the force platform, impact forces as well as parallel breaking forces were significantly larger in decline running (6 degree grade) compared to incline running with a similar grade (Gottschall, 2005). Yokozawa et al. found that the vertical impact peaks were larger in decline running at -3.2%, -6.4%, and -

9.1% compared to level running and that there was no significant difference between horizontal breaking and propulsive forces in level and decline running (Yokozawa, 2004). These studies are in agreement that decline running produces larger ground reaction forces than incline or level gaits.

Hip extensor torque was found to be lower in decline running at 3.3 m/s, 4.2 m/s, and 5.0 m/s compared to level running (Yokozawa, 2004). It was reported by Roberts et al., that there was an extensor torque at heel contact followed by a flexor torque from mid-stance until just before toe-off in level running (Roberts, 2005). In the incline running trials, hip extensor torque was found to be higher and was seen throughout the entire stance phase (Roberts, 2005). Hip power was close to zero in level running and was found to be slightly negative in the decline running conditions (Yokozawa, 2004). Positive power was produced at the hip during incline and was used to help propel the runner up the incline surface (Roberts, 2005).

The rate of knee extensor torque development increased at -6.4% and -9.1% grades just after heel contact but there was no significant difference between the peak values of knee extensor torques in level and decline running (Yokozawa, 2004). It was found that when runners ran up an incline a decrease in knee extensor torque was produced compared to level running (Roberts, 2005, Buczek, 1990). Both positive and negative power decreased at the knee during inclined running, but the net power was unchanged compared to that of level running (Roberts, 2005). A bias of negative power was found at the knee during decline running and negative power increased with higher negative slopes (Yokozawa, 2004).

No significant differences in plantar-flexor torques at the ankle were found in incline running compared to level (Buczek, 1990, Roberts, 2005). Yokozawa and colleagues, however, found significant decreases in plantar-flexor torque in two of the decline running conditions, -6.4 and -9.1 degrees (Yokozawa, 2004). More positive work is produced during incline gait while more negative work is produced during decline conditions compared to level gait at the ankle (Lay, 2007).

Lay et al. found that there were changes in hip, knee, and ankle torques in both incline and decline walking compared to level walking (Lay, 2005). The findings by Buczek, Yokozawa, and Roberts and colleagues only partially support Lay et al.'s findings. The differences in joint torque found by Lay et al. may be due to differences between walking and running on sloped surfaces. These findings may also be different due to the fact that Lay and colleagues had subjects walk at extreme grades that were much higher than those found in the running studies (Lay, 2005).

Positive and Negative Work in Level and Non-Level Locomotion

As humans perform locomotion, walking or running, both positive and negative mechanical work is produced. For example, when the leg contacts the ground or when it pushes off from the ground, negative and positive work is produced, respectively (Alexander, 1991; Umberger, 2007). It has been previously believed that in level gait tasks, the amount of positive mechanical work produced by skeletal muscles is the same as the negative work dissipated by skeletal muscles (Minetti, 1993). DeVita et al., however, showed that the amount of positive work generated by skeletal muscles in level walking was 47% greater than that of the amount of work dissipated by these muscles (DeVita, 2007).

As humans walk or run on different slopes, such as on level or inclined and declined ground, the type of mechanical work that is predominately produced is different between the level and non-level ground (DeVita, 2007, 2008). More positive work is produced in ascent locomotive tasks, while more negative work is produced in descending tasks (Minetti, 1993, Gabaldon, 2004, DeVita, 2007, 2008). It appears that more positive work is produced when raising the center of mass compared to the amount of negative work dissipated when lowering the center of mass (Minetti, 1993).

Shortening, or concentric contractions produce increases in total mechanical energy of the body during incline locomotion (Elftman, 1966, Laursen, 2000). Net positive work is produced through these shortening contractions. Roberts et al. suggest that positive mechanical work must be performed in order to increase the potential energy in inclined running (Roberts, 2005). The work produced at the hip was found to be the leading determinant in propelling the runner up the incline surface compared to the knee and ankle (Roberts, 2005).

During decline locomotion, lengthening, or eccentric muscle contractions dissipate mechanical energy causing a decrease in total mechanical energy of the body (Elftman, 1966, Laursen, 2000). It has been reported that the knee performs negative work and dissipates mechanical energy in both level and decline running conditions (Buczek, 1990). Buczek et al. found, however, that the greatest amount of negative work done by the knee was performed during the decline running conditions (Buczek, 1990).

The previous literature has shown that certain kinetic and energetic changes must occur for runners to run up and down a sloped surface. This review has supported the justification for the hypothesis that muscles produce more mechanical energy in gait tasks

that raise the center of mass compared to the amount of energy dissipated by muscles in gait tasks that lower the center of mass.

Summary

Kinematic and kinetic changes are found when the body changes from walking to running and changes are seen with increases in running speed. Speed increases in running alter muscle function by either generating or absorbing more energy. Positive hip power is produced through hip extensor torques and can be seen in the early and late stages of foot contact (Belli, 2002). The amount of work produced at the hip is mostly positive and is produced through shortening contractions (Laursen, 2000). Knee extensor torques increase when speed increases through eccentric muscle contractions and help to counterbalance the effects gravity (Laursen, 2000, Belli, 2002). Peak plantar-flexor torque increases with speed which causes a net positive amount of work to be produced at the ankle (Arampatzis, 1999).

Muscle function in running also changes when running from level to incline or decline surfaces. Energy is produced to propel the runner up the incline surface. The hip can be considered the prime mover in ascent gait tasks because of the large amount of positive work produced (Roberts, 2005). The positive work produced at the hip is also accompanied by positive work done by the ankle (Lay, 2007). Decline gait conditions causes large amounts of energy to be dissipated through eccentric muscle action with the greatest amounts of negative work occurring at the knee and ankle joints (Elftman, 1966, Buczek, 1990, Lay, 2007).

From the previous articles it has been established that certain changes occur in running due to increases in speed and due to changes in slope. The total and segmental

work produced at the hip, knee, and ankle change during changes of both slope and speed. From this knowledge the following hypothesis has been developed:

> Skeletal muscles generate more mechanical energy in gait tasks that raise the center of mass compared to mechanical energy dissipated by muscles in gait tasks that lower the center of mass.

Several methods can be used to test this hypothesis in many different ways. The purpose of the present study will be to compare the positive and negative muscle work produced during incline and decline running at three speeds in healthy young adults.

Methodology

Subject Characteristics

Twenty male and female subjects were recruited to participate in the incline and decline running conditions with a mean age of 20.5 ± 1.1 years. Mean mass and height for all subjects was 67.5 ± 11.8 kg and 1.73 ± 0.08 m, respectively. Subjects were either included or excluded based on the following criteria:

Inclusion Criteria:

1. Subjects were considered apparently healthy and had no history of previous lower extremity injuries or illness.
2. Subjects were recreational runners who ran between 10 and 20 miles per week.

Exclusion Criteria:

1. Subjects were excluded from the study after performing a familiarization trial where it was found that running velocity could not be maintained during any of the incline or decline test conditions.
2. Subjects with BMI of 30 kg/m^2 or above were excluded.

Measures and Instruments

All trials were filmed using an eight-camera ProReflex Motion Capture system (Qualisys Medical AB, Gothenburg, Sweden). The cameras were mounted above the runway to capture three-dimensional running mechanics. The cameras sampled at 240 Hz during each trial. An infrared timing system (Brower timing systems, model IRD-T175, Salt Lake City, Utah) placed 3 meters apart was used to measure the velocity of the subjects. Ground reaction force data for the incline and decline running conditions was recorded from a force platform (OR6-6, 2000, AMTI, Newton, MA) surrounded by a

four-meter ramp with a ten-degree slope. The force platform sampled at 960 Hz. Qualisys Track Manager Software (Innovision Systems Inc., Columbiaville, MI) was used to track passive reflective markers during each trial. Inverse dynamics was calculated using Visual 3D software (C-Motion Inc., Rockville, MD).

Procedures

All testing was conducted in one session lasting between 90 to 120 minutes. Subjects were required to wear T-shirt, shorts, and athletic footwear. Spandex shorts were required when the subjects' shorts would not allow for accurate placement of reflective markers. Tracking markers were placed on selected body segments of the lateral right lower limb and pelvis. Body segments included: pelvis, right thigh, right shank, and right foot.

Subjects performed incline and decline running trials on the ramp and both force platform and motion capture data were collected for each trial using Qualysis Motion Capture Software. Subjects ran at 2.68 m/s, 3.35 m/s, and 4.47 m/s during both the incline and decline running conditions. The three selected running speeds were chosen because they are equal to a 10 min/mile, 8 min/mile, and 6 min/mile pace. Timing information was used to ensure that all subjects ran at the correct speed. Trials were only kept if the subjects were found to have run within +/- 5% of the selected speed. During the incline and decline running trials, velocity time curves were examined to ensure that subjects maintained the selected speed without accelerating. Trials were discarded if the subjects' right foot did not come in complete contact with the force platform and if the subjects altered their running technique to ensure contact with the force platform. A total

of three acceptable trials were collected for each running speed during both the incline and decline conditions for a total of 18 acceptable trials.

Data Analysis

The analysis focused on the movement of the right limb for all running trials. The data was reduced using the Qualisys Track Manager software and focused on position data of the tracking markers for all subjects in the lab's global coordinate system. Static standing trial position data was collected to create an individual model to locate joint centers, segment center of masses, local coordinate system for each segment, and to calculate a transformation matrix to determine the location of all markers in the global coordinate system. The transformation matrix was calculated by first locating the local coordinate system for each segment from the standing static trial. Next, a 4 x 4 matrix was calculated by combining the position and orientation vectors and was used to define the local coordinate system in the lab's global coordinate system. The inverse of this matrix was calculated and allowed for the transformation of the local coordinate system to the global coordinate system. This method was used for all frames of data.

A rigid, link segment model was created from the static standing trial in Visual 3D software and was used to calculate three-dimensional lower extremity joint torques and powers using inverse dynamics. Segmental masses, their moments of inertia, and the locations of the mass centers were estimated by Visual 3D from the position data using anthropometric data (Dempster, 1955) and the individual subject's anthropometric data (i.e. body mass). Virtual joint centers for the right knee and ankle were calculated by finding the center of the medial and lateral joint markers placed at each joint. The right hip joint center was calculated by finding one fourth the distance between the right and

left greater trochanters.

The inverse dynamics method uses linear and angular Newton-Euler equations of motion to predict joint reaction forces and joint torques from the measured kinematics and ground forces. (Buchanan, 2004) The inverse dynamics method is first applied to the foot where unknown joint reaction forces are calculated at the ankle by the equation:

$$JRF_{ankle} = ma_{cm} - mg - f_{grf}$$

where m is the segment mass, a_{cm} is the linear acceleration of the segment center of mass, mg is the gravity vector, and f_{grf} is the ground reaction force vector applied to the body. The vector describing the ankle joint torque was expressed by the following formula:

$$JT_{ankle} = I\alpha - (d_1 \text{ x } JRF_{ankle}) - (d_2 \text{ x } F_{GRF})$$

where I is the moment of inertia matrix, α is the angular acceleration matrix, d_1 x JRF_{ankle} is the vector describing the torque resulting from the joint reaction force, d_2 x F_{GRF} is the vector describing the torque resulting from the ground reaction force. All force and moment calculations were performed in the local coordinate system of the specific segment and for all frames of data. The ground reaction force component was replaced by the components of the distal joint reaction forces in the adjacent segment for the joint torque and joint reaction force calculations in the remaining segments which are represented with the following equations:

$$JRF_{Prox} = ma_{CM} - mg - JRF_{Distal}$$

$$JT_{Prox} = I\alpha - (d1 \text{ x } F_{jrf\_Prox}) - (d2 \text{ x } F_{jrf\_Distal}) - JT_{Distal}$$

Support torque was calculated as the sum of the joint torques and used to compare the total muscle effort between incline and decline running. The torques represented the internal torques produced by the skeletal muscles and other tissues crossing the joints.

Positive torques represented net extensor or plantar-flexor, internal rotation, and adduction directions. Torques were normalized to the subject's body mass and height (%body weight x height) to correct for larger resistive torques expected for taller and heavier subjects with longer limbs and higher moments of inertia.

Joint powers were calculated from joint torques and joint angular velocities from the following formula:

$$P = JT \times (\omega_{Proximal} - \omega_{Distal})$$

where P is the joint power vector, JT is a vector representing the three-dimensional components of the joint torque and $\omega_{Proximal}$ and ω_{Distal} are the vectors representing the three-dimensional proximal and distal segment angular velocities. A total power curve was calculated as the sum of the hip, knee, and ankle joint powers and used only to provide a visual description of the simultaneous power output of the three joints. The total areas under the sagittal, frontal, and transverse planes power curves were used to calculate positive and negative work throughout the stride cycle. These work estimates represent the total contributions by the various muscle groups to the movements. Work values were normalized to body mass.

Statistical Analysis

The work data from both the incline and decline running conditions were analyzed using a two-factor analysis of variance (ANOVA). Mean work differences for the two factors (direction, incline vs. decline, and speed, 2.68, 3.35, and 4.47 m/s) were examined. Mean differences with alpha levels below 0.05 were considered significant.

Results

The hypothesis for this study was that skeletal muscles generate more mechanical energy in gait tasks that raise the center of mass compared to mechanical energy dissipated by muscles in gait tasks that lower the center of mass. This hypothesis was explored through this study, the purpose of which was to compare the positive and negative muscle work produced during incline and decline running at three speeds in healthy young adults. In the following chapter, evidence for this experiment will be given through biomechanical gait analysis of incline and decline running.

Stride Length, Ground Reaction Forces, and Total Body Energetics in Incline and Decline Running

Stride length (Figure 1) was 5% longer in decline compared to incline running (2.56 vs. 2.44 m, $p < 0.001$) conditions and stride length increased with running speed (2.17, 2.50, & 2.82 m in slow, medium, and fast speeds , $p < 0.001$). The interaction effect, however, was not statistically significant.

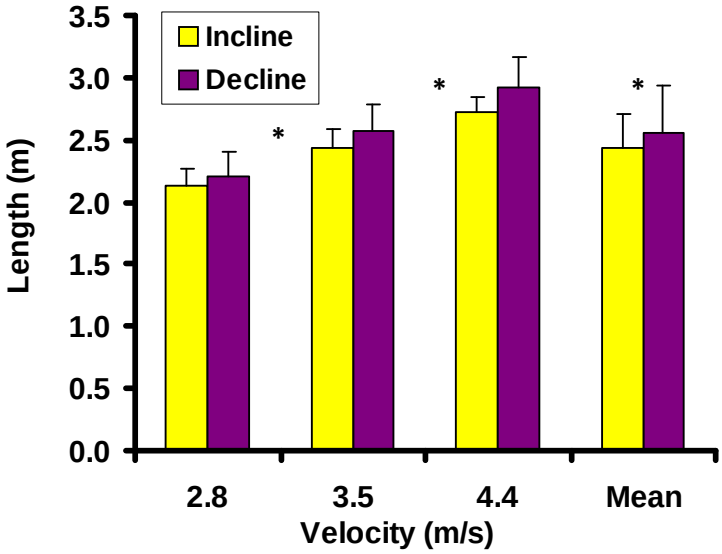

Figure 1-.Stride length for incline and decline running at various speeds. Subjects had significantly different stride lengths in incline compared to decline running and across running speeds. * denotes significant difference, $p < 0.001$.

Ground reaction force (GRF) curves were qualitatively different in incline and decline running and were therefore not compared statistically between these conditions (Figure 2). The normal GRF in decline running had an impact force peak in early stance whereas incline running did not. The peak impact force appeared to increase with running speed. The parallel GRFs were distinctly different between incline and decline running. Decline running had large braking forces whereas incline running had large propelling forces. The peak braking and propelling forces also appeared to increase with running speed.

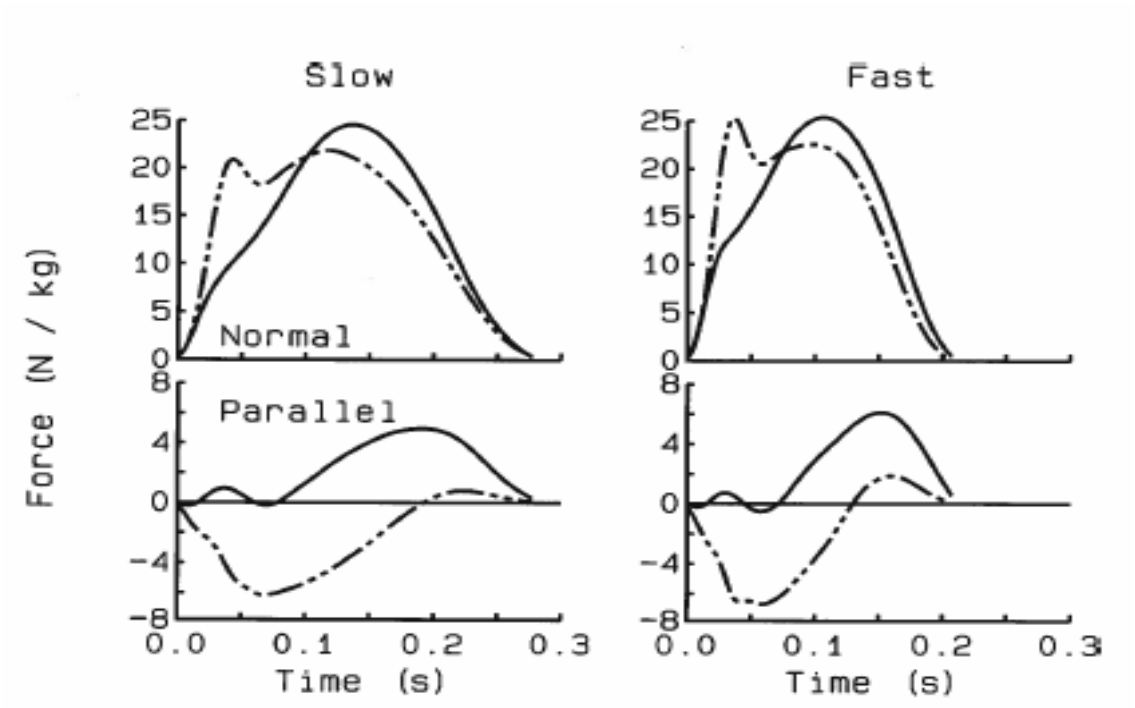

Figure 2- . Average normal and parallel ground reaction forces during incline and decline running.

The overall goal was to maintain constant kinetic energy (Figure 3) over the stride cycles and to change potential energy over the stride in each task. Kinetic energy was held constant over the strides in incline running ($p= 0.240$) but did increase over the strides in decline running ($p< 0.001$). This increased kinetic energy also showed a

significant interaction effect ($p < 0.001$) in which the increases were 0.26, 0.70, and 1.21 J/kg from slow to fast speeds. Potential energy showed the expected effect by increasing in incline and decreasing in decline running.

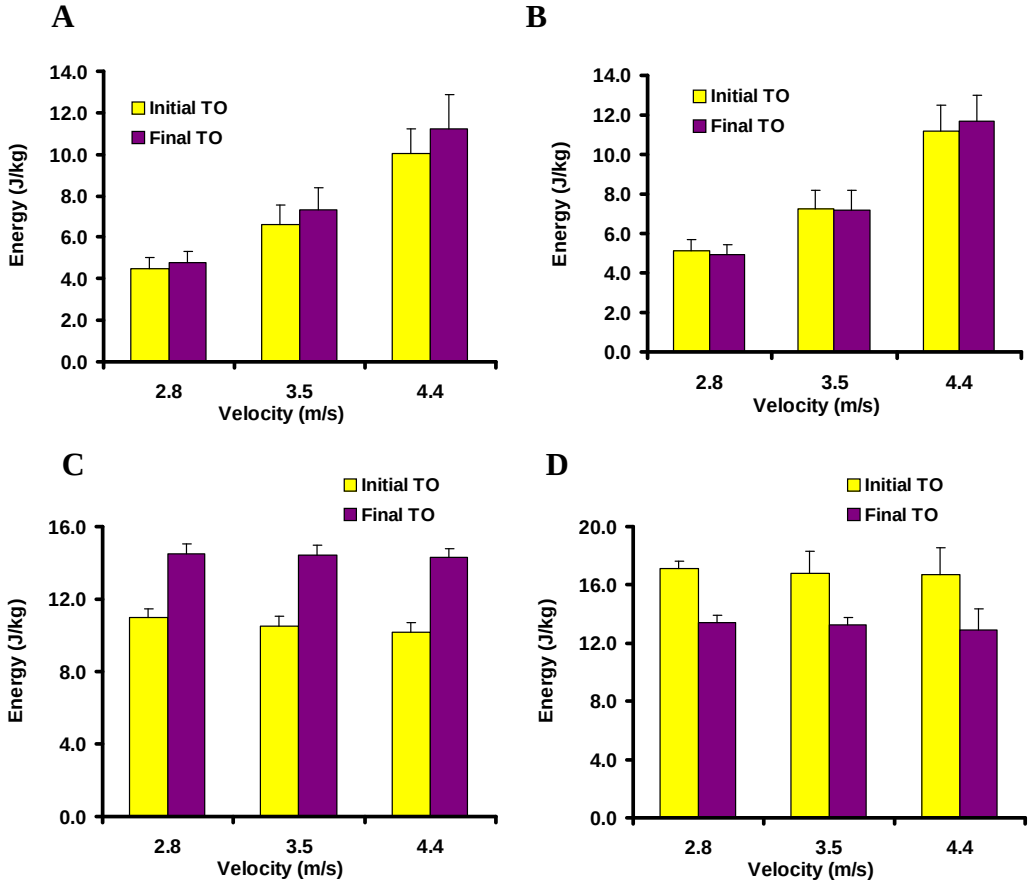

Figure 3-. Kinetic and potential and energy in decline and incline running. A- Kinetic Energy Decline, B- Kinetic Energy Incline, C- Potential Energy Incline, D- Potential Energy Decline.

Joint Torques during Incline and Decline Running

Average sagittal plane joint torque curves for slow and fast speeds during incline and decline running are shown in figure 4. Only the sagittal plane mechanics are presented here because the sagittal plane is recognized as the fundamental component of locomotion and provides the best visual description of running. Mean extensor angular impulses for each joint during incline and decline running are shown in figure 5, and

extensor angular impulse values for each joint during the direction and speed conditions are shown in figure 6.

Support extensor angular impulse (figure 5) was 28% larger in incline vs. decline running ($p<0.001$) and significantly decreased as running speed increased ($p<0.001$). The interaction effect was not significant. Hip and ankle extensor angular impulses were 115% and 60% larger in incline vs. decline running (both $p<0.001$). Hip impulse increased with running speed ($p<0.001$), the interaction effect was not significant. The interaction effect was significant however at the ankle ($p<0.032$) indicating that while ankle angular impulse decreased with speed in both incline and decline running, the magnitude of the decrease was larger in incline running. Extensor angular impulse at the knee was 50% larger in decline vs. incline running ($p<0.001$) and significantly decreased as speed increased ($p<0.001$). Overall joint torques were larger in inclined vs. decline running despite apparently the larger GRFs in decline running and joint torques increased with running speed.

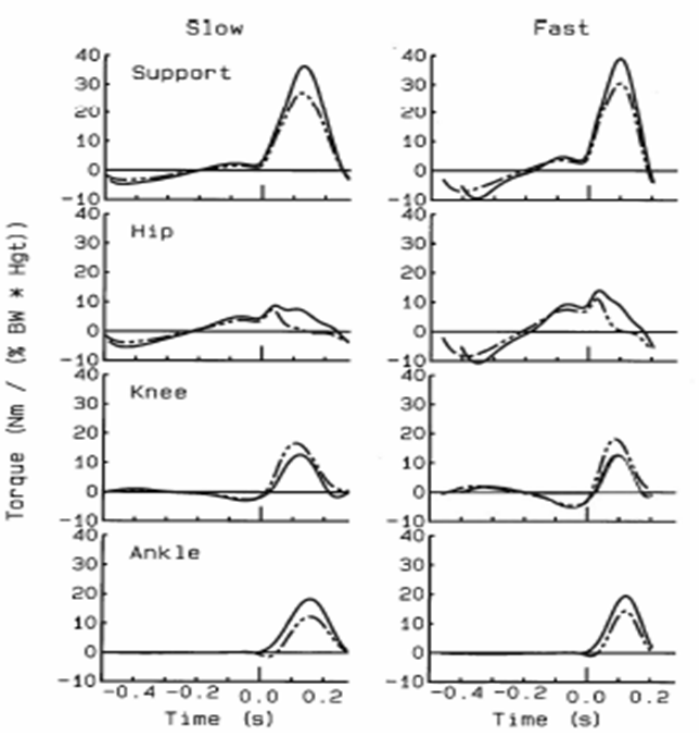

Figure 4- . Mean joint torque curves for incline vs. decline running. Solid lines represents incline running while dashed lines represents decline running.

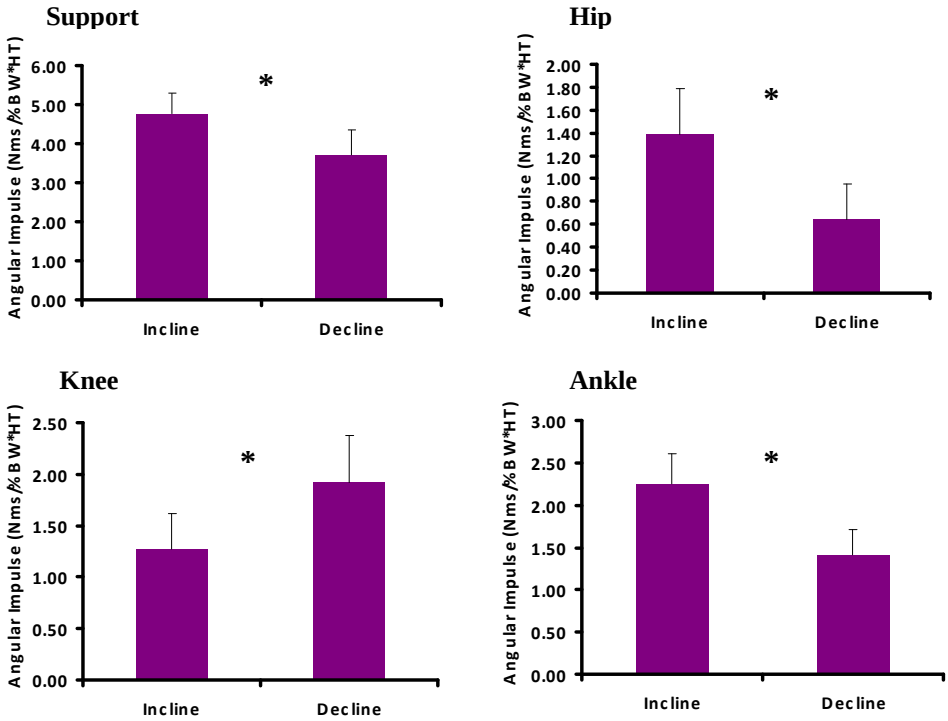

Figure 5- . Support and individual joint extensor angular impulses. * denotes significant difference, p< 0.05.

Hip

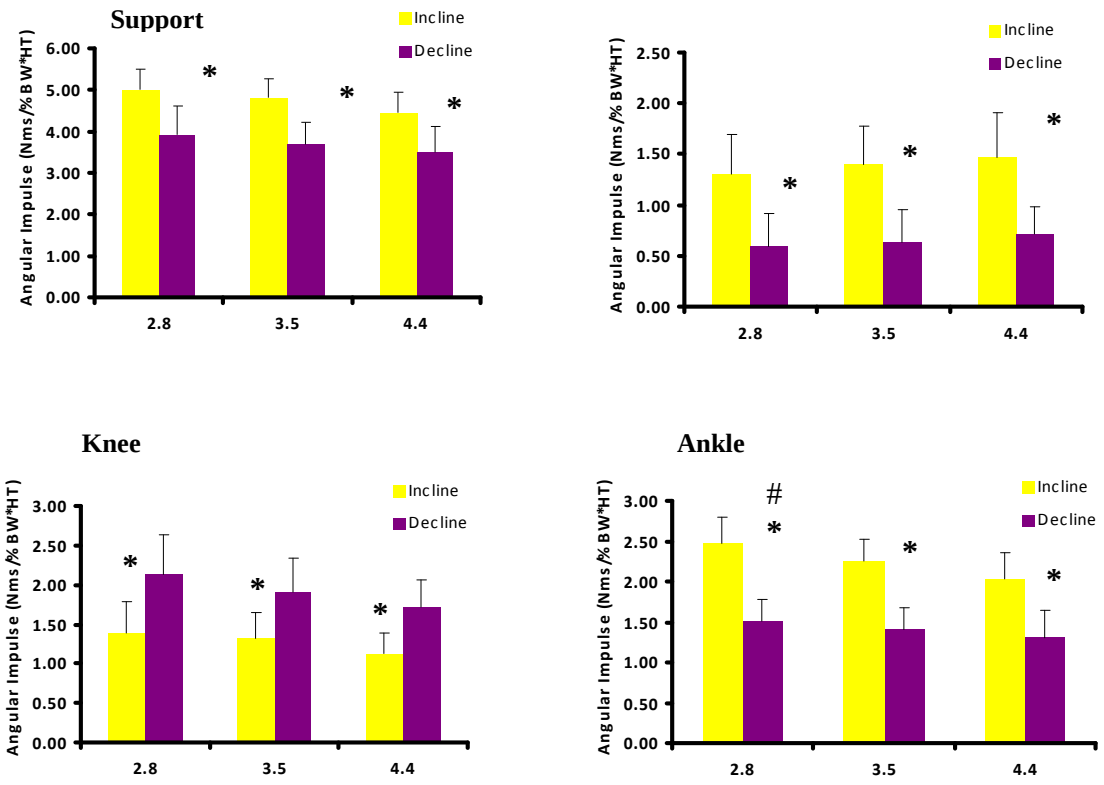

Figure 6- . Support and individual joint extensor angular impulse. * and # denote significant differences and interaction, p< 0.05.

Joint Powers during Incline and Decline Running

Average sagittal plane joint power curves for slow and fast speeds during incline and decline running are shown in figure 7, total three dimensional net work and net work at each joint for incline and decline running are shown in figure 8, three dimensional net work at each joint and running speed are shown for incline and decline running in figure 9 (absolute values for the ankle), and total three dimensional net work (in absolute values) for each direction and speed are shown in figure 10.

Two major power phases, negative power and positive power, were observed in both incline and decline running during the stance phase at each speed (Figure 7). Negative vs. positive power was however larger in the decline conditions whereas

positive vs. negative power was larger in the incline conditions. Hip power was generally positive in both gait directions whereas knee power was generally negative in both gait directions. Similar negative and positive power bursts were seen at the ankle in decline running whereas the positive ankle bursts were larger than the negative bursts in incline running.

Maximum negative power in the sagittal plane was found to be 3.63 times larger in decline vs. incline while maximum negative power increased by 19% during decline conditions from slow to fast speeds but was not found to be significant. A significant interaction effect, however, was found between direction and speed for maximum negative power ($p<0.001$). Maximum positive power increased in both decline and incline running by an average of 34% from slow to fast speeds ($p<0.001$). This increase is partly due to an increase in peak positive power at the ankle but mainly due to the 107% and 109% increases in hip maximum positive power found during incline and decline running, respectively (both, $p<0.001$).

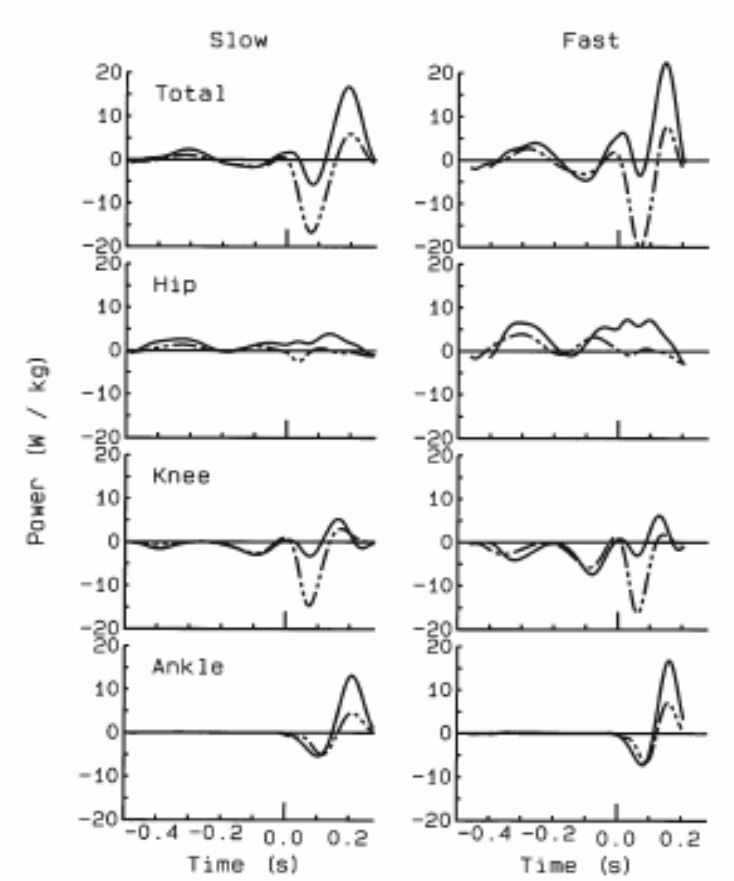

Figure 7- . Mean joint power curves for incline vs. decline running. Solid lines represents incline running while dashed lines represent decline running.

Total magnitude of the summed three dimensional muscle work for both the swing and stance phases (Figure 8) was 36% higher in incline running compared to that of decline running ($p<0.001$). The type of net muscle work found at the hip for both incline and decline running was positive, however, incline running was 6.3 times larger compared to that of decline running ($p<0.001$). Net muscle work at the knee was negative in both incline and decline running and the amount of negative work was 2.43 times larger in decline running ($p<0.001$). Ankle work was positive in incline and negative in decline running however the magnitude of the positive work was 419% larger ($p<0.001$). Significant interactions ($p<0.001$) in joint work were observed at the hip and ankle (figure 9).

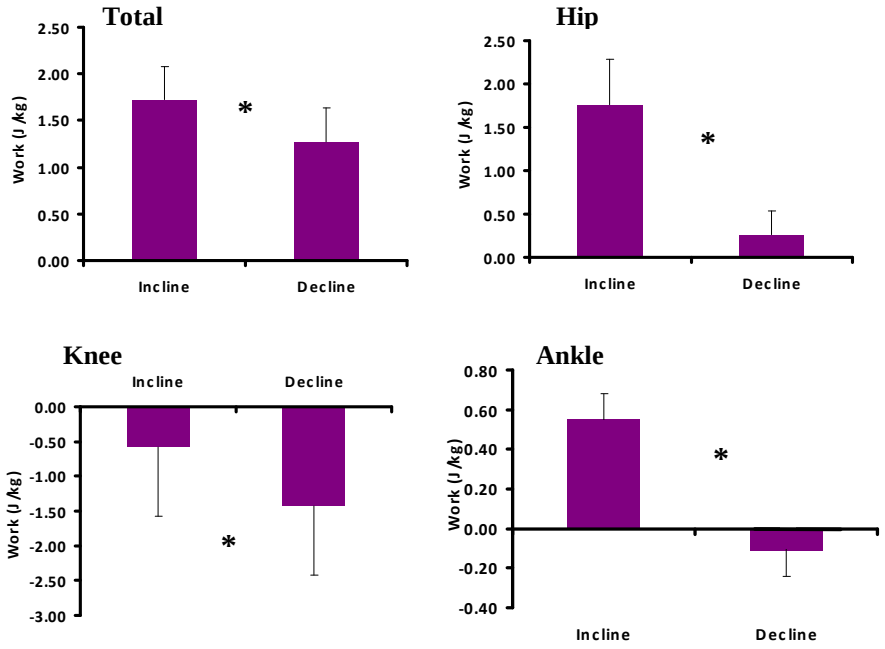

Figure 8- . Mean total and joint muscle work for incline and decline running. Significant differences were found between total muscle work and across all joints. * denotes significant difference using p< 0.001.

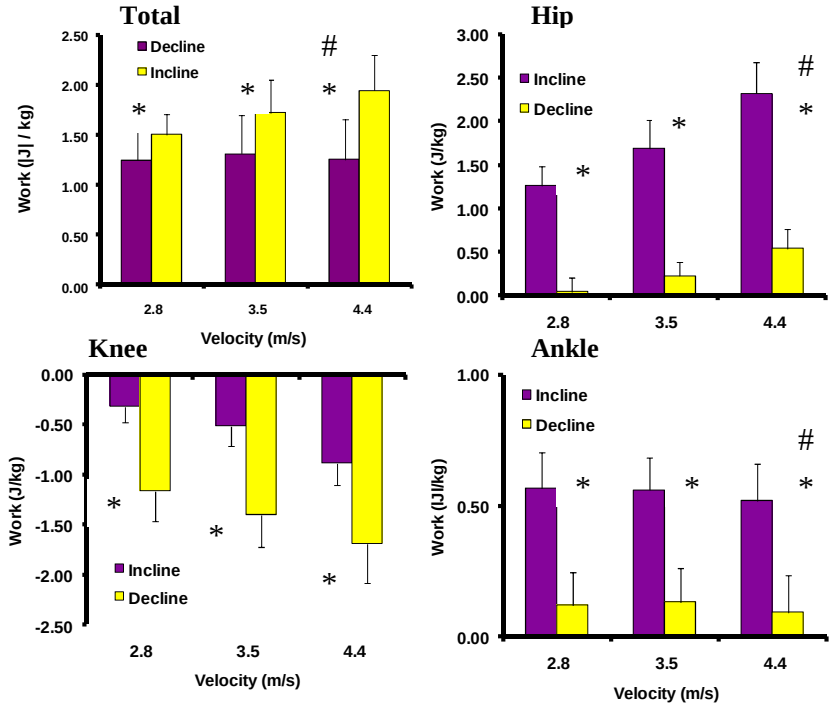

Figure 9- . Mean total and joint positive and negative muscle work for incline vs. decline running at three speeds. * and # denote significant differences and interaction, p< 0.05.

The major finding from this study (figure 10), was that incline running had 36% more net muscle work compared to decline running ($p<0.001$). Additionally, there was a significant interaction effect between gait direction and running speed such that the difference between positive and negative work increased with running speed ($p<0.001$). Figure 10 shows that net muscle work increased with speed in incline running but remained relatively constant with speed in decline running. Most of the increase in total net muscle work during incline running with speed was derived from an 84% increase ($p<0.001$) in total positive muscle work at the hip (figure 10).

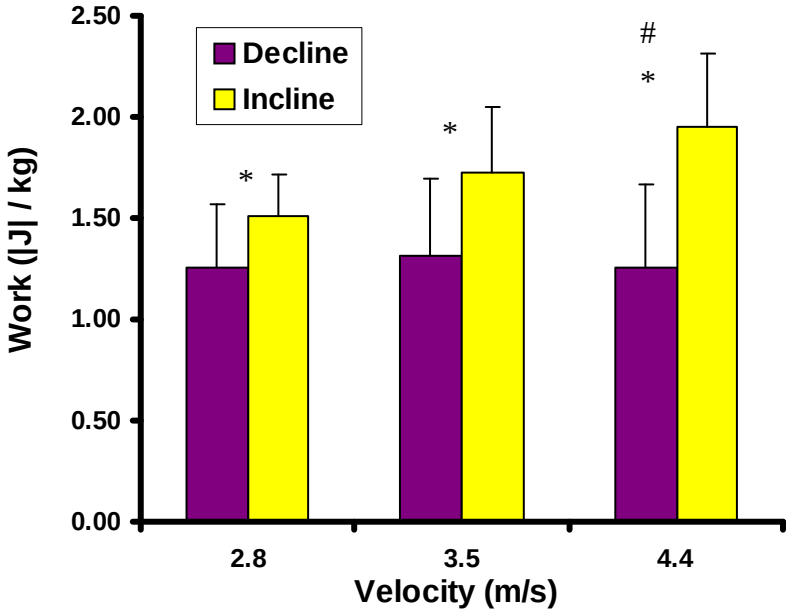

Figure 10- . Total muscle work (absolute values) in incline and decline running at three speeds. More muscle work was observed in incline vs. decline and the difference in the amount of muscle work between incline and decline increased as speed increased. The amount of positive muscle work during incline running at the fastest running speed was found to be significantly higher than compared to the slowest speed. * and # denote significant differences and interaction, p< 0.001.

Summary

Incline running is associated with large mechanical output of the hip and ankle musculature while decline running is controlled mainly by the knee extensor muscles. As

speed increased, the mechanical demand of the hip extensor muscles increased with decreases at the other joints. Total absolute muscle work was higher in incline vs. decline running and as speed increased the difference in muscle work between incline and decline running became larger.

Discussion

This study was designed with the purpose of comparing positive and negative muscle work produced during incline and decline running at three speeds in healthy young adults. This purpose was developed from the hypothesis that muscles generate more mechanical energy in gait tasks that raise the center of mass compared to the amount of mechanical energy dissipated by muscles in gait tasks that lower the center of mass. An interaction effect between gait direction and running speed was expected for net muscle work in that the difference between positive and negative work would increase with faster running speeds.

Three-dimensional gait analysis of incline and decline running was performed to compare the kinetic and energetic differences between these two running conditions at speeds of 2.68 m/s, 3.35 m/s, and 4.47 m/s. The results from this comparison will be related to the literature and hypothesis by discussing the following topics: 1) Development of the Hypothesis, 2) Causes of Muscle Work Discrepancy, 3) Clinical Relevance, 4) Summary and Conclusions, and 5) Future Recommendations.

Development of the Hypothesis

Previous research has shown that both positive and negative mechanical energy of the body in level gait tasks is generated and dissipated an equal amount (Laursen, 2003; Minetti, 1993). This is due to the fact that the body's center of mass is raised and lowered an equal amount throughout the stride cycle under constant average velocity. In gait tasks where the body's center of mass is primarily raised (incline running) potential energy of the body is increased causing gains in total mechanical energy. The opposite can be said about gait tasks that lower the center of mass (decline running); where total

mechanical energy of the body is decreased due to the loss of potential energy. The change in mechanical energy of the body is equal in both incline and decline gait tasks if kinetic energy is maintained.

These ideas have led some to wonder how muscles are functioning during these equivalent energy changes of the body in ascending and descending gait tasks. DeVita et al. (2008), explored muscle function during incline and decline running under constant average velocity and showed that there was in fact a bias in muscle function during these gait tasks. DeVita et al. (2008), showed that the amount of energy generated by muscles in incline running was 28% more than the amount dissipated by muscles in decline running. This work by DeVita and others showed that muscle function is biased towards more energy generation than energy dissipation in gaits that raise and lower the body equally.

This work has led to the hypothesis that muscle function is biased in tasks that primarily raise the center of mass compared to tasks that primarily lower the center of mass. The altered muscle function in descending gait could potentially be due to larger ground reaction forces associated with decline running and faster running speeds (Belli, 2002; Gottschall, 2005; Weyand, 2000; Yokozawa, 2004). To test this, kinetic and energetic biomechanical analysis was performed on incline and decline running at three speeds in healthy young adults.

Causes of Muscle Work Discrepancy

Mean positive muscle work was 36% higher in incline running compared to negative muscle work in decline running. This was consistent with previous research that found that muscles generate more energy than they dissipate in non-level and level

locomotive tasks (DeVita et al., 2007, 2008; Elftman., 1966). As speed increased, there was a 29% increase in total net muscle work in incline running. Decline running experienced no significant difference across speed in the amount of total net negative muscle work. These results caused the bias for more positive muscle work in ascent running vs. negative muscle work in descent running to increase as speed increased.

One reason for this bias in muscle work is due to the differences in ground reaction forces seen in incline and decline running. Decline running is associated with higher impact and braking forces while incline running is associated more with propulsive forces. Decline running at all speeds had large impact forces in both the normal and parallel directions and thus also in the resultant force. Incline running in contrast had much lower forces during the first half of stance that were applied at a lower rate. The impact forces found in decline running caused soft tissues to accelerate more, leading to more energy dissipation by the soft tissues rather than from muscle lengthening (DeVita et al., 2008; Pain & Challis, 2001, 2006). With the increase in speed, the contribution of energy dissipation from vibrational motion became larger leading to the discrepancy in muscle work.

A second reason for the discrepancy in muscle work in incline vs. decline running is due to the differences in muscle mechanical advantage at each joint during the running conditions. Roberts et al. (2005), explains that incline running produces more torque and power at the hip and ankle due to the loss of muscle mechanical advantage seen in incline vs. level running. In decline running, the ground reaction forces are higher but operate at smaller moment arms reducing the load on skeletal muscles (DeVita, 2008). The perpendicular distance from the ground reaction force to the hip and ankle joint centers in

decline running provides a favorable muscle mechanical advantage and reduces the amount of both joint torque and power needed by the lower extremity musculature in order to perform decline running.

The increase in running speed caused a 36% increase in positive muscle work during incline running. In contrast, decline running experienced no change in negative muscle work with the speed increase. This was due in part to the mean stride lengths associated with faster running speeds in both incline and decline running, with decline running having the longest strides. The increase in stride length in decline running can be interpreted to mean that the runners in this study fell through the air as projectiles further compared to incline running (DeVita, 2008). DeVita et al. (2008), explains that 77% of the vertical displacement, during the stance phase, of the body's center of mass in incline running is due to concentric contractions. In decline running, only 65% of the vertical displacement is due to eccentric contractions during the stance phase. The decline running stance phases limit the power and work that can be dissipated by activated muscles compared to incline running (DeVita, 2008). Additionally, the longer airborne phases in decline running lead to the larger ground reaction impacts and their resultant accelerations of soft tissues as described above.

The results of this work show that muscles produce and dissipate work differently during differing gait tasks. Several reasons for the difference in muscle work have been identified which include: increased vibrational motion of soft tissues due to larger ground reaction forces in decline running, poorer mechanical advantage in incline running causing more power and work to be produced, especially at the hip, to execute the task, and longer stride lengths in decline running cause the runner to fall further and have less

active vertical displacement during the stance phase. The data of the present study support the hypothesis that skeletal muscles generate more mechanical energy in gait tasks that raise the center of mass compared to mechanical energy dissipated by muscles in gait tasks that lower the center of mass

Clinical Relevance

This work provides valuable insights on muscle function during incline and decline running. Specifically, all three lower extremity joints were examined to see how they produce both torque and power during differing running conditions. This information may lead to improvements in the treatment of clinical conditions or in training protocols for performance improvements. For example, these data suggest the use of incline running as a mode of rehabilitation for certain lower extremity pathologies, human movement musculoskeletal modeling, and powered prosthetic design.

The data presented earlier shows that the hip is the prime forward mover in incline running and both torque and power requirements are increased at the hip with the increase in speed during incline running. These results were consistent with previous literature by Roberts et al. (2005) and DeVita et al. (2007, 2008). Clinicians could use this information to rehabilitate certain knee and ankle pathologies due to the increased demand of the hip musculature with the decrease, especially at the knee, at the other joints. Incline running also provides cardiovascular benefits due to the increase demand in oxygen consumption needed to perform the task (Pivarnik, 2000). In decline running the torque, power and work requirements at the knee are increased compared to incline and level running. Therefore, decline running might be considered a contraindication for runners with knee pathologies.

Musculoskeletal modeling programs are being developed to simulate human movement and to treat various pathologic gait problems with a non-invasive approach. These programs model muscles' origin, insertion, and activation patterns. This technique is used to "treat" pathologic gait problems found in, for example, cerebral palsy. The work presented in this study shows the developers of these models how muscles function during incline and decline gait tasks. This work could be used to create more reliable and accurate models of human movement to better treat patients.

Prosthetic designers and other researchers benefit by this thesis because of the significant insights into muscle function this work is able to provide. In the data presented above, conclusions can be made about how both the muscle and tendon generate and dissipate energy as a single entity. Recently, several researchers have examined powered prosthetic designs for human locomotion. Specifically, Sawicki et al. (2008), have used powered ankle plantar-flexors to alter mechanical power output of the ankle plantar-flexor muscles. Sawicki and colleagues were able to tease out work done by muscles to power a pneumatic ankle-foot orthosis. The work provided by thesis helps prosthetic designers better adapt their powered prosthetics to actual musculoskeletal function.

Future Recommendations

Decline running is associated with higher ground reaction forces compared to incline running causing soft tissues to accelerate more. The acceleration of these soft tissues dissipates energy during the decline running conditions. In future research, obese populations (BMI > 30 kg/m^2), who have more soft tissue, could be tested during non-

level gait to see how they compare to the healthy, recreational runners that participated in this study.

The work presented in this thesis was limited to a single right limb of the lower extremity. Arm swing mechanics were not examined in the present study and conclusions about what role the arms might play in energy generation and dissipation of the body cannot be concluded from this study. Previous work has shown that work done by swinging arms during level walking and running was relatively balanced between positive and negative work (Willems, 1995). DeVita et al. (2007) conjectured that this balance between positive and negative work done by swinging arms would essentially cancel one another out and therefore would not contribute to the discrepancy found in the present study. Willems et al.'s work, however, was limited to level walking and running and one might expect higher energy generation and dissipation requirements by arms during non-level running, especially as speeds increase. Future research could examine how arms add and dissipate energy during non-level running at various speeds.

Summary and Conclusions

Total mechanical energy of the body is raised and lowered an equal amount during level walking and running under constant kinetic energy (Laursen, 2000; Minetti, 1993). As slope changes, under constant kinetic energy, from level to incline or decline, total mechanical energy of the body is either primarily raised or lowered, respectively, during walking or running (Laursen, 2000; Minetti, 1993). Muscles function to add energy to the body through concentric contractions during incline running and help to dissipate energy of the body through eccentric contraction during decline running (Elftman, 1966).

Decline running is associated with higher ground reaction forces compared to incline running. This higher external load causes tissues of the body to accelerate more in decline vs incline running helping to dissipate energy (DeVita, 2008). These tissues of the body are recognized as subcutaneous fat, the muscle bellies throughout the body, organs and other soft tissues in the trunk, and cartilage found in the knee. When runners run down a decline surface at increasing speeds, high external loads cause these soft tissues to dissipate more energy.

When comparing the amount of muscle work performed by the lower extremity musculature during incline and decline running, one can see that muscles function in a more active role, through shortening or concentric contractions, during incline running to produce more net muscle work compared to decline running. With increasing speed the difference between the amount of muscle work produced during incline running vs. the amount of muscle work dissipated during decline running becomes larger. This has led to the conclusion that the hypothesis that skeletal muscles generate more mechanical energy in gait tasks that raise the center of mass compared to mechanical energy dissipated by muscles in gait tasks that lower the center of mass, was in fact supported by the data presented in this thesis. It can also be concluded that gait tasks with seemingly higher ground reaction forces, such as decline vs. incline or fast vs. slow running, will cause a larger bias in positive compared to negative muscle work.

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Appendix A

University and Medical Center Institutional Review Board
East Carolina University
Ed Warren Life Sciences Building • 600 Moye Boulevard • LSB 104 • Greenville, NC 27834
Office **252-744-2914** • Fax **252-744-2284** • **www.ecu.edu/irb**
Chair and Director of Biomedical IRB: Charles W. Daeschner, III, MD
Chair and Director of Behavioral and Social Science IRB: Susan L. McCammon, PhD

TO: Paul De Vita, PhD, Dept of Exercise and Sport Science, ECU

FROM: UMCIRB

DATE: May 23, 2007

RE: Expedited Continuing Review of a Research Study

TITLE: "Biomechanics of ascending and descending gait"

UMCIRB #05-0468

The above referenced research study was initially reviewed and approved by expedited review on 09-28-05. This research study has undergone a subsequent continuing review using expedited review on 05-23-07. This research study is eligible for expedited review because collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.) Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subject's privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual; and collection of data from voice, video, digital, or image recordings made for research purposes. Dr. S. McCammon deemed this **unfunded** study **no more than minimal risk** requiring a continuing review in **12 months**. Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The investigator must adhere to all reporting requirements for this study.

The above referenced research study has been given approval for the period of **05-23-07** to **05-22-08**. The approval includes the following items:

- Continuing Review Form dated 05-15-07
- Consent Document (no version date)

Dr. S. McCammon does not have a conflict of interest on this study.

The UMCIRB applies 45 CFR 46, Subparts A-D, to all research reviewed by the UMCIRB regardless of the funding source. 21 CFR 50 and 21 CFR 56 are applied to all research studies under the Food and Drug Administration regulation. The UMCIRB follows applicable International Conference on Harmonisation Good Clinical Practice guidelines.

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Chair and Director of Biomedical IRB: L. Wiley Nifong, MD
Chair and Director of Behavioral and Social Science IRB: Susan L. McCammon, PhD

TO: Paul DeViita, PhD, Dept of EXSS, 332 Ward Sports Medicine Building, ECU

FROM: UMCIRB KK

DATE: April 17, 2008

RE: Expedited Continuing Review of a Research Study

TITLE: "Biomechanics of Ascending and Descending Gait"

UMCIRB # 05-0468

The above referenced research study was initially reviewed and approved by expedited review on 9.28.05. This research study has undergone a subsequent continuing review using expedited review on 4.14.08. This research study is eligible for expedited review because it is on collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.) Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subject's privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual. It is also on collection of data from voice, video, digital, or image recordings made for research purposes.
Dr. S. McCammon deemed this **unfunded** study **no more than minimal risk** requiring a continuing review in **12 months**. Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The investigator must adhere to all reporting requirements for this study.
The above referenced research study has been given approval for the period of **4.14.08** to **4.13.09**. The approval includes the following items:

- Continuing Review Form
- Protocol Summary
- Informed Consent Form

Dr. S. McCammon does not have a conflict of interest on this study.

The UMCIRB applies 45 CFR 46, Subparts A-D, to all research reviewed by the UMCIRB regardless of the funding source. 21 CFR 50 and 21 CFR 56 are applied to all research studies under the Food and Drug Administration regulation. The UMCIRB follows applicable International Conference on Harmonisation Good Clinical Practice guidelines.

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Chair and Director of Behavioral and Social Science IRB: Susan L. McCammon, PhD

TO: Paul DeVita, PhD, Dept of EXSS, ECU—332 Ward Sports Medicine Building

FROM: UMCIRB

DATE: April 6, 2009

RE: Expedited Continuing Review of a Research Study

TITLE: "Biomechanics of Ascending and Descending Gait"

UMCIRB #05-0468

The above referenced research study was initially reviewed and approved by expedited review on 9.28.05. This research study has undergone a subsequent continuing review using expedited review on 4.1.09. This research study is eligible for expedited review because it is on collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.) Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subject's privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual. It is also a study on collection of data from voice, video, digital, or image recordings made for research purposes.

The Chairperson (or designee) deemed this **unfunded** study **no more than minimal risk** requiring a continuing review in **12 months**. Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The investigator must adhere to all reporting requirements for this study.

The above referenced research study has been given approval for the period of **4.1.09** to **3.31.10**. The approval includes the following items:

- Continuing Review Form (dated 3.27.09)
- Protocol Summary
- Informed Consent (received 3.31.09)

The Chairperson (or designee) does not have a conflict of interest on this study.

The UMCIRB applies 45 CFR 46, Subparts A-D, to all research reviewed by the UMCIRB regardless of the funding source. 21 CFR 50 and 21 CFR 56 are applied to all research studies under the Food and Drug Administration regulation. The UMCIRB follows applicable International Conference on Harmonisation Good Clinical Practice guidelines.

Appendix B

Informed Consent Form
Walking and Running on Ramps

Principal Investigator: Paul DeVita, Ph.D.
Institution: East Carolina University
Address: Dept. of Exercise and Sport Science
Telephone #: 252 - 737 - 4563

INTRODUCTION:

I have been asked to participate in a research study being conducted by Paul DeVita, Ph.D. The purpose of this study is to examine the how people walk and run on level surfaces and on ramps.

PLANS AND PROCEDURES

1) I will participate in an interview to determine whether I am eligible for the study. I understand that I cannot participate if I: 1) have a medical condition that precludes safe participation (e.g. heart disease, stroke, insulin dependent diabetes, osteoporosis), 2) have a recent (last 6 months) injury to the lower extremity; 3) have a history of recurrent injury to the lower extremity.

2) I will be tested once. All data will be collected and analyzed in the Biomechanics Lab, room 332 Ward Sports Medicine Building, ECU.

I will be tested while wearing athletic shoes, a t-shirt, shorts and an athletic bra or tight fitting shirt. My height and weight will be measured, and reflective markers will be placed on my right leg and on my pelvis. I will perform 5 trials at each of the conditions, walking, ascending and descending, while being recorded with a high-speed motion camera. I will also be connected to an EMG machine to collect data describing my muscle activations during the trials.

3) I understand that the instruments include a motion analysis system to record how I walk and run, a force platform to measure the forces between my foot and the floor, and an electromyography (EMG) system to measure my muscle activity. The force platform is a metal plate lying flush with the floor and walking or running on it will feel like a regular walking and running The EMG system will have surface electrodes taped to my skin and a waist-pack transmitter. The EMG system will not affect my movements and is safe and non-invasive.

4) I will be allowed to rest any time I feel tired or have pain during the testing session.

5) I understand that I can quit the testing sessions without any penalty or repercussions.

RISKS AND DISCOMFORTS

A few possible risks are involved in this study. Because this project involves physical activity, there is always the risk of injury. I will be required to walk and run on level ground and up and down a ramp of varying slopes. I may feel some fatigue or pain within 24-48 hours after the test. However, my experience running may eliminate any discomfort.

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I also understand that if I feel pain or fatigue, I will be allowed to rest until the pain has subsided. If the pain does not subside I can stop the testing until I feel better. One or more research assistants will always be present during all testing.

POTENTIAL BENEFITS
The benefits of this project far outweigh the risks. Overall from this study, we expect to better understand the biomechanics of gait during flat, ascending and descending walking and running. Future research from the ECU Lab will build on these results. It is expected that the research will be disseminated in the biomedical research literature. These data will contribute to our knowledge base on human locomotion.

TERMINATION OF PARTICIPATION
My participation in this research may be terminated without my consent if I become injured during the study.

COSTS AND COMPENSATION
I will not be compensated for my participation in the study. The policy of East Carolina University does not provide for compensation or medical treatment for subjects because of physical or other injury resulting from this research activity. However, every effort will be made to make the facilities of the School of Medicine available for treatment in the event of such physical injury.

CONFIDENTIALITY
I understand that my personal data will be held in strict confidence by the researchers and that a code name will be used to identify my data. I understand that my name will never be associated with any of the data or results in any public presentation or publication of this study. All data and records will be stored in the Biomechanics Laboratory, room 332 Ward Sports Medicine Building. Dr. DeVita and his research assistants will have access to the data. After the study is completed the data will be permanently stored in the Biomechanics Laboratory.

Video excerpts and/or still photographs from recordings created during research are sometimes used in research presentations or publications, and/or for educational purposes such as a classroom lecture. I MAY INDICATE NOW THAT I DO NOT WISH FOR MY DATA TO BE USED FOR OTHER RESEARCH OR EDUCATION PURPOSES OTHER THAN DATA COLLECTION BY INITIALIZING HERE _____.

If you deny permission to use the recording for research or educational purposes, the tape will be used only for analysis, and will be destroyed at the end of the research study.

VOLUNTARY PARTICIPATION
I understand that my participation in this study is voluntary. Refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled. Furthermore, I may stop participating at any time I choose without penalty, loss of benefits, or without jeopardizing my continuing medical care at this institution.

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PERSONS TO CONTACT WITH QUESTIONS
The investigators will be available to answer any questions concerning this research, now or in the future. I may contact the investigator, Paul DeVita (phone: 252-737-4563, days, or 252-756-8070, nights and weekends). Also, if questions arise about my rights as a research subject, I may contact the Chairman of the University and Medical Center Institutional Review Board at phone number 252-744-2914 (days).

CONSENT TO PARTICIPATE
I certify that I have read all of the above, asked questions and received answers concerning areas I do not understand, and have received satisfactory answers to these questions. I willingly give my consent for participation in this research study. (A copy of this consent form will be given to the person signing as the subject or as the subject's authorized representative.)

_____
Subject's Name (Print)

_____
Signature of Subject (date)

AUDITOR WITNESS: I confirm that the contents of this consent form were orally presented.

_____
Auditor's Name (Print)

_____
Signature of Auditor Witness (date)

_____
Principal Investigator's Name (Print)

_____
Signature of Principal Investigator (date)