CHANGES IN BONE MINERAL DENSITY OF COLLEGIATE MIDDLE DISTANCE
AND LONG DISTANCE RUNNERS ACROSS AN INDOOR SEASON

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CHANGES IN BONE MINERAL DENSITY OF COLLEGIATE MIDDLE DISTANCE AND LONG DISTANCE RUNNERS ACROSS AN INDOOR SEASON

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Thesis

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ABSTRACT

Bone mineral density (BMD) is an important aspect of bone health in endurance runners. Musculoskeletal overuse injuries to the bone, such as stress reactions and stress fractures, are of major concern to endurance runners and coaches because of the debilitating nature they have on training and performance. It is possible that a greater understanding of BMD in these athletes can lead to a reduction in stress injuries to bone. The purpose of this study was to determine if BMD in certain anatomical regions, especially that of the lower appendicular skeleton, changed over the course of an indoor track season and if there was any significant difference between middle distance and distance runners. Participants were scanned for BMD estimates before the start of the indoor track and field season and after the indoor track and field season. On both testing days they were asked to complete a questionnaire through which they self-identified into either a middle distance or long distance group and also through which they provided any recent history of musculoskeletal injuries. Among the BMD measure comparisons, it was found that a statistically significant difference (p < 0.05) existed between middle distance and long distance runners when comparing pre-season to post-season changes of BMD in the legs. Additionally, the difference between pre-season and post-season values of total body BMD for male middle distance runners (p < 0.01) and the difference between pre-season and post-season values of leg BMD for male middle distance runners (p < 0.05) were both significant. Finally, statistically significant differences were found (p < 0.05) between the pre-season and post-season total body BMD values for female middle
distance runners and statistically significant differences were found (p < 0.05) between the pre-season and post-season pelvis BMD values for female long distance runners. These statistical findings may not translate directly into practical application, but given the nature of the potentially precarious balance between the microstrain placed on bone and bone remodeling during a following endurance running, these results should at least be scrutinized closely.
ACKNOWLEDGEMENTS

Firstly I would like to express my deepest thanks to the endurance runners of the University of Akron’s Track and Field team for their willing participation in this study. Furthermore, the willingness and helpfulness of the coaches in allowing their athletes to partake is greatly appreciated. Also, the task of scheduling testing dates and times went smoothly thanks to the coaches.

I would also like to recognize the School of Sports Science and Wellness Education at The University of Akron for allowing testing to take place in their facilities and also for their help and advice during the entire research process, including the development of this manuscript. Specifically, I would like to thanks the Committee Chair and Committee members for their insight and revisions: Dr. Ronald Otterstetter, Dr. Laura Richardson, Dr. Matthew Juravich, and Mrs. Michelle Boltz.
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CHAPTER I
INTRODUCTION

Low bone density has been found to be a risk factor for stress fractures in multiple populations; distance runners included (Kelsey et al., 2007; Lauder et al., 2000). Additionally, it has been suggested that track and field athletes in particular experience a high incidence rate of stress fractures annually and the tibia has been shown to be the bone at which most stress injuries occur in runners (Bennell et al., 1996). Endurance running is a mechanical activity which produces load on the bone. Bone formation occurs in accordance with the overload principle. When stress is applied to bone in the form of mechanical loading, and when sufficient rest is allowed afterwards, new formation occurs and the bone becomes stronger. If the bone formation process is hindered and one continues to train, they are at risk for bone overuse injuries, namely stress fractures. Stress fractures are of great concern to athletes and coaches because of the debilitating effect they have on training and racing.

A difference may exist in BMD values of middle-distance runners compared to longer distance runners. Training modalities for longer distance runners usually correspond to longer duration workouts where frequency of bone loading is high but maximum strain is relatively low. In contrast, training modalities for middle distance runners usually correspond to workouts in which the frequency of bone loading is relatively low but where force production and strain are high. Multiple studies have
concluded that activities which require higher strain magnitudes result in higher BMD whereas activities which require more repetitive loading, even at lower strain magnitudes, shows less propensity for increased BMD (Bennel et al., 1997; Fredericson et al., 2007).

This research was attempting to determine if the BMD in long distance runners (3k-5k) will experience more deleterious effects when compared to middle distance runners (800-1500). It is theorized that differences could be due to the mechanical loading differences in strain and frequency between longer distance runners and middle distance runners.
CHAPTER II

REVIEW OF LITERATURE

Middle distance and distance runners undertake training which, by nature, places varying amount of stress on their bones, especially of the lower appendages. It was long ago suggested by the early anatomist Wolff, and has since been universally accepted, that mechanical loading of bone produces a stimulus which leads to structural adaptation within certain boundaries and limits. Recently, multiple studies have attempted to expound upon this idea often referred to as Wolff’s Law. There are many measures which have been used to assess the quality and integrity of bone. These measures might take into account, among other things, the shape and geometry of the bone, the volume of bone mineral content, the BMD, and the polar moment of resistance.

In one study, the authors set out to determine the differences in bone characteristics and quality between athletes whose sports require frequent mechanical loading and those who do not (Schipilow et al., 2013). They found that when adjusting for age and body characteristics, athletes who participated in alpine skiing and soccer showed much greater bone quality, bone strength, and higher failure loads at the loaded tibia when compared to swimmers and controls. They concluded that impact loading is a major predictor in bone quality. Similarly, Bennell et al. (1997) found in their 12 month longitudinal study that both power track athletes, those participating in sprinting and jumping, as well as endurance athletes had higher BMD values in lower limb sites when compared to controls. They proposed that due to the magnitude of strain
required in sprinting, jumping, and running, bone formation is triggered, leading to increased BMD at those sites nearest the mechanical load. In a study specifically comparing distance runners to controls in terms of bone strength and favorable bone geometry, it was found that female runners had much greater estimated tibia bone strength of 17-19\% (Smock et al., 2009). In the same study, male runners showed no greater tibia bone strength when compared to controls but they did show favorable bone geometry. This led the authors to conclude that running possibly elicits favorable bone adaptations over time.

While high impact activities, such as those mentioned above, do seemingly trigger a bone formation response there still exists a large incidence of lower limb musculoskeletal injuries in athletic populations with a large number of these injuries being overuse injuries to bone. Bennell et al. (1996) found that 28.9\% of all lower limb musculoskeletal injuries were categorized as stress fractures in their 12-month study of track and field athletes. In a retrospective study of college athletes over a ten year period at the University of Minnesota, Arendt et al. (2003) found that lower limb stress injuries for both males and females were more common among distance runners than any other sport. In a study which set out to measure bone turnover via biomechanical markers in track and field athletes who belonged to a Victorian athletics club, there was a 21.1\% incidence of stress fracture over the 12-month study period (Bennell et al., 1998).

The pathophysiology of bone injuries, namely those of stress reactions and stress fractures, has by no means been completely elucidated, but some theories have been put forth. Warden et al. (2006) proposed a theory by which repetitive bone strain, and subsequently microdamage, may eventually create an imbalance between said strain and
the remodeling mechanism which bone goes through for self-repair. The authors define usual strains as those between 400 and 1500 microstrain whereas they define strains causing complete failure to be 10,000 microstrain. Strain refers to the change in length of a unit of bone. Milgrom et al. (2015) used the concept of strain on the bone in terms of shear forces. They proposed that when microstrain on the tibia reaches beyond a certain threshold the number of loading cycles needed to reduce the fatigue life of the bone decreases because of the increased microdamage to the bone.

There has been a wealth of recent literature devoted to exploring the risk factors associated with stress injuries to bone, especially stress fractures. There does not seem to be agreement in the literature as to a single risk factor which outweighs all others but rather a plethora of risk factors have been studied and addressed. One study broke the risk factors into two major categories: extrinsic risk factors, or factors from the environment, and intrinsic risk factors, or risk factors that are inherent to the individual and how they adapt and respond to the mechanical load of running (Warden et al., 2006). In terms of extrinsic risk factors, the authors focused on type of sport or activity, training program factors, equipment factors and environmental factors. They theorized that participation in almost any sport or activity will at least slightly increase the risk of a stress fracture due to the mechanical loading inherent in most sports. They touched on the fact that both sprinters and distance runners are at heightened risk compared to many other sports, but for somewhat different reasons. Whereas sprinters load with high magnitude strain and rate, distance runners load with a much lower magnitude strain and rate but experience a much higher number of load repetitions.
Other studies have attempted to look for risk factors which may or may not be shared among both males and females. One such study went on to show that the most predictive risk factor for obtaining a stress fracture was the history of a prior stress fracture (Tenforde et al., 2013). They then went on to identify unique risk factors to each sex. While they did not find a difference in the incidence of stress fractures in males and females they did clearly identify major potential differences in the risk factors that lead to said stress fractures. In females they identified low body mass index, late menarche, and prior participation in dance and gymnastics as all being risk factors. Unique to males was that those who had prior participation in basketball were far less likely to obtain a stress fracture. This may indicate not so much that basketball in and of itself is a protector against stress fractures, but rather the movements and patterns required during the game or practice help to inhibit these injuries. This is possibly due to the triggering of the bone remodeling response found in high magnitude strain activities such as jumping. Bennell et al. (1996) also reported on risk factors being different between the two genders. In their study, females who incurred stress fractures had much lower total body bone mineral content, lower BMD in their lumbar spine and foot, a later age of menarche, fewer annual menses since menarche, a diet which is lower in fat, and a discrepancy in the lengths of their legs when compared to those who were not diagnosed with a stress fracture. Interestingly, none of the potential risk factors analyzed for men came out to be predictive of stress fractures. This seems to suggest that risk factors complex in their nature, partly because of their potential interactions and also, likely, because of every individual’s genetic predispositions and tolerances.
One risk factor that has been scrutinized heavily in the literature, especially regarding females, is that of BMD. The reason so much focus has been put on the BMD of female runners may be because it seems to be a greater risk factor compared to males. One study which looked at the bone health of elite male runners showed that there was no negative effect on the BMD due to long distance training, and when compared to non-training controls which were age and BMI matched the runners’ BMD was much higher at loaded sites (Kemmler et al., 2005). More specifically, the authors of this study detected no significant correlation between training distance and bone parameters. This finding was a break from some previous studies which suggested that there was a correlation between training volume and bone parameters. In one such study the results showed that while, once again, endurance trained runners had higher BMD at certain loaded sites when compared to controls, a negative relationship did emerge between total body BMD and training volume (Brahm et al., 1992). They concluded that while some running was better than none in terms of increasing BMD, eventually one could run too much to a point where it became detrimental to BMD. Burrows et al. (2003) also found a negative, statistically significant relationship between the weekly distance run and BMD for the lumbar spine and femoral neck of female distance runners.

As reported previously, Bennell et al. (1996) showed that females who suffered stress fractures in their study showed a lower total body bone mineral content, lumbar spine BMD and foot BMD. Another study which tracked both high school and adult female athletes for over a year seemed to support the findings of Bennell et al. (Kaga et al., 2004). They reported that long distance training, especially in younger, high school aged females, was detrimental to bone health. One reason females may experience greater
disturbances in bone metabolism, and thus BMD, compared to males is because of the way endurance training seems to affect menstruation. Kaga et al. (2004) showed that high school female runners who menstruate regularly have statistically significant higher leg BMD than those who menstruate irregularly and furthermore those who menstruate irregularly have a higher leg BMD than those who do not menstruate at all. Yet another study which looked specifically at amenorrheic runners found that their BMD at multiple sites was significantly lower than that of both a eumenorrhea running group and a control group (Pettersson et al., 1999).

Because BMD seems to be of great importance for female distance runners, and to a lesser extent male distance runners, in not suffering a stress fracture, it is vital to understand potential mechanisms for increasing bone health among these populations. In their review of the literature regarding bone mass and exercise, Guadalupe-Grau et al. (2009) state the following: “Although aerobic exercise and weight-bearing physical activity are important in maintaining overall health and healthy bones, resistance exercise has been shown to have a more potent effect on bone density.” (p. 39) Tsuzuku et al. (2001) concluded that high intensity resistance training leads to increased BMD when compared to controls, whereas low intensity resistance training does not. A study which compared the BMD values of soccer players, runners and controls found that soccer players had statistically significant higher values at the hip and lumbar spine in relation to runners (Fredericson et al., 2007). The authors proposed that due to the high intensity, yet intermittent, nature of movements required during soccer, participants are benefiting by stimulating the proper channels for bone formation. Given review of the previous literature, it is possible that these high magnitude strain movements involved with soccer
are similar to high intensity resistance training and thus similar BMD results are seen.

Yet more evidence for the idea that impact and resistance leads to bone formation comes from Reinking et al. (2015) in which they found that BMD for collegiate swimmers and divers was significantly less than for collegiate field hockey, soccer and cross country/track athletes.

There is evidence to suggest that even within the sport specific discipline of running, there may be differences in bone adaptability. A study comparing power track athletes (ie. jumpers and sprinters) with endurance track athletes found that baseline measures of BMD were similar in lower limb bones but different at the lumbar spine, with the power athletes possessing greater BMD (Bennell et al., 1997). Furthermore, they found that over the course of 12 months, the power athletes experienced BMD increases at the lumbar spine site whereas the endurance runners did not. Wilks et al. (2009) looked narrowly at racing athletes whose speed required during racing fell on a continuum, of sorts, from faster to slower: sprinters, middle distance runners, long distance runners, race walkers. Within this study they also had a control group and attempted to delineate any differences in bone mass and geometry among these groups. The greatest differences in bone geometry measures were between sprinters and controls, and the least differences were found when comparing race walkers and controls. Furthermore, it was shown that cortical BMD of the tibia decreased as one went from sprinters down to race walkers. Put in another way, BMD decreased as training volume increased. This makes it seem very possible that increased strain magnitudes and decreased loading cycles lead to the best environment for bone formation and osteogenesis.
CHAPTER III
METHODS

Overuse injuries such as stress reactions and stress fractures are a huge concern to endurance athletes and their respective coaches at all levels. This concern is especially intensified once runners reach the collegiate level and beyond. The nature and structure of training for endurance runners at the higher levels of cross country and track are such that the likelihood of developing these types of injuries is increased. Furthermore, the debilitating nature of a stress fracture usually leads to a disruption in training which puts the fitness of the individual at great risk and often leads to decreased performance. Because of the magnitude of the effect stress fractures have on training and competing, an understanding of potential risk factors is necessary.

Decreased BMD is one measurable anatomical characteristic that has been categorized as a risk factor for stress fractures (Bennell et al., 1996; Pettersson et al., 1999; Kaga et al., 2004). While there has been vacillation in the literature as to the extent of the role BMD plays in determining stress fracture susceptibility, the differences which may exist between male and female endurance runners, and the differences which may exist between maturing and adult endurance runners, there nevertheless seems to be a link between the two: BMD and stress fractures.

It has been shown in multiple studies that activities requiring impact and mechanical loading of the bone induce bone formation (Bennell et al., 1997; Reinking et al., 2015; Schipilow et al., 2013). Smock et al. (2009) showed that running, specifically,
seems to lead to increased bone formation and BMD over time. The process of bone formation, however, can also be thought of as a risk due to the fact that the formation is not triggered without microtrauma. Over time, without enough rest the adaptability of the bone is potentially diminished and an imbalance can occur between microtrauma and bone formation, leading to stress injury (Warden et al., 2006). Bennell et al. (1997) and Tsuzuku et al. (2001) surmised that the higher resistance, higher strain activities did more for bone health than lower resistance, lower strain activities.

When looking at BMD of different athletic populations, endurance runners are usually grouped together as one with no divider being set between middle distance runners and long distance runners. While on the surface these two disciplines may seem nearly identical, the training can be quite different due to the energetic demands of the races in which each respective group runs. A long distance runner quite possibly trains at a lower intensity but for a longer time whereas a middle distance runner might train at a higher intensity but for a shorter time. A novel study by Wilks et al. (2009) broke their subjects into groups along a continuum of speed: sprinters, middle distance runners, long distance runners and race walkers. They came to the conclusion that the more volume required for training purposes, the less advantageous for bone health. The research question of this study being investigated continued along that line of thought in that middle distance runners will show greater bone health, primarily at loaded sites, as evidenced by BMD values, when compared to long distance runners. Specifically, it is proposed that long distance runners will experience more deleterious effects over the course of a competitive season when compared to middle distance runners.
Subjects were recruited from a large, mid-western, division 1 collegiate track team. There were 27 athletes (N=27) who agreed to participate in the study with only 21 subjects (N=21) completing all necessary testing requirements to be included in the results. These subjects, at the start of the study, averaged 20.29 years of age, 174.81 cm in height, 64.00 kg in weight, and 13.17 percent body fat. A more detailed breakdown by gender and training group can be found in Table 1 in the results section. In order to be considered for inclusion, subjects indicated that they planned on competing in the 2016 Indoor Track season in events ranging from the 800m to the 5000m. A complete list of exclusion criteria was provided to the subjects with the Informed Consent Form (Appendix A). Testing took place over a period of 8 weeks in conjunction with the indoor track season. Before any testing took place, subjects signed an Informed Consent document in which they were made aware of the requirements and potential risks and benefits of participating in the research study. The Institutional Review Board at the Office of Research and Services and Sponsored Programs at the University of Akron approved this study.

Initial testing of subjects took place in the Exercise Physiology Laboratory at the university during week one of the study. They were given a questionnaire before testing through which they indicated whether they belonged to the middle distance group or long distance group and whether or not they had suffered any number of musculoskeletal injuries in the past month. A copy of the questionnaire is provided in Appendix B. After completing the questionnaire, subjects were weighed using a digital medical scale (Doran Scales, Batavia, IL, USA). Subjects’ body composition,
included BMD, was estimated using a GE Prodigy bone densitometer (GE Lunar Corp, Madison, WI, USA). Densitometry procedures took approximately 10 minutes for each subject. Subjects were instructed to remove all jewelry and metals and to lay quietly with arms at their sides on the scanning platform as the scan took place.

Laboratory testing procedures took place for a second time the week immediately following the conclusion of the subjects’ indoor track season. The subjects completed the questionnaire and had their body composition estimated using the same techniques and instruments as were used for their initial testing visit. The purpose of this study was to be observational in nature and thus in no way was the subjects’ training manipulated in any way for purposes of this study between the initial and final round of testing.
CHAPTER IV

RESULTS

The purpose of this research study was to determine if there was a relationship between type of endurance training, middle distance vs. long distance, and the changes in BMD, from the beginning to the end of a competitive season. The BMD values of primary interest were legs and pelvis, with a secondary interest in total body BMD. Statistical analyses were conducted to determine if differences existed between pre-season, post-season, and pre-season to post-season changes of BMD between the two groups, middle distance and long distance runners. Male and female results have been reported separately of one another as the statistical tests were run separately so as not to skew the data for one gender or another.
### Participant Physical Characteristics (Pre-Season)

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Body Fat %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (N=13)</td>
<td>20.46 ± 1.05</td>
<td>179.92 ± 6.38</td>
<td>69.61 ± 6.50</td>
<td>8.69 ± 2.58</td>
</tr>
<tr>
<td>Female (N=8)</td>
<td>20.0 ± 1.20</td>
<td>166.50 ± 3.25</td>
<td>54.83 ± 3.19</td>
<td>20.45 ± 4.13</td>
</tr>
<tr>
<td>Total (N=21)</td>
<td>20.29 ± 1.10</td>
<td>174.81 ± 8.53</td>
<td>64.00 ± 9.11</td>
<td>13.17 ± 6.65</td>
</tr>
<tr>
<td>Female Mid D (N=4)</td>
<td>20.25 ± 1.50</td>
<td>164.25 ± 3.00</td>
<td>53.07 ± 2.16</td>
<td>18.13 ± 4.71</td>
</tr>
<tr>
<td>Female Long D (N=4)</td>
<td>19.75 ± 0.96</td>
<td>168.75 ± 1.5</td>
<td>56.58 ± 3.30</td>
<td>22.78 ± 1.82</td>
</tr>
<tr>
<td>Made Mid D (N=9)</td>
<td>20.67 ± 0.87</td>
<td>178.44 ± 5.57</td>
<td>70.11 ± 7.32</td>
<td>8.22 ± 1.51</td>
</tr>
<tr>
<td>Male Long D (N=4)</td>
<td>20.00 ± 1.41</td>
<td>183.25 ± 7.68</td>
<td>68.49 ± 4.84</td>
<td>9.75 ± 4.29</td>
</tr>
</tbody>
</table>

Note: Values are presented as M ± SD
Table 2

Participant Physical Characteristics (Post-Season)

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age (years)</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Body Fat %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male (N=13)</td>
<td>20.46 ± 1.05</td>
<td>179.92 ± 6.38</td>
<td>70.45 ± 6.55</td>
<td>8.10 ± 2.22</td>
</tr>
<tr>
<td>Female (N=8)</td>
<td>20.0 ± 1.20</td>
<td>166.50 ± 3.25</td>
<td>55.34 ± 2.92</td>
<td>19.88 ± 4.16</td>
</tr>
<tr>
<td>Total (N=21)</td>
<td>20.29 ± 1.10</td>
<td>174.81 ± 8.53</td>
<td>64.69 ± 9.26</td>
<td>12.58 ± 6.66</td>
</tr>
<tr>
<td>Female Mid D (N=4)</td>
<td>20.25 ± 1.50</td>
<td>164.25 ± 3.00</td>
<td>53.64 ± 1.87</td>
<td>17.45 ± 5.37</td>
</tr>
<tr>
<td>Female Long D (N=4)</td>
<td>19.75 ± 0.96</td>
<td>168.75 ± 1.5</td>
<td>57.04 ± 3.40</td>
<td>22.30 ± 1.30</td>
</tr>
<tr>
<td>Made Mid D (N=9)</td>
<td>20.67 ± 0.87</td>
<td>178.44 ± 5.57</td>
<td>70.81 ± 7.22</td>
<td>7.57 ± 1.30</td>
</tr>
<tr>
<td>Male Long D (N=4)</td>
<td>20.00 ± 1.41</td>
<td>183.25 ± 7.68</td>
<td>69.63 ± 5.57</td>
<td>9.25 ± 3.53</td>
</tr>
</tbody>
</table>

Note: Values are presented as M ± SD
Table 3
Comparison of Pre-Season, Post-Season and Seasonal Changes of BMD between female Mid D and Long D runners

<table>
<thead>
<tr>
<th></th>
<th>Female Mid D (N=4)</th>
<th>Female Long D (N=4)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-Season BMD Legs (g/cm²)</td>
<td>1.35 ± 0.03</td>
<td>1.34 ± 0.05</td>
<td>0.751</td>
</tr>
<tr>
<td>Post-Season BMD Legs (g/cm²)</td>
<td>1.36 ± 0.03</td>
<td>1.34 ± 0.06</td>
<td>0.488</td>
</tr>
<tr>
<td>Pre-Post Difference BMD Legs (g/cm²)</td>
<td>0.01 ± 0.02</td>
<td>-0.01 ± 0.02</td>
<td>0.307</td>
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<tr>
<td>Pre-Season BMD Pelvis (g/cm²)</td>
<td>1.24 ± 0.06</td>
<td>1.22 ± 0.07</td>
<td>0.616</td>
</tr>
<tr>
<td>Post-Season BMD Pelvis (g/cm²)</td>
<td>1.25 ± 0.05</td>
<td>1.24 ± 0.08</td>
<td>0.848</td>
</tr>
<tr>
<td>Pre-Post Difference BMD Pelvis (g/cm²)</td>
<td>0.01 ± 0.02</td>
<td>0.03 ± 0.01</td>
<td>0.259</td>
</tr>
<tr>
<td>Pre-Season BMD Tot. Body (g/cm²)</td>
<td>1.19 ± 0.04</td>
<td>1.18 ± 0.03</td>
<td>0.643</td>
</tr>
<tr>
<td>Post-Season BMD Tot. Body (g/cm²)</td>
<td>1.23 ± 0.06</td>
<td>1.20 ± 0.04</td>
<td>0.465</td>
</tr>
<tr>
<td>Pre-Post Difference BMD Tot. Body (g/cm²)</td>
<td>0.03 ± 0.01</td>
<td>0.02 ± 0.01</td>
<td>0.194</td>
</tr>
</tbody>
</table>

Note: Values are presented as M ± SD

Table 3 represents the BMD values of female middle distance and long distance runners for different anatomical regions: total body, legs, and pelvis. Pre-season, post-season and pre-season to post-season changes were recorded for all three regions for both groups. Independent means T-Tests were used to compare each set of corresponding values between middle distance and long distance, female runners. No significant differences were found between the two groups for any of the measures.
Table 4

Comparison of Pre-Season, Post-Season and Seasonal Changes of BMD between Male Mid D and Long D runners

<table>
<thead>
<tr>
<th></th>
<th>Male Mid D</th>
<th>Male Long D</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(N = 9)</td>
<td>(N = 4)</td>
<td></td>
</tr>
<tr>
<td>Pre-Season</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMD Legs (g/cm²)</td>
<td>1.56 ± 0.11</td>
<td>1.48 ± 0.13</td>
<td>0.265</td>
</tr>
<tr>
<td>Post-Season</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMD Legs (g/cm²)</td>
<td>1.54 ± 0.10</td>
<td>1.49 ± 0.14</td>
<td>0.507</td>
</tr>
<tr>
<td>Pre-Post Difference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMD Legs (g/cm²)</td>
<td>-0.02 ± 0.03</td>
<td>0.01 ± 0.02</td>
<td>0.037*</td>
</tr>
<tr>
<td>Pre-Season</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMD Pelvis (g/cm²)</td>
<td>1.33 ± 0.10</td>
<td>1.24 ± 0.12</td>
<td>0.213</td>
</tr>
<tr>
<td>Post-Season</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMD Pelvis (g/cm²)</td>
<td>1.34 ± 0.09</td>
<td>1.23 ± 0.10</td>
<td>0.095</td>
</tr>
<tr>
<td>Pre-Post Difference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMD Pelvis (g/cm²)</td>
<td>0.01 ± 0.03</td>
<td>-0.01 ± 0.03</td>
<td>0.351</td>
</tr>
<tr>
<td>Pre-Season</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMD Tot. Body (g/cm²)</td>
<td>1.29 ± 0.09</td>
<td>1.21 ± 0.09</td>
<td>0.195</td>
</tr>
<tr>
<td>Post-Season</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMD Tot. Body (g/cm²)</td>
<td>1.31 ± 0.09</td>
<td>1.23 ± 0.09</td>
<td>0.171</td>
</tr>
<tr>
<td>Pre-Post Difference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMD Tot. Body (g/cm²)</td>
<td>0.02 ± 0.01</td>
<td>0.02 ± 0.01</td>
<td>0.534</td>
</tr>
</tbody>
</table>

Note: Values are presented as M ± SD
*p < 0.05

Table 4 illustrates the BMD values of male middle distance and long distance runners for different anatomical regions: total body, legs, and pelvis. Pre-season, post-season and pre-season to post-season changes were recorded for all three regions for both groups. Independent means T-Tests were used to compare each set of corresponding values between middle distance and long distance, male runners. A significant difference (p = 0.037) was found between middle distance and long distance runners when comparing...
pre-season to post-season changes of BMD in the legs. All other differences between middle distance and distance runners were not significant.

Table 5

Comparison of Pre-Season to Post-Season BMD Changes among Male Runners

<table>
<thead>
<tr>
<th></th>
<th>Pre-Season BMD</th>
<th>Post Season BMD</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male Mid D Tot Body</td>
<td>1.29 ± 0.09</td>
<td>1.31 ± 0.09</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td></td>
<td>Male Mid D Legs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tot Body (N=9)</td>
<td>1.56 ± 0.11</td>
<td>1.54 ± 0.10</td>
<td>0.022*</td>
</tr>
<tr>
<td>Leg (N=9)</td>
<td>1.33 ± 0.10</td>
<td>1.34 ± 0.09</td>
<td>0.573</td>
</tr>
<tr>
<td>Pelvis (N=9)</td>
<td>1.21 ± 0.09</td>
<td>1.23 ± 0.09</td>
<td>0.087</td>
</tr>
<tr>
<td>Male Long D Tot Body</td>
<td>1.48 ± 0.13</td>
<td>1.49 ± 0.14</td>
<td>0.415</td>
</tr>
<tr>
<td></td>
<td>Leg (N=4)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pelvis (N=4)</td>
<td>1.24 ± 0.12</td>
<td>1.23 ± 0.10</td>
<td>0.488</td>
</tr>
</tbody>
</table>

Note: Values are presented as M ± SD
*p < 0.05, **p < 0.01

Table 5 depicts the pre-season and post-season BMD values of different anatomical regions for middle distance and long distance male runners. Paired T-Tests were used to determine if significant differences existed at any anatomical region between the pre-season and post-season values among both middle distance and long distance groups. The difference between pre-season and post-season values of total body BMD for male middle distance runners (p < 0.001) and the difference between pre-season and post-season values of leg BMD for male middle distance runners (p = 0.022) were both significant.
Table 6

Comparison of Pre-Season to Post-Season BMD Changes among Female Runners

<table>
<thead>
<tr>
<th></th>
<th>Pre-Season BMD</th>
<th>Post Season BMD</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female Mid D Tot Body (N=4)</td>
<td>1.19 ± 0.04</td>
<td>1.23 ± 0.06</td>
<td>0.022*</td>
</tr>
<tr>
<td>Female Mid D Legs (N=4)</td>
<td>1.35 ± 0.03</td>
<td>1.36 ± 0.03</td>
<td>0.463</td>
</tr>
<tr>
<td>Female Mid D Pelvis (N=4)</td>
<td>1.24 ± 0.06</td>
<td>1.25 ± 0.05</td>
<td>0.254</td>
</tr>
<tr>
<td>Female Long D Tot Body (N=4)</td>
<td>1.18 ± 0.03</td>
<td>1.20 ± 0.04</td>
<td>0.081</td>
</tr>
<tr>
<td>Female Long D Legs (N=4)</td>
<td>1.34 ± 0.05</td>
<td>1.34 ± 0.06</td>
<td>0.509</td>
</tr>
<tr>
<td>Female Long D Pelvis (N=4)</td>
<td>1.22 ± 0.07</td>
<td>1.24 ± 0.08</td>
<td>0.021*</td>
</tr>
</tbody>
</table>

Note: Values are presented as M ± SD
*p < 0.05

Table 6 portrays the pre-season and post-season BMD values of different anatomical regions for middle distance and long distance female runners. Paired T-Tests were used to determine if significant differences existed at any anatomical region between the pre-season and post-season values among both middle distance and long distance groups. Statistically significant differences were found (p = 0.022) between the pre-season and post-season total body BMD values for female middle distance runners. Additionally, statistically significant differences were found (p = 0.021) between the pre-season and post-season pelvis BMD values for female long distance runners.
Stress fractures, and/or the possibility of such, are of major concern to endurance runners and their coaches due to the debilitating effect they can have on training and subsequently performance. The effect of endurance running on bone health has given inconclusive results in the literature (Zanker & Swain, 2000), and many different risk factors for stress fractures have been proposed and presented on in an attempt to shed light on the issue. BMD is one such risk factor that has been evaluated. Kelsey et al. (2007) and Lauder et al. (2000) identified multiple populations for which low BMD seems to be a risk factor and that included some populations of endurance runners.

Wolff’s law suggests that bone is a highly adaptable tissue and will meet the demands put upon it over time. This seems to be confirmed in studies which show that athletic populations whose sports require impact and loading of the bone have greater bone quality and bone strength when compared to controls or athletic populations who do not frequently require mechanical loading (Schipilow et al., 2013; Bennell et al., 1997; Smock et al., 2009).

Still, a dichotomy seems to exist between the apparent benefits of mechanical loading and the prevalence of bone injury, especially when considering endurance training runners. Multiple studies have pointed the high incidence rate of stress fractures among track and field and cross country athletes. One study found that injuries to the
bones of the lower limbs were more common among male and female endurance runners than any other athlete population (Arendt et al., 2003). In corollary with that, another study of track and field athletes belonging to a Victorian athletics club saw a 21.1% incidence of stress fractures over a 12-month period (Bennell et al., 1998). These seemingly confounding factors of increased bone health with mechanical loading and a high incidence of stress fractures among endurance runners may be at least partially explained by an imbalance of bone trauma and bone formation. It is possible that over periods of time without sufficient rest, the microstrain and microtrauma delivered to bones by mechanical loading is too much for the bone remodeling process to handle (Warden et al., 2006). This imbalance then leads to stress reactions and stress fractures because of over use. Therefore, it was partially the purpose of this study to determine whether or not trained endurance runners of both the middle distance and long distance type suffered any deleterious effects to their BMD.

The male endurance runners in this study (N=13) were separated into two groups: middle distance runners (N=8) and long distance runners (N=4). Likewise, the female endurance runners in this study were also separated into two groups: middle distance runners (N=4) and long distance runners (N=4). Three different anatomical regions were assessed for BMD values both before the indoor track season began (pre-season) and after the indoor track season concluded (post-season). Upon statistical analysis of the pre-season and post-season values, when compared within each group, there were some statistically significant findings. Interestingly, these statistically significant differences did not always trend in the same direction. For instance, total body BMD values for male middle distance runners increased, on average, from 1.29 g/cm² to 1.31 g/cm² and this
difference was found to be statistically significant with a p-value of <0.001. Likewise, female middle distance runners also saw a similar trend in that their total body BMD estimates went from 1.19 g/cm$^2$ to 1.23 g/cm$^2$ on average with the p-value being 0.022. Contrastingly, the male middle distance runners’ leg BMD values decreased from 1.56 g/cm$^2$ to 1.54 g/cm$^2$ with the p-value being 0.022. While statistically significant, in terms of practicality these measured changes seem quite minimal. It is important to keep in mind, however, that as has already been cited, when repetitive loading occurs and thus induces microtrauma at the loaded bone(s), a certain amount of bone remodeling is needed in order for the bone to adapt. It is therefore possible that even small declines in BMD values may be enough to indicate future risk for bone injury. More study needs to be done in this area to determine if this is true.

In addition to studies pointing to the enhancement of bone health due to mechanical loading, there have also been questions raised as to whether this effect might have depending on the strain magnitude of the loading as well as the frequency with which the loading occurs. One study showed that soccer players seemed to be at an advantage in terms of BMD at certain sites when compared to runners (Fredericson et al., 2007). It was considered that because soccer involves movements which are mainly of high intensity and strain, yet relatively intermittent in nature, it is more advantageous than the type of mechanical loading endurance runners deal with which is of less strain but occurs much more frequently and with less rest. This idea of the magnitude of loading versus the frequency of loading has been extrapolated out in other studies when comparing different types of track athletes (Bennell et al., 1997; Wilks et al., 2009). It was proposed in the study by Wilks that even middle distance and longer distance runners
may experience enough difference in training requirements in terms of mechanical loading so as to see a difference in the effects on their bone health. They showed that higher training volumes lead to lower values of cortical BMD. This study attempted to build on that idea. It was an additional purpose of this study to investigate whether BMD values of long distance runners were more adversely affected than those of middle distance runners.

In determining if there was a significant difference of BMD values among middle distance and distance runners, pre-season, post-season, and pre-season to post-season changes were compared between these groups, with male and female runners being compared separately. Statistically speaking, only one significant finding surfaced. The pre-season to post-season difference for male middle distance runners was significantly different than that of the male long distance runners (p<0.05). The change in the BMD values of the legs for middle distance runners from the pre-season to the post-season was -0.02g/cm² whereas the change for the long distance runners was 0.01g/cm². This is actually opposite of the hypothesized trend. When looking at the practical significance of these minute changes, not many conclusions can be drawn, especially since the BMD values when compared across the groups at every other anatomical region, both male and female, were not significant.

In conclusion, the original research question regarding differences in BMD between middle distance and long distance runners over the course of a competitive season has been in answered. Based on the data collected and analyzed, there was no noticeable pattern present to suggest that meaningful differences between the two groups existed over the course of the competitive indoor season.
Limitations

The main limitations of this study are two-fold. Firstly, the time period during which this study was conducted was very short: 8 weeks. This time period was chosen so as to correspond with the indoor track and field season of the athletes at the University of Akron but was quite possibly too short a time span to elicit significant anatomical changes to the bones. Ideally, athletes would be monitored for upwards of a year with measurements taken multiple times in order to gain a better understanding of the potential changes in BMD.

Secondly, the sample size was fairly small. While the overall number of subjects, twenty one, was somewhat representative of a collegiate middle distance/long distance team, because they had to be broken down into subgroups due to the nature of the study, it left small sample sizes. Three of the sub-groups, female middle distance, female long distance, and male long distance, only had four subjects each. The male middle distance group had nine subjects. Having a larger sample population for each group would lend more credence to the statistics.

Future Directions

Future research studies should take into account the size of the sample population(s) and the degree to which they will break the sample population into smaller groups. There is value in looking closely at a homogenous group such as this because of the similarities they posses, but possibly expanding beyond a single team into multiple teams of the same sport would be beneficial. Additionally, future studies would ideally
track measures such as BMD over a much longer time period than eight weeks. Bone microstrain, remodeling and adaptation are complicated processes and much more could be discerned by taking multiple measurements over the course of a full year, or even longer. In conjunction with longer observation periods, a detailed assessment of subjects’ training volume and intensity would be meaningful in attempting to further understand the relationship between endurance discipline, middle distance versus long distance, and BMD and whether or not a difference exists between the two.

Finally, as there are so many potential factors influencing BMD in endurance trained runners other than the mechanical loading intensity and frequency, future studies could take these into account. Things such as dietary intake and micronutrients, hormonal changes and, for the females, menstrual status, could all be important factors to consider and a better overall picture of the influences on BMD could be ascertained.
REFERENCES


APPENDICES
APPENDIX A

INFORMED CONSENT FORM
INTRODUCTION: You are invited to participate in a research study conducted by Marissa Baranauskas, Jordan T. Olson, and Dr. Ronald Otterstetter in the School of Sport Science and Wellness Education at The University of Akron. The purpose of the study is to evaluate certain parameters that could potentially affect maintenance of performance over the course of an indoor track season. Physiological, psychological, overall performance, and nutritional habits will be assessed throughout the course of a competitive season. Maximal aerobic capacity (VO2 max), resting metabolic rate, and bone density will all be assessed via laboratory procedures. You will be required to record your dietary and training habits daily in a journal. Additionally, participants will be responsible for completing a brief mood and lifestyle questionnaire several times throughout the study. From the information collected, we hope to gain a better understanding of potential factors that could contribute to performance decreases in collegiate athletes.

PROCEDURES: Testing will take place the weeks of January 10th to January 16th and February 29th to March 6th 2016 at The University of Akron Physiology Laboratory, which is located in Rm. 407 of Infocision Stadium. You will sign up for testing dates and times. You will sign up for a 15-minute session to assess your bone density and a 30-minute session to test your maximal aerobic capacity. Subjects will be expected to refrain from consuming food and to be normally hydrated two-hours prior to all testing procedures. You will also be expected to wear comfortable, loose, athletic clothing and running shoes for all laboratory procedures.

Bone density and body composition with be assessed via Dual Energy X-Ray Absorptiometry (DEXA). For this procedure, you will be asked to remove all jewelry and metals and to lay quietly with your arms at your sides on a scanning table for the duration of the test. The bone scan will began at your head and progress slowly to your feet. The bone density scan will provide us with information about your total average bone density, regional bone density, lean mass, and fat mass.

Maximal aerobic capacity will be assessed using VO2 max test protocol for highly trained subjects on a treadmill. Testing will take approximately 12-15 minutes. This test
requires you to exercise at a near maximal intensity. Test procedures follow running at a consistent speed of 8.9 mph at 0% grade and then increasing grade by 2% every two-minutes. You will be wearing a heart rate monitor and facial mask that encloses your entire mouth and nose and may make breathing difficult. The test will be terminated once you reach certain physiological parameters indicative of a maximal effort as determined by the test administrator. You are also free to terminate the test at any time by indicating you would like to stop.

Outside of the laboratory procedures, you will be asked to record all training and dietary practices from January 10th to March 6th. You will record your diet and physical activity at the conclusion of each day during the study period. You will be given access to a Google Doc template to electronically record your daily food intake and you will be asked to record daily training on the Running2Win site.

**EXCLUSION:** Only subjects who are current members of The University of Akron Track team and plan to compete in the 2016 indoor track season will be eligible for participation in the research study. If you have a known metabolic disorder such as thyroid disease, or are taking thyroid medications you are ineligible to participate. Also, if have a diagnosed bone injury you will not be able to participate. Please check the attached list to see if you can be included in the research study.

**RISKS:** There are minor risks and/or discomforts associated with bone density and VO2 max procedures. All research participants will be exposed to minimal amounts of radiation that are emitted during DEXA scan procedures. The amount of radiation exposure is low and is well below levels of normal background radiation that people receive from natural sources everyday. The risks associated with VO2 max testing are similar to those of high-intensity physical activity. The incidence of risk for healthy, well-trained subjects is near zero.

**BENEFITS:** The benefits of participating in this research study are that you will learn information that valuable to your training such as bone density, body composition, and aerobic fitness.

**RIGHT TO REFUSE OR WITHDRAW:** Participation in this research study is voluntary and you have the right to refuse to participate or withdraw from the study at any time.

**ANONYMOUS AND CONFIDENTIAL DATA COLLECTION:** The data collection process will be confidential. Any identifying information collected will be kept in a secured location that only the researchers have access to. Participants will not be identified by name and the only information linking your identity to study results will be a key that links numbers to identifying information. Your identity and test results will not be shared with anyone who is not affiliated with the research study.
WHO TO CONTACT WITH QUESTIONS: If you have any questions about this study, you may contact Marissa Baranauskas (440) 223-7837, Jordan Olson (513) 314-0631 or the research advisor Dr. Ronald Otterstetter at (330) 972-7738. This project has been reviewed and approved by The University of Akron Institutional Review Board. If you have any questions about your rights as a research participant, you may call the IRB at (330) 972-7666.

ACCEPTANCE & SIGNATURE:

I have read the information provided above an all of my questions have been answered. I fully understand the risks and benefits associated with participation in this research study and the expectations of my participation have been clearly explained. I voluntarily agree to participate in this study. I will receive a copy of this consent form for my information.

Participant signature  Date
EXCLUSION CRITERIA

• Current Bone Injury
  ▪ Diagnosed with a stress reaction, stress fracture or complete bone fracture within the last 6 weeks

• Thyroid Disease
  ▪ Hypothyroidism
  ▪ Hyperthyroidism
  ▪ Hashimoto’s Disease
  ▪ Graves’ Disease

• Taking thyroid medication
  ▪ Synthroid
  ▪ Levothyroxine
  ▪ Armour Thyroid
  ▪ Levoxyl
  ▪ Cytomel

• Taking a medication that influences bone metabolism
  ▪ Antacids containing aluminum
  ▪ Antiseizure medications Dilantin or Phenobarbital
  ▪ Cancer chemotherapeutic medications
  ▪ Cyclosporine
  ▪ Gonadotropin releasing hormone Lupron and Zoladex
  ▪ Heparin
  ▪ Lithium
  ▪ Depo-Provera
  ▪ Methotrexate
  ▪ Proton Pump Inhibitors Nexium, Prevacid, Prilosec
  ▪ Selective Serotonin Reuptake Inhibitors (SSRIs) Lexapro, Prozac, Zoloft
  ▪ Steroids (glucocorticoids) Cortisone and Prednisone
  ▪ Thiazolidinediones Actos and Avandia
APPENDIX B

MOOD AND LIFESTYLE QUESTIONNAIRE
Mood and Lifestyle Questionnaire

How do you feel today? (Circle your response)

Based on current and past training do you identify yourself as either a middle distance (800m-1500m) or long distance (3,000m-5,000m) runner? 

How many hours on average did you sleep per night over the previous week? 

How many hours of sleep do you normally get? 

Have you developed any sicknesses within the past month? 
- Respiratory infection - common cold, sore throat, fever
- Influenza
- Pneumonia
- Streptococcus
- Mononucleosis
- Bronchitis
- Hepatitis
- Meningitis
- Chickenpox
- Herpesviruses

Do you have a current diagnosis of an eating disorder? 

Have you had a musculoskeletal overuse injury within the past month? 
- Stress reaction
- Stress fracture
- Complete fracture
- Medial tibial stress syndrome (shin splints)
- Tendonitis
  - Achilles
  - Patellar (knee)
  - Hamstring
  - Quadriceps
- Ligament sprain/strain
- ACL
- MCL
- PCL
- Posterior tibial (ankle)
- Muscle strain
  - Hamstring
  - Quadriceps
  - Calf

Have you ever been diagnosed with any existing inflammatory diseases or any other chronic illnesses? 
- HIV
- Diabetes
- Systemic inflammatory disease
- Rheumatoid arthritis
- Myocarditis
- Heart valve issues
- Abnormal heart arrhythmias
Have you felt extremely fatigued or exhausted for > 4 weeks? __________

On the chart below, indicate (by circling) the choice that best represents the intensity of each mood you have felt over the previous week.

<table>
<thead>
<tr>
<th></th>
<th>Not at all</th>
<th>A little bit</th>
<th>Somewhat</th>
<th>Quite a bit</th>
<th>Extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sadness</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Anger</td>
<td>0</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Happiness</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Fatigue</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Worthless</td>
<td>0</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
</tbody>
</table>
Office of Research Administration

Notice of Approval

Date: January 6, 2016
To: Melrose Biemann, Jordan Olson
Sport Science and Wellness Education

From: Shannon McWhorter, IRB Administration
IRB Number: 20151200
Title: Relationship Between Carbohydrate Intake, Bone Mineral Density, and Performance in Collegiate Track Runners

Thank you for submitting your Application for Research Involving Human Subjects to the IRB for review. Your protocol represents minimal risk to subjects and has been approved.

Approval Category: Expedited 7
Approval Date: January 5, 2016
Expiration Date: January 5, 2017
Compliance Application Due: December 3, 2016

In addition, the following issues apply:

☐ Research Involving children
☐ Research Involving prisoners
☐ Waiver of documentation of consent
☐ Waiver or alteration of consent
☐ IRB approval is given for not more than 12 months. If your project will be active for longer than one year, it is your responsibility to submit an Application for Continuation prior to the expiration date.
☐ If changes are made to the protocol before the expiration date you must submit a Request for Change for review and approval before the change is implemented.
☐ When the project is completed you must submit a Final Report to close the IRB file.
☐ If this research is being conducted for a master’s thesis or doctoral dissertation, you must file a copy of this letter with the thesis or dissertation.
☐ All forms are available on the OIRA website at [http://www.ohio.edu/research/university/ohiorun](http://www.ohio.edu/research/university/ohiorun).
☐ CTI Certifications are valid for three years. Any continuation of this protocol or approval of new research is contingent upon maintaining a current CTI certification. It is your responsibility to update your certification as needed. The link to the CTI online log-in access is: [https://www.cti-certification.org](https://www.cti-certification.org).

☐ Approved consent form(s) utilized

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Uniting the Arts & Humanities with Science & Technology