



RADIAL AND TIBIAL BONE ULTRASOUND DENSITOMETRY IN WEIGHT BEARING AND NON-WEIGHT BEARING ACTIVITY: A COMPARATIVE ANALYSIS

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Abstract Objective of the research was to determine effects of physical activity on speed of sound (a bone property) at radial and tibial bone site in swimming (non-weight bearing) and softball (weight bearing). Design was made as a cross-sectional study of age matched subjects. Total of 120 subjects i.e. 40 swimmers and 40 softball players (university level) and 40 non-athletes served as participants in the study. Subjects were assessed for bone properties by measuring Speed of Sound (SOS) at radial and tibial sites by Omnisense 7000s ultrasound densitometer. Past and current bone specific physical activity level was calculated by BPAQ questionnaire. Main outcome measures were: SOS (m/sec), past BPAQ and current BPAQ. Results showed that three sites for softball players and one site for swimmers had greater bone properties (SOS) than control. There was a significant difference in bone properties favoring dominant radial bone SOS than non-dominant radial bone SOS in softball players ($p=0.0001$) and swimmers ($p=0.02$). The swimmers showed a marked difference favoring non-dominant tibial SOS over dominant tibial SOS ($p=0.013$); however, no such significant differences were recorded in softball players and non-athletes. A positive correlation was recorded between past BPAQ algorithm with dominant tibial SOS and non-dominant tibial SOS in softball players ($r=0.495$ and $r=0.446$), swimmers ($r=0.579$ and $r=0.725$), and non-athletes ($r=0.678$ and $r=0.736$), respectively. We can conclude that bone properties were greater in softball players than swimmers, followed by non-athletes (softball>swimming>non-athletes). The past physical activity levels as measured by past-BPAQ were positively associated with tibial bone properties in all the subjects.

Key words: Swimming, bone density, quantitative ultrasound, densitometry, speed of sound

INTRODUCTION

Wolf's law states that the "bone changes its external shape and internal (cancellous) architecture in response to stresses acting on it", i.e. that the bone models and remodels in response to the mechanical stresses [24]. Mechanical stress or loading is a product of gravity force and muscular force involved in the nature of sports games. Weight bearing activity involves gravity and muscular force acting on the bone, but non-weight bearing activity involves a relatively negligible amount of gravity and greater muscular force acting on the bone; thus, weight bearing activity induces greater mechanical loading units than those involved in non-weight bearing activity. As bone loading increases, the bone will adapt by becoming stronger to resist the load by the process of remodeling. Remodeling involves adaptive changes in the internal trabecular system and external cortical changes resulting in thickening and denser bone tissue. Consequently, as loading on the bone decreases and there is no stimulus for the process of remodeling to occur, the bone loses density at the rate of its metabolic cost. Bone growth depends mainly on effective loading stimulus on the bone induced by physical activity.

Studies have demonstrated measurements of effective loading stimulus in different physical activities. The effective loading stimulus is a product of peak GRF and rate of loading involved in specific physical activity on the bone [7]. Swimming is considered to be a non-impact physical activity which involves negligible effective loading stimulus on bones. Weeks and Beck, 2008 calculated effective loading on bones in swimming, which is 0.07 [7]. The effect of exercise is seen mainly following impact or weight bearing activity, and not in response to an active load which does not involve weight bearing, such as swimming [4]; however, animal studies on swimming have shown a positive bone mass adaptation. Studies have shown that high and medium gravitational overload sports such as volleyball and running, respectively, had greater

BMD than non-overload sports such as swimming or the control groups [10]. Softball is a moderate intensity, weight bearing game that involves an effective load stimulus of 13.62 with peak GRF of 2.9 and the rate of 117 [7]. These rates of impact can induce a differential loading pattern over the bones to cause adaptation correspondingly. Thus softball is an active game that has potential to induce a substantial osteogenic effect. However, we believe that although swimming lacks ground reaction force, it may still positively influence other bone properties and parameters of bone health like elasticity, porosity and microstructure as reflected by quantitative ultrasound measurement.

The fact that weight bearing activity has a positive osteogenic effect in improving bone mass has been detected by DEXA in several studies [9, 12, 22]. DEXA studies have detected contralateral differences in limb bone mineral density in different games [2, 15]. However, these measurements were related to bone strength and do not reflect bone properties such as elasticity, internal architecture and geometry [19]. SOS (Speed of Sound) as measured by quantitative ultrasound is influenced by specific gravity, porosity, orientation, water content and elasticity in the cortex [13], as well as thickness of the compact bone [21]. SOS is a function of both density and elasticity of the cortex [20]; the higher the value of SOS, the stronger the bone reflecting greater osteogenesis. Very few investigations have focused on the differences in bone properties measured at multiple loading sites as detected by QUS in different athletic populations based on the loading patterns induced by gravity and muscular force.

Thus the aim of the present study was to use radial and tibial QUS to determine the effect on the actively loaded bone in swimming and softball when compared to non-athletes. A secondary objective was to determine an association between bone specific physical activity level and QUS parameters in all the groups.

MATERIALS AND METHODS

SUBJECTS AND PROCEDURES

Softball university level players (n=40, age: 21.9±1.70 yrs., height: 1.69±0.69 m, weight: 63.12±9.8 kg) and university level swimmers (n=40, age: 22.4±1.75 yrs., height: 1.75±0.4 m, weight: 1.66±0.75 kg) volunteered to take part in this study. The non-athletes (n=40, age: 22.5 ±1.96 yrs., height: 1.66 ±0.75 m, weight: 61.5 ±10.2 kg) who volunteered did not take part in any sports. The entire group had 20 female and 20 male subjects each; also, athletes and controls were matched for age and BMI. The details for physical activity level, training frequency and volume were obtained by Bone Specific Physical Activity Questionnaire (BPAQ). Two algorithm scores, namely past BPAQ and current BPAQ scores, were derived from it (Weeks). The study was ethically approved by the institutional ethical committee. The subjects were excluded if they had been diagnosed with any medical condition affecting bone growth, history of eating disorder or taking any drug treatment that is known to affect bone metabolism (for example, steroids and thyroid replacement therapy). None of the female subjects experienced any form of menstrual dysfunction. Written informed consent was taken from the individuals and the details of the method executed, the benefits and the potential risk or discomforts were explained prior to participation. All subjects were measured for: grip strength (kg) by hand held dynamometer; height (m) by stadiometer; weight (kg) by weighing scale; and the BMI was calculated.

QUANTITATIVE ULTRASOUND MEASUREMENT

The distal 1/3 radial bone SOS and midshaft tibial bone SOS were bilaterally measured according to standard operating procedures, using a sunlight Omnisense 7000s Quantitative ultrasound sonometer. The results of SOS scan were recorded in m/sec. The procedure followed for the measurement of ultrasound densitometry was the same as that conducted by Njeh et al [17].

To ensure measurement accuracy and reliability, the system quality verification was done daily using a standard acrylic phantom supplied by the manufactures before scanning. All scans were done by the same investigator. The coefficient of variation (CV) was calculated by repeated scanning at the same site using the inbuilt software to test CV every week. The CV for distal 1/3 radial bone scan ranged between 0.22%–0.26% and the CV for midshaft tibial bone scan ranged between 0.36%–0.42%. These CV ranges were considered to be good and reliable measuring ranges.

STATISTICAL ANALYSIS

The statistical analysis was carried out using SPSS version 16. The results are expressed as mean ± SD. A one-way ANOVA was used to determine if significant (p<0.05) difference existed among the groups for strength, experience and physical activity level. Significant differences (p<0.05) between QUS variables were also tested by one-way ANOVA. When significance was found, a Tukey's HSD post hoc test was performed to localize the difference. Dominant and non-dominant side differences in QUS variables were tested by paired student t-test. Relationships between QUS and selected descriptive variables were assessed using a Pearson's two tailed correlation.

RESULTS

Table 1. Descriptive characteristics of subjects

Variables	Softballers (n=40)	Swimmers (n=40)	Non-athletes (n=40)
Age (yrs)	21.9±1.70	22.4±1.75	22.5±1.96
Height (m)	1.69±0.69 ^φ	1.75±0.48 ^{†ψ}	1.66±0.75 ^φ
Weight (kg)	63.12±9.8	66.5±7.4 [†]	61.5±10.2 ^φ
BMI (kg/m ²)	21.97±2.66	21.52±2.1	22.18±3.44
D Hand grip	41.95±9.7	40.37±11.72	38.27±11.32
ND Hand grip	35.52±9.7	35.6±11.85	35.57±11.44
past-BPAQ	23.52±10.69 ^{φ*}	15.86±3.5 ^{ψ*}	10±3.91 ^{ψφ}
current-BPAQ	51.41±19.5 ^{φ*}	33.84±13.5 ^{ψ*}	21.33±8.1 ^{ψφ}
Experience (yrs.)	8.3±3.6	9.07±3.05	NA

BPAQ, Bone specific Physical Activity, BMI, Body Mass Index, D, Dominant, ND, Non-dominant
^{*}significant difference from non-athletes, ^φ significant difference from swimmers, ^ψ significant difference from softball group. Values are Mean ± SD

There was no significant difference ($p>0.05$) in age and BMI between the groups. Swimmers were significantly taller than softball players ($p>0.05$) and non-athletes ($p>0.05$) and also significantly heavier than non-athletes ($p>0.05$). Softball players had experience of 8.3±3.6 and swimmers of 9.07±3.05 years. There was no significant difference in hand grip strength between the groups, however there was a marked difference favoring dominant hand grip strength when compared with non-dominant side in all the groups ($p<0.05$).

There were 2 components that determined bone specific physical activity level. The estimated past-BPAQ algorithm scores and current-BPAQ algorithm scores for softball, swimmers and non-athletes were given in Table 1. The past-BPAQ and current-BPAQ levels were found significantly greater in the following order: softballers>swimmers>non-athletes (past-BPAQ: 23.52±10.69 > 15.86±3.5 > 10±3.91, current-BPAQ: 51.41±19.5 > 33.84±13.5 > 21.33±8.1) respectively. Quantitative ultrasound densitometry values are presented in Table 2.

Table 2. Quantitative Ultrasound Densitometry

Bone Site	Softballers (n=40)	Swimmers (n=40)	Non-athletes (n=40)
D Radial bone SOS (m/s)	4063.3±93.39 ^{abz}	4018.2±67.99 ^z	4005.2±72.30 ^c
ND Radial bone SOS (m/s)	4018.6±104.3 ^z	3987.9±87.04 ^z	3980.4±96.16
D Tibial bone SOS (m/s)	3915.6±97.21 ^b	3909.4±77.81 ^{bz}	3854±106.6 ^{ac}
ND Tibial bone SOS (m/s)	3925.9±94.90 ^b	3882.3±90.21 ^z	3843.8±81.58 ^c

D: Dominant, ND: Non-dominant, SOS: Speed of sound
^a significant difference from swimmers, ^b significant difference from non-athletes
^c significant difference from softballers, ^z significant difference from contralateral side

There was a significant difference in bone properties favoring dominant radial bone SOS over non-dominant radial bone SOS in softball players ($p=0.0001$) and swimmers ($p=0.02$). No significant differences were recorded between dominant radial SOS and non-dominant radial SOS in non-athletes ($p=0.083$). Intergroup comparison of dominant radial bone SOS revealed marked differences favoring softball when compared with swimmers ($p=0.031$) and non-athletes ($p=0.004$). No significant difference was found in dominant radial SOS between swimmers and softballers. Intergroup comparison of non-dominant radial SOS revealed no significant difference between the groups of softball cricketers, swimmers and non-athletes (Figure 1).

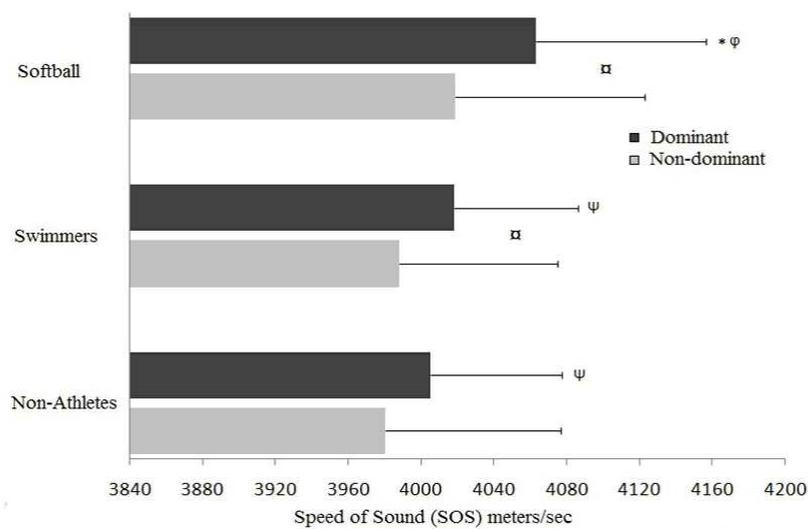


Figure 1. Differences in upper extremity bone properties; Dominant and Non-dominant side Radial SOS (m/s) in softball, swimmers and nonathletes.

* Significant difference from Non-athletic group; φ significant difference from Swimming group; ψ significant difference from Softball group; α significant difference from contralateral side

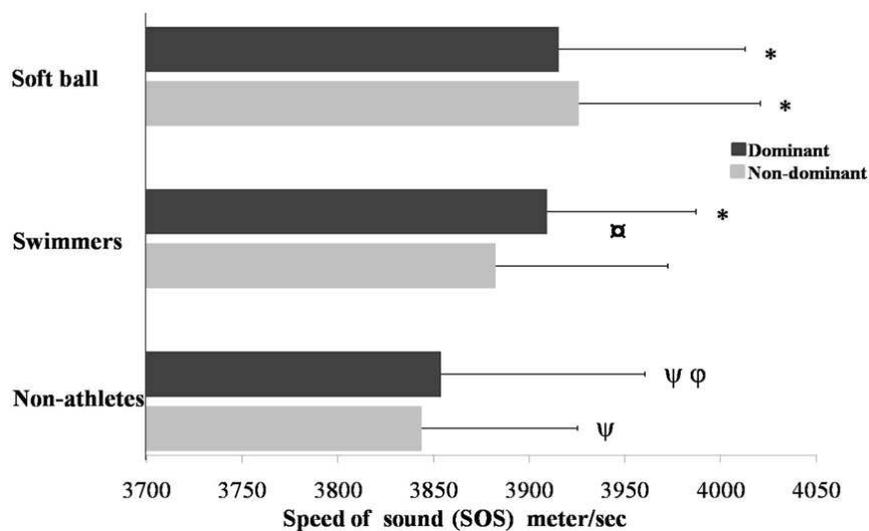


Figure 2. Differences in lower extremity bone properties; Dominant and Non-dominant side Tibial SOS (m/s) in softball, swimmers and nonathletes.

* Significant difference from Non-athletic group; φ significant difference from Swimming group; ψ significant difference from Softball group; α significant difference from contralateral side

The swimmers showed a marked difference favoring non-dominant tibial SOS over dominant tibial SOS ($p=0.013$); however no such significant differences were recorded in softballers and non-athletes. Intergroup comparison of dominant tibial bone SOS recorded no significant difference between softballers and swimmers but significant differences were found between softballers and non-athletes ($p=0.012$) and also between swimmers and non-athletes ($p=0.027$). Intergroup comparison of non-dominant tibial SOS showed significant difference between softballers and non-athletes ($p=0.001$), but no such differences were recorded either between softballers and swimmers ($p=0.07$) or between swimmers and non-athletes ($p=0.133$). Relationships between physical activity and ultrasound bone properties are presented in Table 3.

Table 3. Correlation between QUS and BPAQ scores (r)

Groups	Algorithm	D Radial SOS	ND Radial SOS	D Tibial SOS	ND Tibial SOS
Softball players	Past-BPAQ	0.306	0.262	0.495**	0.446**
	Current-BPAQ	0.056	-0.047	-0.025	-0.036
Swimmers	Past-BPAQ	0.481**	0.150	0.638**	0.784**
	Current-BPAQ	-0.261	-0.082	0.086	0.028
Non-athletes	Past-BPAQ	0.073	0.196	0.678**	0.736**
	Current-BPAQ	-0.006	0.065	0.046	0.088

BPAQ: Bone specific Physical Activity, D: Dominant, ND: Non-dominant, SOS: Speed of sound
** significant correlation

No correlation was recorded between current BPAQ algorithm with that of SOS of radial and tibial bone in softballers, swimmers or non-athletes. A positive correlation was recorded between past BPAQ algorithm with dominant tibial SOS and non-dominant tibial SOS in softball players ($r=0.495$ and $r=0.446$), swimmers ($r=0.579$ and $r=0.725$), and non-athletes ($r=0.678$ and $r=0.736$) respectively. The past BPAQ scores were not significantly correlated to dominant and non-dominant radial bone SOS in any of the groups except for swimmers where dominant radial bone SOS ($r=0.481$) was positively correlated.

DISCUSSION

The aim of the study was to determine the QUS in weight bearing exercise (softball) and in non-weight bearing exercise (swimming) and to compare the results with non-athletes. Higher calcaneal bone properties have been reported through ultrasound parameters in weight bearing exercise such as dancing and soccer [5] and in non weight bearing exercise such as swimming [6] as compared to healthy non-athletes. Studies have shown that aquatic and weight-bearing exercises are both determined to be effective in increasing the QUS scores of the calcaneal bone [18]. The present study, which measured QUS at the tibia and the radius showed significantly higher properties in swimmers and softball players than non-athletes ($p<0.05$) only at specific measured sites. Heinrich et al. proved that college swimmers showed no higher bone mass than physically non-active controls [14], but in our study swimmers showed a statistically greater difference favoring SOS of dominant tibial bone (i.e. in lower limb) than non-athletes. Consequently, the means of SOS at other 3 sites, namely dominant radial, non-dominant radial and non-dominant tibial bone, were greater in swimmers than in non-athletes, but not statistically significant. Although aquatic exercise conditions did not cause a statistically significant difference in bone properties as compared to non-athletes, the observation of the mean values, which are greater at all sites in swimmers, indicates that swimming may confer clinically relevant improvements or even help to maintain the bone properties in recreational athletes as well as sedentary adults who pursue swimming. Active muscular forces under aquatic conditions (i.e. even without the influence of gravity) can induce an effective loading stimulus to impart osteogenesis. However, the minimum amount of swimming that may be an osteogenic stimulus has not been determined.

The softball players had significantly greater bone properties at 3 sites which are dominant: radial, dominant tibial and non-dominant tibial bones, when compared with non-athletes ($p<0.05$), indicating that moderate weight bearing exercise definitely caused increments in QUS values due to the differential strain loading pattern involved in the softball game. Swimming and softball as an active bone loading game produced positive osteogenic stimulus; however, the fact that there were greater SOS values measured at 3 sites in softball players and only 1 site in swimmers as compared to non-athletes indicates that the pattern of greater osteogenic effect is in the order: softball>swimming>non-athletic group. This indicates that osteogenic effect occurs in the order: weight bearing exercise>non-weight exercise>non-athletic activity.

Many studies show that higher BMD were seen in weight-bearing regions in active soccer players and that the effect was region specific [1, 16, 11, 23]. We confirmed that softball players, due to the nature of the game (upper extremity action in addition to lower limb movement), had better bone properties in the upper limb as well as the lower limb than non-athletes. It is also possible that dominant upper limb action as compared to contralateral side would have had greater joint reaction forces and effective loading stimulus and thus had significantly greater ($p<0.05$) SOS in the dominant radial bone than in the non-dominant bone (Table 2). Consequently, in our study QUS parameters were able to identify the difference occurring due to

the effect of greater weight loaded region (dominant limb) than lesser weight loaded region (non-dominant) of the same limb. The swimmers also showed greater SOS at the dominant radial bone than the non-dominant radial bone (Figure1). The possible explanation was that the swimmers in our study also played water polo, where throwing with upper limb (especially dominant side) came into action and had better effective loading force than non-dominant side.

Available evidence suggests that physical activity is associated with QUS measurements on the heel independently of BMD [8]; also it was found that history of physical activity levels in postmenopausal women were moderately associated with bone parameters such as bone area and density [3]. Although these studies were able to estimate the physical activity level, the tools used were mostly based on hours of activity per week and caloric expenditure for specific type of activity, but did not relate to mechanical loading. The bone specific physical activity questionnaire tool we used specified the type of activity and was based on ground reaction force predetermined for that particular activity. The beneficial fact of BPAQ tool was its ability to add the scores of each activity and condense them into one score based on the particulars given on one's participation in past month and years. The scores were expressed in two components, namely past-BPAQ and current-BPAQ. The past-BPAQ scores had moderate to high positive association with tibial SOS in all the groups (Table 3). The current-BPAQ scores were not correlated with any of the bone SOS values; the possible explanation could be that the equation of current-BPAQ was only based on frequency but not volume of activity per week.

CONCLUSION AND PRACTICAL APPLICATION

In conclusion, bone properties were greater in softball players than in swimmers and were least in non-athletes. This study generates evidence for the fact that swimming as an activity definitely maintains bone health and if pursued competitively and at greater intensities it may even produce a substantial osteogenic stimulus. The potential for its implications in fracture rehabilitation of limbs during non-weight bearing stages should be explored. QUS also can predict the side to side difference that occurs due to the nature of exercise and games. Swimming and softball are active bone loading activities that impart better bone properties in young population as detected by QUS. Thus, involvement in either aquatic games or weight bearing exercise on a regular basis improves bone properties such as strength, elasticity and micro-architecture and may prevent osteoporosis in later life. The past physical activity levels as measured by past-BPAQ were positively associated with tibial bone properties in all the subjects.

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