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Quantitative Ultrasound and bone's response to exercise: A meta analysis

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ABSTRACT

The utility of Quantitative Ultrasound (QUS) for assessing and monitoring changes in bone health due to exercise is limited for lack of adequate research evidence. Restrictions to bone density testing and the enduring debate over repeat dual energy absorptiometry testing spells uncertainty over clinical and non-clinical evaluation of exercise for prevention of osteoporosis. This study, via systematic review and meta-analysis, aimed to paint a portrait of current evidence regarding QUS' application to monitoring bone's adaptive response to exercise interventions.

Methods: Structured and comprehensive search of databases was undertaken along with hand-searching of key journals and reference lists to locate relevant studies published up to December 2011. Twelve articles met predetermined inclusion criteria. The effect of exercise interventions for improving bone health, as measured by QUS of the calcaneum, was examined across the age spectrum. Study outcomes for analysis: absolute (dB/MHz) or relative change (%) in broadband ultrasound attenuation (BUA) and/or os calcis stiffness index were compared by calculating standardised mean difference (SMD) using fixed- and random-effects models.

Results: Quality of included trials varied from low to high on a scale of one to three. Four to 36 months of exercise led to a significant improvement in calcaneum BUA (0.98 SMD, 95% CI 0.80, 1.16, overall effect Z-value = 10.72, $p = 0.001$) across the age spectrum.

Conclusion: The meta-analysis attests to the sensitivity of QUS to exercise-induced changes in bone health across the age groups. QUS may be considered for use in exercise-based bone health interventions for preventing osteoporosis.

Introduction

With a projected worldwide increase in prevalence of osteoporosis due to an ageing population [1] and an increasing financial, social and psychological cost of treatment subsequent to fracture [2,3], the indication for a paradigm shift from anti-osteoporotic drug treatment and or secondary prevention to non-pharmacologic primary prevention is strong [4] and yet evolving [5]. Exercise for maximising peak bone mass, minimising age-related bone loss via weight-bearing physical activity, and minimising fall and fracture risk through strength, flexibility and balance training sits at the central core of this demand.

The measurement of bone mineral density (BMD) with the aid of dual energy absorptiometry (DXA) is widely acknowledged as the gold standard for radiographic diagnosis of osteoporosis, the prediction of fractures, and monitoring of bone health status [6]. Recent bone densitometry guidelines do not support routine bone density screening for the entire population [7]. This restriction and the enduring debate over repeat DXA testing spells uncertainty over both clinical and non-clinical monitoring of responses to exercise intervention as a public health strategy for prevention and management of osteoporosis [7,8]. The bulk of current evidence on the benefits of exercise for management of osteoporosis had been garnered from BMD measurements. Considering the argument on ethical issues and cost-effectiveness associated with repeat DXA testing, exposure to ionising radiation (especially to the immature skeleton) and the rapidly evolving aspects of exercise interventions that may enhance bone health, research on the role of QUS for monitoring the effect of exercise intervention on bone health is well situated.

The QUS has been valued for its high correlation with BMD measurements [9,10]. Its portability, radiation-free, time-saving capability, and low-cost is purported to make it an attractive alternative to DXA [11,12]. However, as opposed to DXA, the dearth of data from prospective controlled trials for both bone health enhancement and anti-osteoporotic treatment using Quantitative Ultrasound (QUS) as a benchmark for efficacy has limited the propensity to recommend the same for monitoring changes in treatment. Hence, the utility of QUS for assessment of response to exercise intervention for the purpose of enhancing bone health across the age spectrum has remained equivocal [13]. While there might have been published and unpublished literatures of strong evidence-based arguments pro and against the use of QUS for monitoring exercise-induced changes in bone mass, a systematic review and meta-analysis of controlled

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studies (across age groups) of exercise intervention and bone health using QUS as an efficacy criterion is yet to be undertaken. The purpose of this study was, therefore, to ascertain the sensitivity of QUS for detecting change in BUA due to exercise intervention.

Methods

A systematic review of published and unpublished literature on the role of QUS in monitoring and evaluating bone's response to exercise across age groups was conducted. The inclusion criteria are given in Table 1. Structured computer searches of MEDLINE/PubMed, EMBASE, Web of Science, SportDiscus, Cochrane controlled trials register, AMED, BNI, HMIC, PROQUEST and CINAHL were undertaken from their inception till December 2011 to locate relevant studies. Search terms, keywords and participant headings in the searches are presented in Appendix A. The search was supplemented by citation tracking and hand searching of reference lists. Full text versions of relevant articles were obtained and assessed by two independent reviewers (OB and JF).

Methodological quality assessment of studies

Quality of studies was assessed independently by two investigators (OB and JF) using the Effective Public Health Practice Project quality assessment tool for quantitative studies [14]. Using this tool, rating opinion was based upon information contained in the study rather than making inferences about what the authors intended. Differences of opinion regarding scoring of articles were resolved between the two investigators through discussion until consensus was reached.

Data extraction and analysis

Data extraction was completed for all included studies independently by OB and JF. The data extracted included: the participants' age; number of allocated participants; number of participants followed up; type of exercise intervention (high impact vs. low impact); mode of exercise intervention (intensity: number of loading cycles, duration: minutes, frequency: number of times per week, length of intervention: months); settings; attrition; compliance; adjuvant pharmacological or nutritional therapy; and outcome measures (QUS instrument; site assessed; BUA parameters — mean values with standard deviation). Where standard deviations were not provided, they were calculated using recommended equations [15].

Results

Description of studies/study quality assessment

Twelve articles (2 cohorts and 10 controlled trials [CT]) involving 878 participants in total were included in this review. A summary of the review process is presented in Fig. 1 and a synopsis of data from the 12 studies is presented in Table 2. Out of the five studies [16–20] that reported randomisation of study participants into exercise intervention groups and control groups, only three [16,18,20] gave details of the randomisation process. The study of Arnett & Lutz [20] reported concealed allocation of subjects to their respective groups while only that of Ay & Yurtkuran [18] reported outcome assessor blinding to group allocation of participants. With a ‘2’ rating, on a scale of 1 to 3, seven of the studies [16–22] were classified as having moderate methodological quality, and three studies [23–25] had a low quality rating of ‘3’. Only two of the studies [26,27] were considered to have high methodological quality rating of ‘1’. The sample size varied from 31 [16] to 246 [25] participants.

Outcome measures/measurement tools

Calcaneal BUA was the prevalent outcome measure of choice by all of the studies included in this review; however there was a wide heterogeneity in the models of Quantitative Ultrasound machines that were employed. These included: the QUS-2, Quidel Inc [16,17]; Osteometer DTU-one ultrasound instrument (Osteometer medi Tech A.S, Denmark) [18]; Achilles ultrasonometer (Lunar Corp., Madison, WI) [20]; SAHARA Clinical Bone Sonometer, Hologic (Bedford, Mass) [19,21,25]; Walker Soniz Ultrasonic Boen Analyzer [23]; McCue Ultrasonics Ltd, subclinical dry system osteodensitometer [24]; and CUBA Clinical ultrasound machine (McCue Ultrasonics, Winchester, UK) [22,26,27]. Other outcome measures included: DXA BMD [16–22,25,27]; quantitative computed tomography [21,27]; quadriceps strength; squat strength; dynamic balance [16,25]; ground reaction forces [16, 20, 26]; serum hormones [18,22,24–26]; accelerometer-based body movement (Newtest, Ltd), [19]; peak muscle torque using a Biodex isokinetic dynamometer and a Digiwalker to assess volume of physical activity for three days [20].

Intervention

There was a considerably large amount of variation in the type of exercise intervention that was employed in the studies included in this review. Exercise intervention ranged from low-impact and/or non-weight bearing exercises [16,18,23] to high-impact, weight-bearing exercises [17,20,21,24–27]. The frequency also ranged from 2 to 3 times per week to daily exercise recommendations. Compliance to exercise intervention in most of the studies ranged from 65 to 98% where reported. Only three studies [22,23,25] failed to report compliance to exercise regime.

Children/young adults

Six studies in this review [17,20,24–27] monitored changes in QUS parameters as a response to exercise programmes in young people between the ages of 7 and 20 years compared to their age-matched controls. The exercise programmes were all high impact in nature ranging from simple jumping exercises to specialised gymnastic activities and strenuous weight-bearing exercises in new army recruits. Over an 18-month period of frequent impact loading of as much as 10.4 times body weight associated with gymnastics training, Daly et al. [26] realised a significant increase in calcaneal BUA z scores compared to that of controls who participated in routine physical education exercise classes, but there was no change in Velocity of Sound (VOS). Similarly, both a self-led and a teacher-led physical activity programme for six months brought about improvements in bone

Table 1
Inclusion criteria.

Design	Randomised controlled trials and controlled trials (English language only)
Population of interest	All age groups: young individuals, adults (premenopausal) and older adults (postmenopausal). No gender restrictions, apparently healthy, no history or presence of diseases affecting bone metabolism)
Intervention	All exercise interventions, with or without concurrent pharmacological interventions
Comparisons	Exercise intervention (as above) compared with no exercise control or sham (e.g. stretching) exercises
Outcome measure	Broadband ultrasound attenuation (BUA) and or speed of sound (SOS) as assessed by quantitative ultrasound examining absolute or relative changes in BUA and or VOS at the calcaneus or other skeletal sites on first follow-up, and post-intervention. Other outcome measures such as the dual energy absorptiometry, ground reaction forces; accelerometer-based body movement monitor; Serum hormones and physical activity recorder.