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ORIGINAL ARTICLE

Greater tibial bone strength in male tennis players than controls in the absence of greater muscle output

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Summary *Background/Objective:* The greatest forces experienced by bones result from muscular contractions—muscles produce most force in high-velocity eccentric contractions. Bouncing movements, e.g., sprinting or hopping—where such contractions occur—are highly beneficial for lower limb bones. However, there is a growing body of evidence that torsional stresses are highly osteogenic. Sports in which frequent quick turning occurs—hence large torsional stresses can be expected—e.g., tennis, may also improve bone strength even in the absence of large ground reaction and muscle forces.
Methods: To investigate the relative effects of bouncing and turning movements on bones, we recruited 47 older men (mean age 62.4 ± 12.9 years). They were competitive sprinters (representing exposure to bouncing movement), competitive tennis players (turning movements), and inactive controls. Peripheral quantitative computed tomography scans of tibial diaphysis at 66% distal–proximal length were taken; muscle sizes from peripheral quantitative computed tomography and countermovement jump performance were also examined.
Results: Bone strength of tennis players was clearly greater than that of controls (23% greater bone mass; $p < 0.001$) and similar to that in sprinters. Tennis players' jump relative power and height were 15% and 25% lower than those of sprinters ($p < 0.05$) and similar to control values, being 2% greater and 6% lower, respectively ($p > 0.5$). Material eccentricity analysis suggests that torsional stresses may be a significant adaptive stimulus to tibial bone.

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Conclusion: Results suggest that sports with quick turning movements are highly osteogenic, even in the absence of greater muscular output. This may be related to the large torsional stresses produced during turning movements.

Introduction

There is good reason to assume that the effects of exercise on bone strength are mainly the result of mechanical signals [1,2]. Moreover, it is now well recognised that the largest forces on bones involve regional muscle contractions [3]. Accordingly, it is assumed that bouncing movements such as running and hopping are particularly beneficial for bones due to the large eccentric muscle forces produced in order to negotiate mass inertia during ground contact. In support of this are results of exercise studies based on bouncing activities in children [4,5] and older adults [6], which have resulted in some of the most impressive exercise effects on bones observed in interventional models. Similarly, athletes in sports involving running or bouncing movements have greater bone strength than those in other sports [7,8]. In particular, master sprinters have 14–23% greater tibial bone mass than age-matched controls [9]. That this difference is comparable to the largest group differences in lower limb bone strength observed between young athletes and controls [8] is particularly impressive, considering that exercise benefits for bones are negatively associated with age [10,11]. Jumpers display large interlimb asymmetries in ground reaction force (GRF), with peak GRFs being much larger than those experienced by sprinters [12,13]. However, side-to-side differences in jumpers are impressively small, amounting to a few percent between jumping and control leg [14]. This suggests that the greater GRFs in jumping do not result in any marked benefits in bones above those accrued through sprinting. In addition, sprinters have far greater muscle strength and power than sedentary controls [15], with values similar to those of Olympic weightlifters [16]. Hence, they can be considered a model of optimal lower limb musculoskeletal health.

However, the discourse has, to date, largely neglected the possibility that different types of deformations could differ in their effectiveness at stimulating bone anabolic responses. This is despite the pioneering study by Rubin et al. [17] in which torsional loading has already been demonstrated as a more potent stimulus to prevent disuse-related bone loss than axial loading. The largest effects so far observed as a result of exercise in humans are found in sports that involve torsional arm bone loading—namely tennis [18] and baseball [19]. Indeed, in a recent study upper limb bones were found to be more than proportionally strong against torsional strain as the moment arm for torsional muscle stress (bone width) increased [18].

Different kinds of exercises involve different amounts of compressive, torsional or bending deformation as shown for the human tibia in a recent study [20]. Bouncing steps—where the tibia is loaded by mass inertia, and mostly over the forefoot—are rare in tennis. In contrast, these are the dominant activities in sprint running, with no sharp turns or changes of direction. While the tibia experiences substantial strain in torsional and both bending axes during linear locomotion at different speeds, the main effect of increasing walking and running speed is in concurrent rise of anterior–posterior bending [20]. Hence, torsional strains are not the likely source of observed greater bone mass in sprinters compared with distance runners, walkers, and controls [9]. Turning movements are highly prevalent in tennis, representing over 50% of movement events, with each player completing several hundred turns during a typical high-level match [21]. These quick turns, both for baseline work and for attack and defence, must be expected to involve particularly large torsional strains in the tibia even in the absence of large reaction and muscle forces. This is supported by the findings of much larger peak knee and ankle torques (likely to cause tibial torsion) in turning movements compared with straight-line locomotion [22,23]. Animal studies have reported greater bone strength in mice whose environment was altered to encourage turning movements, compared with those where linear locomotion was favoured [24]. Existing studies investigating the effects of regular tennis play on lower limb bone [25–28], muscle size [26–28], and muscular output [26,29,30] have produced conflicting findings. However, these differences may be, at least in part, attributable to methodological issues such as use of dual-energy X-ray absorptiometry for bone assessment, different methods of muscle assessment, and study of players with different levels of ability. Comparisons of the bone strength of sprint runners and tennis players would be an ideal way of discerning the relative importance of bouncing versus turning movements in tibial bone strength.

Hence, to examine the relative effects of these two movement types on bone strength, a study of veteran tennis players and sprinters was conducted. For the first time in tennis players, lower limb peripheral quantitative computed tomography (pQCT) scans were taken for analysis of bone geometry. Jumping mechanography was used to measure muscular performance. This technique is highly repeatable and sensitive compared with other common neuromuscular and locomotory tests, such as maximum gait speed and chair-rise tests [31]. It can be successfully applied even in very old and frail individuals incapable of performing other tests, and assesses the effects of both athletic type [32] and age [33]. Old age is associated with a significant loss of lower limb force, particularly power [34] as well as bone strength [35]; therefore, the effects of exercise in older age are particularly important. In order to