

Title: Exercise for bone in childhood – hitting the sweet spot

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Running Head: Optimal exercise timing for bone in childhood

Abstract

Purpose The goal of the current work is to challenge the enduring notion that pre-puberty is the optimum timing for maximum bone response to exercise in childhood, and to present the evidence that early puberty is a more a potently receptive period.

Method The relevant literature is reviewed and the causes of the misconception addressed in detail.

Results Contrary to prevailing opinion, ample evidence exists to suggest the peri-pubertal years represent the developmental period during which bone is likely to respond most robustly to exercise intervention.

Conclusion Public health initiatives that target bone-specific exercise interventions during the pubertal years is likely to be the most effective strategy to harness the increased receptiveness of the growing skeleton to mechanical loading.

Keywords: bone mass, children, exercise, maturity, physical activity, puberty

Background

Puberty ensues when marked alterations in circulating hormones in childhood stimulate dramatic physical and physiological transformations. It is therefore small wonder that the body can be observed to respond differently to certain stimuli according to the timing of the provocation in relation to puberty. Such may be the case for exercise and bone.

Statements that bone is optimally responsive to the stimulus of exercise in the years prior to puberty are abundant in the literature (12, 18, 19, 30, 33, 77, 85) and a multitude of works have been cited to support the claim (5, 10, 11, 13, 15, 20-22, 24, 26, 29, 31, 32, 34-36, 38, 39, 43, 44, 47, 51-53, 63, 66, 68, 79, 82, 84-86, 90). The sentiment is frequently presented in introductory sections of scientific reports in a manner that suggests it to be accepted lore (62, 86, 90). Oddly, the belief runs counter to the preponderance of the evidence (6, 15, 22, 24, 34, 37, 39, 44, 55, 56, 60, 67, 68, 70, 72, 73, 88), and to the conclusions of many reviews of the evidence (23, 27, 41, 48, 50, 54). In fact, study outcomes have long indicated that exercise *during* puberty, particularly early puberty, will invoke the strongest response from bone. As the astute reader will note, some of the studies cited to support an optimal *pre*-pubertal timing are also frequently cited to support optimal timing *during* puberty! Almost 15 years ago a systematic review entitled “Is there a critical period for bone response to weight-bearing exercise in children and adolescents?” concluded the ‘window of opportunity’ for bone to respond to exercise in children appears to be open most widely in early puberty (54). And yet the pre-puberty notion has persisted. Clearly there is a disconnect between research observations and how they are interpreted and conveyed in subsequent scientific and lay literature.

There appear to be a number of reasons for this disconnect. The first reason is the self-fulfilling practice of making over-arching conclusions from studies that examined *only* pre-pubertal children such that comparisons between responses of children at different stages of maturity cannot be made (11, 21, 31, 51, 52, 82, 84). Second, there have been flaws in the interpretation and/or representation of the outcomes of paediatric exercise studies, including a lack of accounting for changes in pubertal status over the course of longitudinal exercise interventions. The third, and probably least defensible reason, is the tendency for authors to employ secondary referencing, rather than reading, interpreting and citing original works. The latter practice, of which virtually all authors are guilty at some point,

inherently perpetuates inaccuracies. The fourth and most subtle but explicable reason, however, is the practice of interchanging non-equivalent terminology to describe the stages of maturation around puberty. This has occurred most influentially in relation to an interesting series of bone-focused racquet sport studies (36, 47, 49) commonly referenced to support the pre-pubertal argument. To be clear, this mistake is not related to the quality of those important studies; rather from the manner in which they have been subsequently interpreted.

Purpose

The purpose of the current work is to present a summary of the origins of the notion that pre-puberty is the optimum time for maximum bone response to exercise in childhood, and to present the evidence that exercise intervention during the early stages of puberty is in fact likely to be more potent timing. The reasons for the pre-puberty myth, outlined in the preceding paragraph, will be addressed systematically, but clarification of terminology is an important place to begin.

Definitions

Puberty is a somewhat general term defined as “the time at which the onset of sexual maturity occurs and the reproductive organs become functional ... These changes are brought about by an increase in sex hormone activity due to stimulation of the ovaries and testes by pituitary hormones” (2). At puberty there is a period of rapid growth which is a consequence of increased secretion of gonadotrophin releasing hormone (GnRH), sex steroids, growth hormone and insulin-like growth factors (8), all of which stimulate bone growth, either directly or indirectly.

Puberty is commonly described in five Tanner stages, coined by the late British paediatrician James Tanner, according to the appearance and development of secondary sex characteristics in response to alterations in circulating hormones (57, 58). Tanner I is the stage of complete absence of secondary sex characteristics and is therefore deemed to be pre-pubertal. Tanner V is the stage when full sexual maturity has been attained and is therefore considered to be post-pubertal. Tanner II-IV describe stages of change between pre- and post-puberty (sometimes referred to as peri-pubertal) and, not surprisingly, coincide with the largest surges of growth-related hormones. (While Tanner staging is a useful and well-accepted index of pubertal maturation, it must be noted that the process of categorising a continuous socio-biological variable has the potential to introduce an element of error

that may have contributed to the problematic situation currently under discussion.) Tanner stages are routinely utilised to describe the optimal timing of exercise to stimulate the greatest osteogenic response. Menarche (first menstruation) typically occurs during Tanner IV, but can be earlier or sometimes later. The mean age of menarche (12.7 ± 0.98 years) essentially coincides with the timing of maximal bone growth (peak bone mineral content velocity; PBMCV), (12.5 ± 0.86 years), which suggests the time just prior to menarche (mid, rather than pre-puberty) is when most rapid skeletal growth occurs (59). As early as 1994, Slemenda and colleagues observed that 30% of adult bone mineral content (BMC) was accrued over three pubertal years; an observation echoed by others more recently (7, 14).

Self-fulfilling study samples

Numerous cross sectional and exercise intervention trials with bone outcomes have exclusively examined pre-pubertal children (11, 21, 31, 51, 52, 82, 84). Investigators have concluded variously that "... weight-bearing exercise undertaken before puberty may increase femoral BMD..." (21) (p1814), "...physical activity could be recommended as a strategy to increase BMC, aBMD, and bone size in prepubertal children" (51) (p 834), and "...exercise in prepubertal boys influences the accrual of bone..." (52) (p 340). Those conclusions were entirely justified, being supported by the outcomes of the studies. However, the findings have been misinterpreted by many to indicate that the period before puberty represents the *best* window of opportunity to stimulate bone with exercise, regardless of the fact that responses from children at other pubertal stages were not examined simultaneously for the purposes of comparison.

It must also be noted that, in some instances, exercise has not been found to enhance the pre-pubertal skeleton (32, 90).

A little misclassification goes a long way

Misinterpretation and/or misrepresentation of study sample maturity has further entrenched the pre-puberty dogma. Some investigators have classified study samples as pre-pubertal when their sample actually included more mature children or children who transitioned from Tanner I at baseline to higher Tanner stages over the course of a study (13, 22, 32, 82, 84, 86, 90). For example, one study included boys classified as both Tanner I and II and yet concluded "football participation is associated

with improved ...BMC masses, and enhanced femoral and lumbar spine BMD in pre-pubertal boys” (86). Another examined six to nine year old children who were Tanner I at baseline but transitioned to Tanner II-IV by the end of the five-year intervention. Although no data specific to the pre-pubertal response to exercise was presented, the authors concluded “...daily moderate physical activity ought to be introduced to pre-pubertal children from the start of school.” (22) (p 392).

There have been only two studies comparing the response of exercise in relation to pubertal stage that have shown most bone was gained pre-puberty (53, 63). Macdonald and colleagues (53) examined the response of tibial strength variables after a 16-month in-school exercise intervention in Year 4 and 5 students (average age 10.2 years). They determined Tanner stage by self-report at baseline and follow up, but categorised the children into maturity groups according to Tanner stage at baseline. On this basis they concluded that bone strength gains occurred in pre- but not early pubertal boys, and not in girls at all. In fact, between one third and one half of the study participants were no longer pre-pubertal by the end of the study, suggesting that they were exposed to the exercise loading in early puberty, not before. Meyer and colleagues (63) examined the effect of nine months of daily physical education including ten minutes of jumping on 158 pre- (Tanner I, 8.7 years) and 133 peri-pubertal (Tanner II-III, 11.1 years) children (of whom 39 transitioned maturity stage during the trial). There was a pubertal stage x group interaction for whole body and femoral neck BMC and lumbar spine BMD favouring pre-puberty but there was no information about the timing of the transition for the 39, which renders the findings difficult to interpret.

Despite the results of a 2010 meta-analysis illustrating an effect of exercise for pre *and* early-pubertal boys, the authors concluded that “...the current data from several intervention trials in children indicate that programmes incorporating a diverse range of weight-bearing impact activities can enhance the mass, structure and strength of bone, particularly in boys during the pre-pubertal years.” (68) A subsequent meta-analysis of 32 interventions, mean age 10.3 ± 2.7 years, of which only 50% were pre-pubertal also surprisingly concluded “Results of this meta-analysis (in children and adolescents) conclude that weight-bearing activities ...significantly improve BMC in pre-pubertal children, justifying the application of this exercise form as an osteoporosis prophylaxis in this stage of maturity.” (15)

Evidence for an optimal effect of exercise on bone during puberty

The endurance of the pre-puberty belief is particularly perplexing in the face of long standing evidence to the contrary. Certainly the age at which bone is most rapidly accumulated has long been well-characterised. In 1983, Ruff and Hayes described changes in femoral length and area between six and 22 years of age in a Pecos Pueblo archaeological sample and concluded that femoral cortical shaft area increases slowly by way of periosteal apposition up to age 14, then rapidly until 16, after which time growth slows through the end of the third decade (76). Another group measured BMC and BMD at different skeletal sites in 151 white European girls at the onset of puberty, during puberty, and at menarche and similarly observed the increase in bone mass formation was highest from mid-puberty to menarche (83). While the timing of natural bone accrual does not necessarily govern when the skeleton will be most responsive to loading, it is not an inconceivable supposition that the presence of hormones that promote regular bone growth might enhance an osteogenic response to mechanical loading.

Indeed longitudinal data indicates that around 30% of adult female spine bone mineral is “accumulated in the 3 years around the onset of puberty” and that physical activity is associated with more rapid mineralisation during puberty than before or after (78). A six year study examining the relationship of physical activity to BMC accrual observed 9% and 17% greater whole body bone mass accumulation during the two years around peak bone mineral content velocity in the most active boys (mean age 14.05 y) and girls (mean age 12.54 y), respectively, compared with the least active, amounting to around 26% of final adult BMC (10). In a later publication, the authors stated: “Based on these observations, bone appears to be most responsive to mechanical stress during Tanner stages II through IV, corresponding to the two year window that has been identified for peak bone mineral accrual around the time of puberty.” (9)

In fact, a large number of studies have reported an osteogenic response to exercise in early pubertal children (34, 42, 55, 56, 60, 61, 63, 66); in some cases in the absence of effect in pre-pubertal children in the same trial (56, 72). A 1997 ten-month study of 71 ‘pre-menarcheal’ girls, who appeared to be Tanner Stages I and II, reported improvements in overall bone outcomes but no maturation-based comparisons were made (66). MacKelvie and colleagues (56) conducted a seven-

month jumping and circuit exercise intervention in pre- and early pubertal girls and found that only the girls in early puberty gained significantly more bone at the femoral neck and lumbar spine than maturity-matched controls. The latter study was the first to suggest that early, but not pre-puberty provided a ‘window of opportunity’ for exercise induced bone gain for girls. Soon thereafter, Petit and others (72) also showed a response to exercise in early but not pre-pubertal girls. In 2003, MacKelvie and colleagues (55) reported additional data to indicate that a two-year exercise intervention improved spine and hip BMC in Tanner I-III girls and in 2005, McKay and others reported increased hip BMC in early pubertal girls and boys in response to the Bounce at the Bell intervention (60). Arnett and Lutz (6) and Weeks and colleagues (88) also reported improvements in bone in response to jump training in mid to late puberty, but no comparisons with pre-pubertal children were made.

A number of reviews have similarly concluded that exercise has the strongest osteogenic effect in early puberty (41, 55, 65). Hind and Burrows (41) reviewed 22 RCTs, nine including a sample in Tanner I, eight in Tanner II-III, and five in Tanner IV-V and showed 100% of trials conducted in early pubertal children reported an exercise effect, as opposed to 67% in pre- and 40% in post-pubertal children. While study heterogeneity and high risk of bias, as well as criticisms of the scoring system in the Hind review (71) have been raised, the preponderance of the evidence for bone response to exercise nevertheless does not lie with the pre-pubertal stage of maturation.

Although cross sectional studies do not offer the highest level of evidence, nor an indication of cause and effect, the data can be informative. A positive association has been reported between radial BMD and time playing sports at age twelve (28). Physical activity at 15 but not 11 years of age (for boys) was positively associated with BMD at age 18 in a recent Brazilian study (17), and teenage activity (ages 12-18) was associated with higher aBMD in Canadian postmenopausal women (75). Swedish athletes have been reported to remain sensitive to exercise loading well after puberty (69, 70). In a study of the relationship of bone-relevant physical activity to cross-sectional bone morphology, Rantalainen and colleagues (73) concluded that the peri- or post-pubertal period is likely a more favourable window of opportunity for enhancing cross-sectional bone geometry than pre-puberty, as the influence of physical activity was not apparent prior to the time of peak height velocity.

A number of studies and reviews have concluded that maturity does not influence the bone response to exercise (24, 50, 61). McKay and colleagues (61) observed no differences in effect of an eight-month school-based jumping program between girls who remained Tanner I (71.7% girls) and those who were Tanner II at follow up, however, the analyses lacked power. In a study of pre/peri- and post-menarcheal tennis players, years playing tennis was negatively related to gains in total area and cortical area over 12 months, however, after adjustment for growth rate, differences in annual increases in bone between pre/peri and post groups disappeared (24). It is difficult to interpret these data, however, as it is not possible to determine actual bone strain exposure over time and thus whether bone adaptation had merely met the loading demands of the activity in the early years of playing. A large (n=1743) longitudinal study of physical activity and calcium on bone mass accrual across the five of stages of pubertal development reported the greatest difference between high and low activity boys in Tanner III, but that overall there did not appear to be differential effects of physical activity on bone mass accrual according to maturational stage (50). They concluded that there are significant longitudinal effects of weight-bearing physical activity on bone mass accrual through all stages of pubertal development. Indeed, some authors of reviews have taken a similarly broad interpretation of the literature with statements such as "...the effect of weight bearing exercise in prepubertal, early pubertal and pubertal girls is small but statistically significant for BMC and aBMD..." (43) (p 890) (67, 79).

Physiological questions that are difficult to address in human studies can sometimes be answered by animal investigations. In the case of the current discussion, many of the animal studies cannot be interpreted for relevance to humans because age of maturity is not fully described, or the intervention is not applied in close proximity to a pubertally equivalent stage. For example, while a 12 week old mouse is considered fully mature, most of the maturity comparison studies are conducted in considerably younger or older animals. Differences in response to mechanical loading have been observed between nine month old versus 19 month old rats, with reduced responsiveness observed in the older rats, however, both groups could be considered mature (80, 81). An exercise trial of five week old versus 17 week old rats found no adaptive differences to 12 weeks of treadmill running between groups (16). Similarly, another trial of young (five week) versus old (33 week) male rats

induced exercise benefits in bone after 14 weeks, but no differences were observed between groups (46). There is some evidence to suggest that oestrogen encourages extra mineral to be deposited into female rat bone during puberty but suppresses the responsiveness of the skeleton to loading at that time (45).

Secondary referencing and other misdemeanours

Examples of statements from reviews of the paediatric exercise literature that have perpetuated the pre-puberty myth abound; at worst, as a consequence of secondary referencing; at best, as genuine misinterpretations of the evidence. As it is not the purpose of the current discussion to discredit reputable scientists for a common but unfortunate practice, these have not been included in the current work, but multiple examples are available from the author on request.

Terminology: (pre)puberty \neq (pre)menarche

The true crux of the propagation and perpetuation of the pre-puberty myth however, is the inadvertent transposition of the terms pre-puberty and pre-menarche. The above definitions of the stages and terminology around adolescent maturation illustrate the distinct differences between the terms pre-pubertal and pre-menarcheal, particularly in light of the considerable dissimilarity in circulating hormones before versus during puberty (the latter of which may include pre-menarche). Problems arise when a study designed and reported as a comparison of pre- versus post- *menarcheal* effects, is interpreted and cited by others as pre- versus post- *pubertal*, thus representing an entirely different maturational stage.

For example, a 1994 paper by Haapasalo (36)(140 Scopus cites, Jan 2017) describing a comparison between 19 national level female squash players and 19 controls of side-to-side (s-t-s) differences in upper extremity bone mass is often used to support the pre-puberty argument. The authors found a relationship between magnitude of s-t-s differences and number of training years and elbow flexion strength. They also reported that starting age of training was negatively related to s-t-s differences; that is, the younger the player when they started training, the greater the evident s-t-s difference in bone mass. Importantly, they also observed that larger differences were found in players who had started their careers before or during *menarche* than after. The authors concluded that the benefits of playing are stronger if initiated at or before *menarche* (not puberty) than after. They

specifically state that “The bone gain seemed to be greater if the exercise was performed during adolescence.”

In 1995, Kannus reported similar s-t-s comparisons from 105 national level female tennis and squash players versus 50 controls (47). The average age of the sample was 27.7 years, average starting age was 16, and average playing years was ten. The study participants were again grouped according to number of years before or after *menarche*. The reported s-t-s differences in racquet sport players were two to four times higher than controls in players who started their playing careers before or at menarche compared with more than 15 years after menarche. No other age group comparison was significant, including pre-menarcheal versus immediately post. The findings clearly do not represent a pre- versus post-*pubertal* comparison (or even pre- versus post-menarcheal comparison; rather a child (7-12 years) vs adult (33.7 years) comparison). The authors conclusion that “...tennis and squash activity started no later than puberty is maximally beneficial for mineralisation of the bones of the playing arm...”(p 31) has nevertheless frequently been interpreted to indicate a pre- versus post-*pubertal* comparison was conducted. Careful reading of the paper easily prevents this common misconception. The influence of the Kannus paper is not to be underestimated, as it is the most highly cited of its type (502 Scopus cites, Jan 2017), including by other highly cited works (11) (427 Scopus cites, Jan 2017).

In 1998, the same group reported additional data examining s-t-s differences of 91 7-17 year old female junior tennis players compared with 58 controls (37). In this study there were significant s-t-s differences in players at all ages, but the authors were unable to detect differences between players and controls until Tanner stage III (roughly 12.6 years of age). Differences in lumbar spine BMD were not observed between players and controls until Tanner IV, mean age 13.5 years and Tanner V, mean age 15.5 years. This high quality work which actually differentiates the level of maturation into Tanner stages has been cited much less frequently than the others (202 Scopus cites, Jan 2017), despite providing a more definitive description of the maturity effect.

In 2001, five year follow up data to Kannus’s 1995 (47) study was reported (49). It was observed that both early and late starters (of racquet sports) largely maintained s-t-s differences despite reducing training volume. Early starters lost more than late, but also reduced their training

hours more. In this report, the terminology used to describe the Kannus (47) cohort changes from *menarcheal* to *pubertal* despite menarche still being used as the delineating criterion. “Our initial investigation of female (racquet) players provided strong evidence that the effect of unilateral loading on the playing arm BMC is about two times greater if the playing is started before or at puberty rather than after it.”

Another influential study (39) (230 Scopus, cites Jan 2017), frequently cited to support the pre-pubertal argument, compared responses to a nine-month exercise intervention between 25 pre-*menarcheal* and 39 post-*menarcheal* girls and 62 controls. The authors observed that pre-*menarcheal* girls increased femoral neck and lumbar spine BMC compared with controls but not post-*menarcheal* and appropriately conclude that “...exercise is more beneficial for bone mineral acquisition during the growth spurt than thereafter...” (p1016). It is vital to note, only four in the exercise group (EX) and eight in the control group (CON) were Tanner Stage I while 21 EX and 25 CON were Tanner Stage II and above. Thus, as only 16% of the EX cohort were genuinely pre-pubertal, the findings of the study are indicative of a greater bone response to exercise in early puberty, not pre-puberty. This very clear conclusion has not prevented others from interpreting the findings to support the pre-puberty myth.

Another study that is sometimes referred to in support of the pre-puberty argument is a small uncontrolled study of 17 pre-, 11 peri- and 19 post-pubertal tennis playing girls aged 8-17 years that concluded “loading before puberty increases bone size and its resistance to bending.” (13). The study is difficult to interpret for a number of reasons. Numbers were low and the players were examined over a 12 month period, during which time some moved from one Tanner stage to another, further reducing statistical power. In addition, the authors use the terms post-pubertal and post-*menarcheal* interchangeably. Greater s-t-s differences in upper extremity bone mass and strength in the pre-pubertal players that did not increase further in the older players was reported, but there nevertheless appears to have been a trend for s-t-s I_p (polar second moment of area, an index of long bone resistance to torsion) differences to *increase* with maturation; 11.3% pre-, 16.9% peri- and 17% post-puberty. The authors’ statement “Loading during the peri- to postpubertal years resulted in medullary contraction at both sites; however, this did not lead to a significant increase in the side-to-side difference in cortical area (Table 3)” is not supported by data presented in the Table which appears to

indicate the pre-pubertal difference in cortical area was 7.7%, vs peri- 11.9% and post- 12.1%.

Notwithstanding the apparent inconsistencies in the report, the authors' conclusion that because the magnitude of s-t-s changes did not increase after pre-puberty the latter age is the most sensitive to loading is a non sequitur, as their data was incapable of determining whether bone adaptation had merely met the loading demands of the activity in the early years of playing. (294 Scopus cites, Jan 2017)

The above examples illustrate the notable difference in meaning conveyed by subtly different terminology.

Implications for research translation

Fortunately, where current guidelines exist, professional and disciplinary bodies appear to have taken a non-specific approach to the issue of optimal exercise timing in youth, including the International Osteoporosis Foundation (IOF) which states merely that "...weight-bearing physical activity plays a key role during the normal growth and development of a healthy skeleton." (4) A recent White Paper sponsored by Osteoporosis Australia takes an appropriately circumspect stance that "Childhood and adolescence may represent the optimal window of opportunity in which exercise can improve bone strength and protect against osteoporosis and fragility fractures in old age..." (25).

Neither the American Society of Bone and Mineral Research (ASBMR) nor the US-based National Osteoporosis Foundation (NOF) has an Exercise Position Stand for children and the Australian and New Zealand Bone and Mineral Society (ANZBMS) has not released a position statement in almost two decades. The existing ANZBMS statement was written before the above-described studies revealed clear preferential response of bone during early puberty and therefore may be forgiven for concluding: "Sufficient exercise during childhood and adolescence, particularly the pre-pubertal years, is more effective for increasing bone mass and strength than exercise in adulthood." (29)

The reliance of the public on web-based sources of health and medical information is widespread and there are no lack of examples of websites and blogs declaring pre-puberty to be the optimal time to exercise for bone. Some examples are as follows:

1. “The exercise effect on BMD was also shown in studies to be greater in prepubertal children verses pubertal children.” (74)
2. “... exercises also have great impact on the development of your bone mass. Weight bearing exercises must be performed before the pre-pubertal period or ages between 10-14 years old.” (89) [Suggesting the pubertal period does not begin until after age 14?]
3. “A recent study from the University of British Columbia in Vancouver shows that a regular vigorous exercise program for prepubertal girls can help to prevent osteoporosis when they are older.” (64)
4. Headline: “Prepubertal exercise increases bone mass, size” (3)
5. “Prepuberty bone is more responsive to calcium, protein and exercise before the onset of puberty.” (1)

So what?

If, as is apparent from the evidence, there is a degree of benefit of exercise on bone at all ages of childhood and youth, some may believe the issue of optimal timing is simply one of semantics. From a public health standpoint, nothing could be further from the truth. Such information provides guidance for parents, practitioners, and education departments who wish to focus energy and limited resources on intervention strategies at times when they are likely to be most efficacious. If the forecast of Hernandez and colleagues in 2003 is to be believed (“A 10% increase in peak BMD is predicted to delay the development of osteoporosis by 13 years...suggesting that peak BMD may be the single most important factor in the development of the disease” (40)), there is indeed much to be gained by particularly targeting (or at least, not missing) the most responsive time in childhood. Some evidence exists to suggest that the benefits of doing so are sustained even when an exercise intervention is withdrawn, at least in the medium term (87).

Moving forward

It would be a mistake to interpret the current commentary as a criticism of the literature discussed. Pediatric exercise interventions are extraordinarily difficult to conduct, with barriers to success that necessitate modifications to perfect study design. In the vast majority of cases those studies have provided the research and clinical community with valuable data that assist our

understanding of the influence of exercise in childhood. Instead, the over-arching message is that the onus to scrutinize, interpret and describe scientific work appropriately is ever-present and firmly in the hands of the reader.

Furthermore, in the wise words of Don Bailey almost two decades ago, “To evaluate effectively the role of childhood and adolescent physical activity on bone mineral accrual, there is a need for longitudinal studies that not only span the entire pubertal period, but in which maturity is controlled for” (10) (p1673). A study on that scale is yet to be attempted.

Conclusion

The pervasive opinion that exercise is most osteogenic for children prior to puberty is supported by remarkably little evidence. By contrast, the evidence that early puberty provides a ‘window of opportunity’ to most effectively stimulate bone through exercise is quite strong. Discussion around preferential exercise prescription for bone during a single childhood ‘window of opportunity’ is somewhat fraught. Exercise is undoubtedly an important strategy to optimise bone health and minimise the risk of fracture across the lifespan. Nevertheless, it behoves the scientific community to determine and convey with the utmost accuracy the outcomes of exercise interventions that are amenable to beneficial public health translation. The current work is an attempt to present the scientific justification to dislodge one of the most enduring myths around the most beneficial timing of exercise for bone health in childhood and provide a more accurate representation of the facts.

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