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Review Article

What is new in neuro-musculoskeletal interactions? From brains to babies

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The skull: a mechanostatic outlaw

JMNI readers know well the importance of habitual strains for skeletal health, but measuring them is tricky. One plucky participant displayed his commitment to knowledge in this field by having strain gauges temporarily attached to his tibia and cranium, in work reported by Hillam and colleagues[1]. He then performed a series of habitual activities likely to stress the two bones (eating, pulling faces and walking, squatting), as well as some unusual movements designed to engender large strains (such as landing from a 1.3 m jump, and heading a medicine ball). Peak strains achieved during both types of activities were around ten-fold greater in the tibia than the skull, suggesting a greater range of strain thresholds between bones than those identified previously within the same bone[2]. The authors suggest that this site-specific strain difference may be related to the consequences of failure of a particular bone. The skull's role in protecting the brain means that a fracture here is likely to have more serious consequences than in the tibia, hence the former bones are 'over-engineered' to allow a greater safety margin. This adds to the mechanoadaptive mystique of the skull, which sees increases in bone mineral density (BMD) following reduced physical activity in spaceflight and recovery from hip fracture[3]; and in which BMD is lower in sportspeople including active footballers presumably loading the area through heading[4]. To those who had to re-read the previous sentence, these results are indeed opposite to those which the Mechanostat might lead us to expect, and in contrast to observed effects in the weight-bearing skeleton in the same participants. It will be interesting to see whether these latest findings spur researchers in this area to add the skull to their 'sites of interest'.

A new technique for *in vivo* bone strain measurement

Whilst strain gauges offer useful information, they can only measure a few bone surfaces free of muscle such as the tibia; also, they only assess local strain and do not offer reliable data on bending and torsion[5]. Recent work from colleagues at the Deutsches Zentrum für Luft- und Raumfahrt (DLR for short) in Cologne offers some advantages in the latter two areas. They used motion capture systems commonly employed in the creation of the CGI monsters invading every summer Hollywood movie (and also occasionally used in biomechanical research – the systems, not the monsters). However, instead of affixing the reflective markers - required to track joint movement – to the skin with double-sided tape, they attached them to the tibial cortex via bone screws under anaesthetic to allow more stable fixation and hence accurate measurement of tibial deformation. They then asked participants to complete a series of typical movements such as walking and stair negotiation, so that they could measure resultant strains with this new optical segment tracking (OST) approach. Results showed substantial anterior-posterior bending during walking and running (which one might reasonably expect), but also mediolateral bending and particularly torsion (less obvious)[6]. Authors could attribute the latter primarily to muscular action[7] which is easy to reconcile with the fact that neither the calf or thigh muscles act in line with the tibia. These torsional strains in particular may be important; in a modelling study, Mittag and colleagues from the same group identified that they are necessary for the development of the tube shape we see in long bones[8]. So now, not only should we consider how much, how quickly, how often and how many times loading deforms bone but whether the result is a squashed, stretched, bent or twisted bone – the plot thickens!

An eccentric approach to resistance training

"It ain't what you do it's the way that you do it, And that's what gets results."

(Bananarama)

For those of us struggling to maintain motivation on a New Year fitness kick, work from Nottingham may help better direct

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your efforts. Conventional resistance training involves both the lifting phase where the muscle shortens (concentric contractions), and the lowering phase where the muscle lengthens whilst still producing force (eccentric contractions). Franchi and colleagues employed a clever approach to isolate the two contraction modes, and examine their separate effects on muscle. They asked ten young males to perform a four-week weight training programme, with one leg only lifting the weight whilst the other performed the lowering movement thanks to a motorised knee extension machine[9]. Overall increases in muscle thickness following training were similar between the two legs. That contraction mode did not affect overall muscle growth was supported by similar levels of new muscle protein created in each limb identified with a deuterium (heavy water) tracing method in muscle biopsies. However, the group also took a deeper look into changes in muscle geometry which is where the interesting results lie. Increase in muscle fibre length was greater following eccentric (lowering) contractions, suggesting that the addition of sarcomeres (the building blocks of muscle fibres) as the muscle grew was primarily in series. In contrast, after concentric (lifting) training fibre angle was substantially increased suggesting that the new material was laid down in parallel. So why is this important? For a start, this arrangement of sarcomeres determines the muscle's functional output, with the number of sarcomeres in series or parallel determining maximum force and shortening velocity. In addition, sarcomere length has recently been implicated as a risk factor in sporting injury by Timmins and co-workers[10]. So, if your sporting or general fitness aims are to get faster or stronger (or prevent injury!), a subtle tweaking of your training regime may help you achieve the desired effects.

Insights on pre-natal life

The forces produced by adult muscles during movement are certainly impressive, but expectant mothers will be acutely aware of equally formidable feats of strength performed very early in life. Limb movements caused by muscular contraction begin in the first trimester of pregnancy as stretches, turns and kicks. However, little is known about them in terms of the load they place upon growing bones and joints, and hence their importance for development of the human musculoskeletal system. Current maternal recall, actograph and ultrasound-based assessments of fetal movement are limited by factors such as field-of-view size, accuracy of recall and an understanding of how they relate to mechanical loading of the skeleton. Consequently, whilst it is clear that fetal movement is important for bone and joint development in cell and animal models[11], effects on the human skeleton are only evident in their absence. In neuromuscular diseases causing fetal immobility, babies are born with small muscles and slender, weak limb bones which frequently fracture at birth[12]. However, help may be at hand in the form of cine-MRI; previously used in the clinic to image the heart or cerebrospinal fluid in motion. This approach offers an opportunity to gain first insight into human fetal loading, allowing 2D video capture of babies' movements with the whole body in view. Verbruggen and colleagues[13] used this technique to measure deformation of the uterus wall due to kicking movements, and using clever modelling and biomechanical techniques estimated muscle forces acting on the bone. Individual muscle forces were estimated at up to 21N, which would equate to around 4-5 times body mass. Simplifications such as consideration of only select muscle groups and application of force only through the heel were made, but this innovative first approach offers clear potential for future applications. Whilst such large forces are observed during movements in adults, this is fascinating first evidence that the situation is not so different *in utero*. Hopefully, this technique is the first step in exploring new opportunities to promote healthy bones and joints from birth.

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