THE ARCHITECTURE OF A HAMSTRING STRAIN INJURY

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INTRODUCTION

In previous issues of the Aspetar Sports Medicine Journal, risk factors for hamstring strain injury (HSI) have been thoroughly reviewed[1,2]. These articles identified age, previous injury, strength and perhaps flexibility as the main risk factors for HSI after rigorously reviewing the literature[1,2]. In recent years large prospective cohort studies have confirmed a significant, albeit weak, association between strength and flexibility as risk factors for HSI, alongside age, body mass and playing position[3,4,5]. However, more recent research efforts have focused on muscle architecture and its relationship with risk of hamstring injury[9,13].

MUSCLE ARCHITECTURE AND 'THE QUADRANT OF DOOM'

Muscle architecture assessment is performed using two-dimensional ultrasound to determine the muscle thickness (distance between superficial and deep/ intermediate aponeuroses), fascicle length (a fascicle is a collection of muscle fibres wrapped in connective tissue) and the angle of these fascicles relative to the tendon (pennation angle), within a given muscle (Figure 1). The majority of the research on muscle architecture concentrated on performance parameters of these architectural variables (e.g. relationship of fascicle length and running speed) in a variety of muscles[6,7,8]. However, an Australian research group completed a series of studies that demonstrated shorter fascicle lengths of the biceps femoris long head (BFlh), the most commonly injured hamstring muscle in high speed running, were associated with an increased risk of HSI[8,9]. Initially, a retrospective design showed fascicle length of previously injured BFlh was significantly less than the contralateral BFlh[8]. This same research group, using a prospective study design in 152 Australian soccer players, demonstrated that athletes with shorter BFlh (<10.56 cm) were 4.1 times more likely to sustain a HSI than those with longer fascicle lengths[9]. Also, athletes with lower eccentric hamstring strength (<337 N) were at 4.4 times greater risk of a subsequent HSI than stronger players[9]. If high levels of eccentric knee flexor strength and long BFlh fascicles were present, the likelihood of a future HSI in older athletes or those with a HSI history was reduced[9]. The presence of short fascicles and lower eccentric strength is now affectionately known as the 'quadrant of doom' (Figure 2). These results suggest, albeit indirectly, increasing biceps femoris fascicle length in concert with improvements in eccentric hamstring strength may be an effective strategy for reducing HSI injury risk.

The mechanism by which shorter fascicles are more prone to injury remains ambiguous. Theoretically, shorter fascicles, with presumably fewer sarcomeres in series, will be more susceptible to damage as a consequence of sarcomere 'popping' while lengthening[10]. It could then be hypothesised that fascicle lengthening may be mediated by the addition of in-series sarcomeres that would reduce excessive lengthening of each sarcomere during eccentric exercise[10-13].

Fortunately, clear clinical strategies are available to alter fascicle length in hamstring muscles utilising eccentric strengthening.

IT WORKS IN THEORY BUT NOT IN PRACTICE?

Repeatedly, eccentric strength training intervention studies have demonstrated an increase in fascicle length of the BFlh[14-17], with concentric interventions demonstrating a decrease in fascicle length[15,18]. These varied interventions include: isokinetic dynamometry[15], leg-curls[14,18], 45° hip extensions[16] and the Nordic Hamstring Exercise (NHE) (Figure 3)[16,17]. The NHE in particular has received much interest in the HSI literature[16,17,19,20], with clear evidence from robustly designed randomised controlled trials of a reduction in HSI[19,20]. Furthermore, a recent systematic review has further demonstrated the efficacy of the addition of the NHE into HSI prevention programmes, displaying a 51% reduction in HSI risk with the inclusion of this exercise[21].

Due to the significant success of the NHE in reducing HSI, it has been described as a hamstring injury 'vaccine' and may well be seen by some as the panacea for hamstring injury prevention. If this is the case, surely then HSI rates must be reducing dramatically since all of this level 1 evidence has emerged? In elite European football (soccer), hamstring injuries rates have not changed (or even slightly increased) between 2001 and 2014[22]. High speed running demands may have increased in elite football during this period which could partly explain the increased injury rates. An apparent contradiction exists between the effective method for reducing hamstring injuries (with evidence from rigorous randomised controlled trials) and reports of increasing hamstring injury rates. In response, a follow-up study of elite football teams was undertaken to investigate their adherence to the evidence-based exercise programmes involving the NHE[23]. Staggeringly, more than 83% of the clubs were seen as non-compliant with the exercise programme outlined in the randomised control trial by Petersen et al[20,23]. Of course, a 'vaccine' will never be effective if it is not actually taken. Perhaps the exercise dosage has been excessive in previous studies and not feasible for sporting implementation.

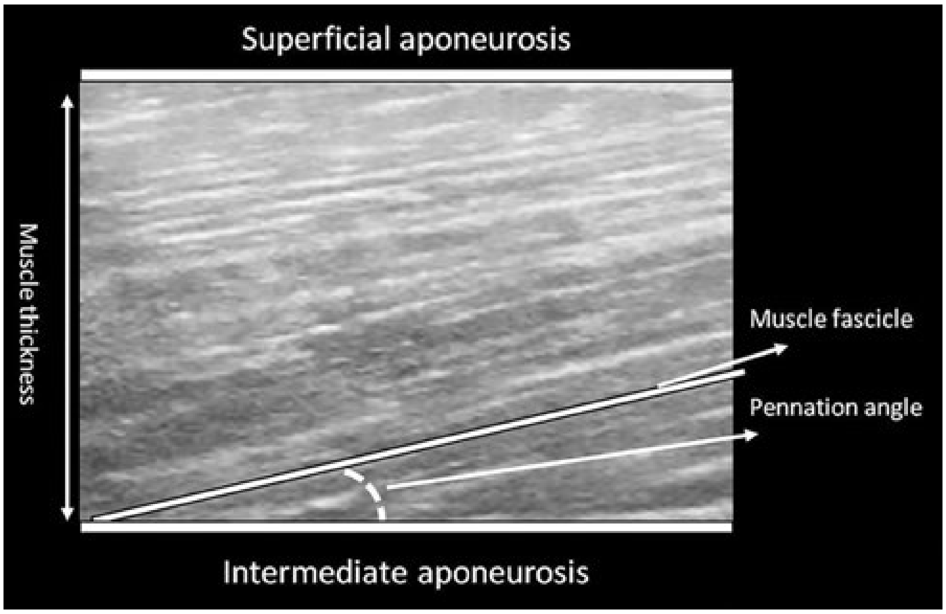

Figure 1: An ultrasound image of the biceps femoris long head.

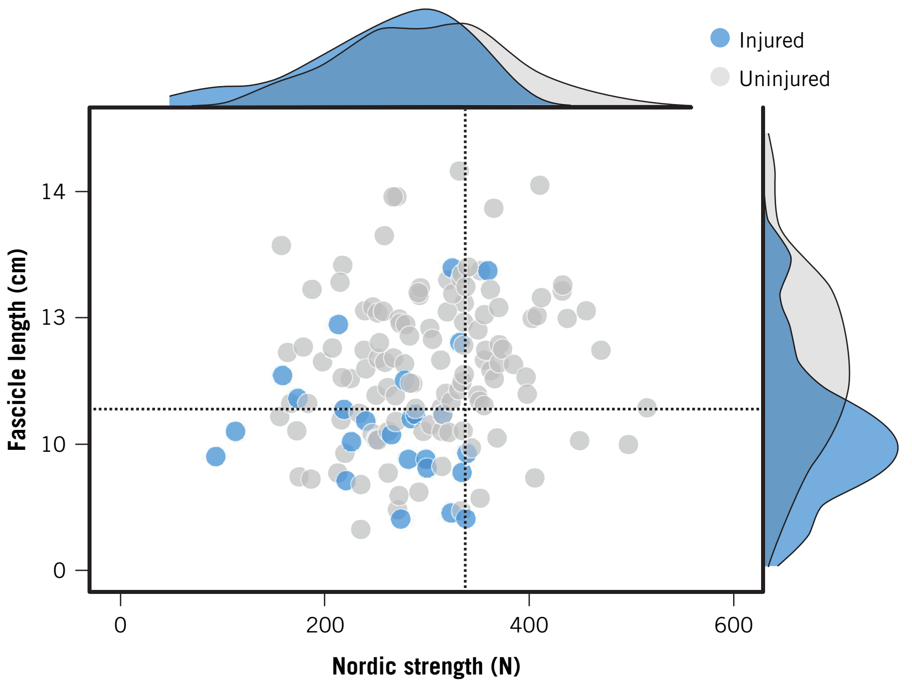

Figure 2: Distribution of biceps femoris fascicle length (y-axis) and eccentric Nordic hamstring exercise (NHE) strength (x-axis) for the injured (blue) and uninjured (grey) players. The bottom left quadrant represents the greatest proportion of injured players known as the "quadrant of doom." The distribution of injured and uninjured players are demonstrated for each variable at the top (eccentric NHE strength) and right (fascicle length) of the graph. With permission from Nirav Maniar.

Most of the NHE programmes used a progressively increasing high volume prescription: within 5 weeks of commencing the exercise, athletes are asked to complete up to 3 sessions a week, each session comprising of 3 sets of up to 12 repetitions per set[20]. The lack of adherence in elite football might be in response to the volume of the training programme, therefore, a recent intervention based study compared a high volume to a low volume NHE programme[17]. The low volume group commenced with two weeks of relatively high volume, where for two days that week they completed four sets of six repetitions of the NHE, similar to the high volume group. Thereafter, the low volume group only completed one session a week of 2 sets of 4 repetitions, while the high volume group increased in volume up to 5 sets of 10 repetitions (Table 1). Surprisingly, both groups had similar increases in eccentric knee flexor strength and BFlh fascicle length, with no statistical differences between the two groups for either variable in response to training[17]. Although this study did not report prospective injury rates, it is very promising regarding the effectiveness of a dramatically lower volume of NHE on indirect markers of HSI risk.

It would be logical that an athlete already engaging in on-field training, strength training, and competitive matches would be much more likely to adhere to 8 repetitions a week of NHE, rather than over 90 repetitions per week, as per previous protocols[20]. Investigations on the effectiveness of even lower doses of NHE on these variables has already commenced and soon a minimal effective dose may be established. Hopefully, these lower volume interventions can subsequently be implemented in prospective trials to investigate their effect on HSI levels directly.

NOT THE ONLY ONE

Although much of the research discussed involves NHE, this exercise certainly is not the only show in town for improving strength and architectural parameters. This was well demonstrated in a recent trial comparing the NHE to the 45° hip extension[16]. The two exercises resulted in similar outcomes for both BFlh fascicle length and eccentric knee flexor strength[16]. Alongside previous alternative exercise protocols that increased both eccentric strength and BFlh fascicle length[14,15,18], these findings illustrate the options and variety available in exercise prescription. It is apparent that eccentric hamstring interventions can be altered, adapted, progressed, and varied depending on the reasoning of skilled practitioners, always with consideration for athlete preference and adherence.

CAN WE (RELIABLY) MEASURE ARCHITECTURE OUTCOMES?

If you're convinced that assessing muscle architecture may be a worthwhile and valuable method to add to your injury prevention and rehabilitation toolkit, you may ask how reliable are the available

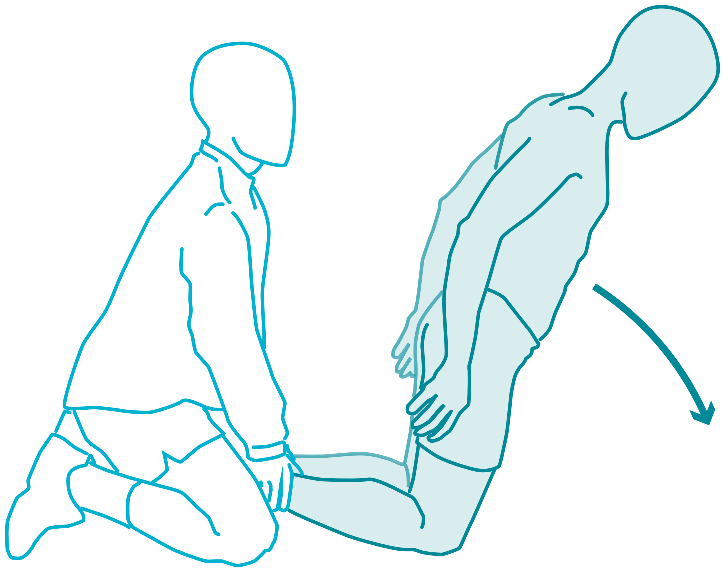

Figure 3: The Nordic Hamstring Exercise.

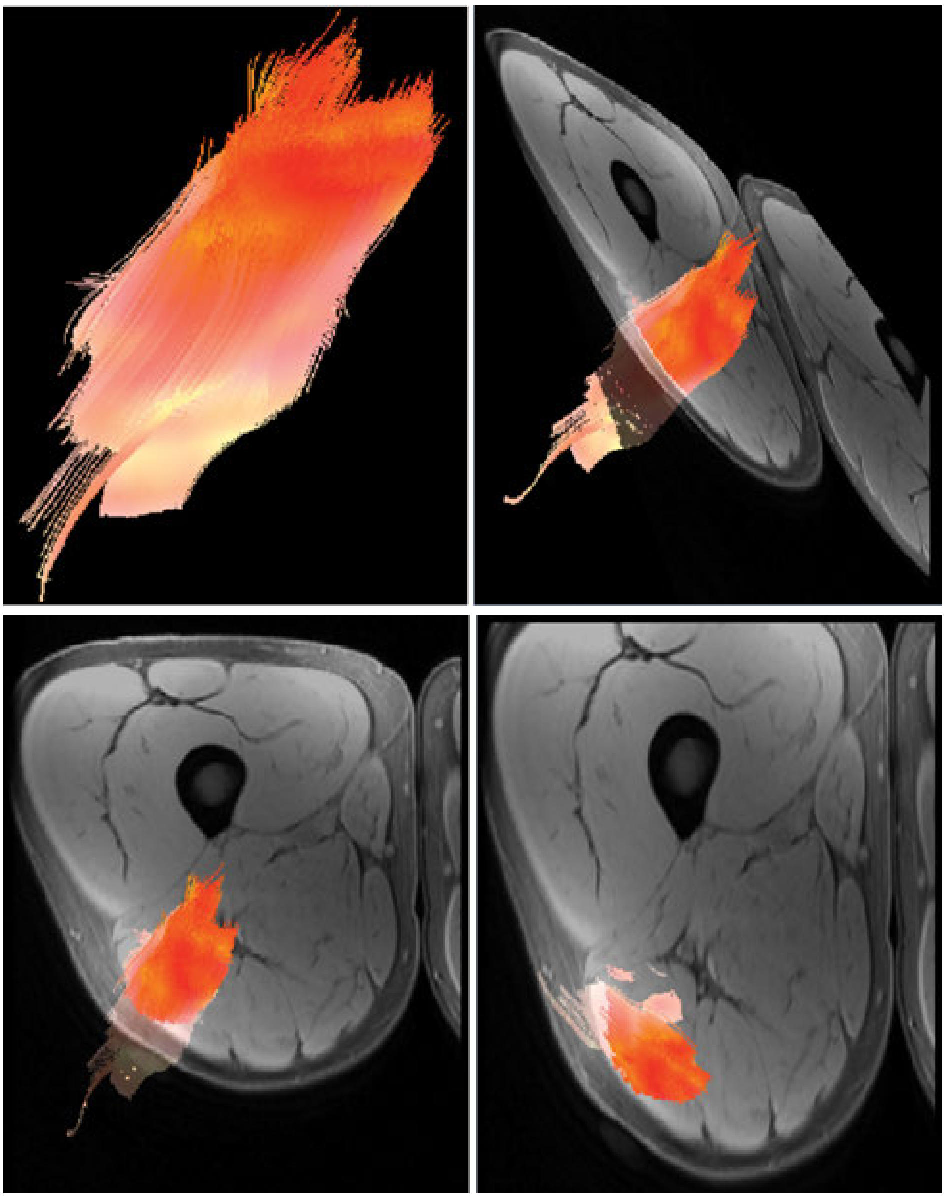

Figure 4: DTI MRI images of the biceps femoris long head.

Table 1

	High Volume Intervention				Low Volume Intervention			
Week	Frequency	Sets	Reps	Total Reps	Frequency	Sets	Reps	Total Reps
1	2	4	6	48	2	4	6	48
2	2	4	6	48	2	4	6	48
3	2	4	8	64	1	2	4	8
4	2	4	10	80	1	2	4	8
5	2	5	10	100	1	2	4	8
6	2	5	10	100	1	2	4	8
Total				440				128

Table 1: Low and High dose Nordic hamstring exercise strengthening interventions (adapted from Presland et al[17]).

methods of assessment? Analysing these variables (muscle thickness, fascicle length, pennation angle) utilising ultrasound in BFlh has yielded very positive results. Excellent reliability has been reported at rest and under varying intensities of isometric contraction[8]. The comparison between measuring BFlh with ultrasound and directly through cadavers has also demonstrated robust outcomes[24]. Although there are clear limitations with measuring a three dimensional structure in two dimensions, certainly it seems to be a reliable, valid and cost effective method for assessing or monitoring muscle architecture[6,8,24], particularly with the development of improved methodology[25]. Technology has inevitably introduced advanced methods for assessing muscle architecture, including diffusion tensor magnetic resonance imaging. These methods have produced fascinating images and demonstrated exceptional results for muscles such as the gastrocnemius and soleus[26,27]. However, this imaging technique is expensive and requires specialised, time consuming post-processing. We recently investigated whether a simplified diffusion tensor imaging (DTI) analysis method (Figure 4), that could be feasibly implemented clinically, was reliable or sensitive enough to be recommended in musculoskeletal clinical practice for BFlh[28]. Unfortunately, this simplified version does not compare favourably with ultrasound and does not appear accurate enough to recommend for clinical practice[28]. Therefore, at present for the assessment of muscle architecture, ultrasound remains a reliable and valid method and certainly the most convenient. With the available expertise, specialist DTI processing is an intriguing area with research currently being undertaken, and it may find its way into clinical practice in the near future.

CONCLUSION

Many questions remain regarding the role of muscle architecture in hamstring injuries. Future prospective studies assessing architectural variables would be informative for this area. However, presently muscle architecture appears to be a valuable target to assess and include in injury prevention programmes within sports medicine. The importance of muscle architecture in rehabilitation is also currently being investigated. In the coming years, we might be able to inform clinicians on the effectiveness of various interventions on muscle architecture and hamstring strain injury prevention, rehabilitation and successful return to play. Ultrasounds at the ready....

References available at www.aspetar.com/journal

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