A MUSCULOSKELETAL MODELLING APPROACH OF ILIOTIBIAL BAND SYNDROME IN CYCLING. IMPLICATIONS FOR INJURY PREVENTION.

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The aim was to investigate the potential risk of developing iliotibial band syndrome (ITBS) through the analysis of the theoretical interaction between joint degrees of freedom and individual pedalling techniques. Experimental lower limb kinematics recorded from ten well-trained healthy cyclists served as input data of a musculoskeletal modelling to calculate the compression force between ITB and the lateral femoral epicondyle (LFE). Cyclists pedalled in a standardized position at a steady state (90rpm and 200W). Results demonstrated that ITBS potential risk increases in individuals whose pedalling technique exacerbate hip extension-adduction and/or knee extension-internal rotation. Furthermore, hip joint kinematics had a greater influence than knee joint angles. This simulation approach could be advantageously implemented as an additional tool to help diagnose and correct potentially harmful sport techniques and optimise equipment setup or design.

KEY WORDS: overuse injury, opensim, simulation.

INTRODUCTION: Iliotibial band syndrome (ITBS) is a common non-traumatic overuse injury of the lateral knee joint. Its which incidence is growing following the increased popularity of endurance sports such as running, cycling and the combination of both disciplines in duathlon and triathlon (Ellis, Hing, & Reid, 2007).
Despite an abundant literature, the treatment of ITBS remains complicated as it lacks evidence-based recommendations (Worp et al., 2015). The aetiology is commonly acknowledged as "multifactorial". ITBS has been widely described as a friction symptom due to the ITB sliding over the lateral femoral epicondyle (LFE) during repetitive knee flexion-extension. However recent anatomical observations suggested that ITBS would rather be a friction syndrome (Fairclough et al., 2006).
Since then, ITBS continues to be considered as a friction syndrome, probably due to the lack of quantitative biomechanical data on that particular issue. Previous experimental research on the pathomechanism of ITBS has mostly focused on kinematic analysis (Grau et al., 2011). Kinematic analysis provides a global external insight on biomechanics that fails to apprehend underlying musculoskeletal solicitations. On the contrary, the analysis of musculoskeletal parameters (e.g. muscle length/velocity, muscle/joint forces) is more relevant, but direct measurement during physical activity is impossible and only assessable through musculoskeletal modelling.
Musculoskeletal modelling has been used to compare biomechanical factors (strain and strain rate) of ITBS runners against a group of healthy participants (Hamill, Miller, Noehren, & Davis, 2008) but never before for investigating of ITB-LFE compression force.
However, the comparison between symptomatic patients against a healthy control group constantly suffers the same issue of not being able to identify the causal relationship and may lead to a "reverse causation fallacy" (e.g whether muscle weakness is the leading cause of injury or the other way around). This may explain the contradictory results on the role that hip abductor weakness may play in ITBS (Fredericson & Wolf, 2012), it also highlights the limitation of such an approach in identifying underlying pathomechanism.
Lower limb kinematics are influenced by pedalling technique and bicycle setup (Bini, Hume, Lanferdini, & Vaz, 2014) and several recommendations have been made to prevent the occurrence of ITBS (Dettori & Norvell, 2006). These recommendations have been made largely through the extrapolation of results found in epidemiological and clinical studies, rather than being based on proven biomechanical determinants (Dettori & Norvell, 2006). An

investigation of the underlying mechanisms is needed to help understanding the biomechanical determinants of ITBS and their association pedalling technique and bicycle setup. This is also required in order to improve the overall therapeutic management.
The aim of this study was to develop a musculoskeletal modelling approach that enabled investigating ITB-LFE compression force in cycling recognized as a contributing factor in the occurrence of injury (Fairclough et al., 2006). A simulation approach of the combined influence of hip and knee joint degrees of freedom on ITB-LFE compression force was further used to assess individual kinematics difference that may exacerbate the potential risk of ITBS.

METHODS: Ten well-trained cyclists without history of knee pain or injury volunteered to participate in the study (age: 30.9 ± 8.6 years, height: 1.75 ± 0.05 m, weight: 65.2 ± 8.3 kg). A stationary cycle ergometer SRM "Indoor Trainer" (SRM, Schoberer, Germany) and a 20-camera motion analysis system (Vicon Motion Analysis Inc., Oxford, UK) were used to acquire three-dimensional kinematics. Participants were instructed to perform a 3-minute trial while keeping constant cadence (90rpm) and power (200W).
A musculoskeletal model of the right limb was developed based on an existing full body model (Hamner, Seth, & Delp, 2010). ITB attachments sites correspond to the most recent anatomical description of iliotibial band; originates at the iliac crest, passes over the lateral femoral epicondyle (LFE) and terminates at Gerdy's tubercle (Eng, Arnold, Biewener, & Lieberman, 2015). LFE was represented as an additional body rigidly attached on the femur with a welded joint. ITB-LFE force was computed as the joint force between LE and the femur. This overcame the inability of the software to calculate forces between tendon and bone at intermediate insertion points.
The calculation of ITB-LFE compression force resulted from the recommended Opensim (Delp et al., 2007) calculation steps: 1) the model (i.e. segment lengths, ITB attachment sites) was scaled to match participants' anthropometry based on experimentally measured markers placed on anatomical landmarks, and location of joint centres that were individualised using a functional method; 2) joint angles were calculated with a global optimisation-based inverse kinematics procedure; 3) ITB-LFE compression force was calculated at the interface between ITB attachment on LE from joint kinematics and ITB force. An arbitrary (100 N) ITB force was fixed for all participants and conditions so that the influence of participants and conditions on ITB-LFE compression force focused on the varying kinematics only. A complementary simulation approach was developed to calculate ITB-LFE force over the entire range of motions of the hip and knee joints. ITB-LFE force was calculated for all combinations of hip and knee degrees of freedom using the same procedure.

RESULTS: First, the musculoskeletal approach showed that the time of peak of compression force occurred at 150.3 ± 2° of the pedalling cycle simultaneously with the peak of knee extension (39.1 ± 11.1°, mean across participants and conditions). Results of the simulation showed that the intensity of compression force was higher when the hip was extended and adducted and when the knee was extended and internally rotated. Maximal hip extension had a greater influence (up to 20N) than knee extension (up to 5 N). Inter-individual kinematic differences (5 ± 2°, average across conditions) were higher than inter setback condition differences (1 ± 0.5°, average across participants) for all degrees of freedom. One pedalling cycle of three cyclists is also drawn to illustrate the importance of individual pedalling technique. Maximal hip extension was 40, 55 and 70°, maximal adduction was -15, -10 and -5°, and the maximal compression force was 11, 6, and 3 N for participant 2 (solid black), 5 (dashed white) and 8 (dotted grey) respectively (Figure 1). Maximal knee extension was -20, -40 and -70°, maximal knee internal rotation was 8, 1, and -3° (external rotation), and maximal compressive forces was 2.8, 2.6, 2.4N respectively.

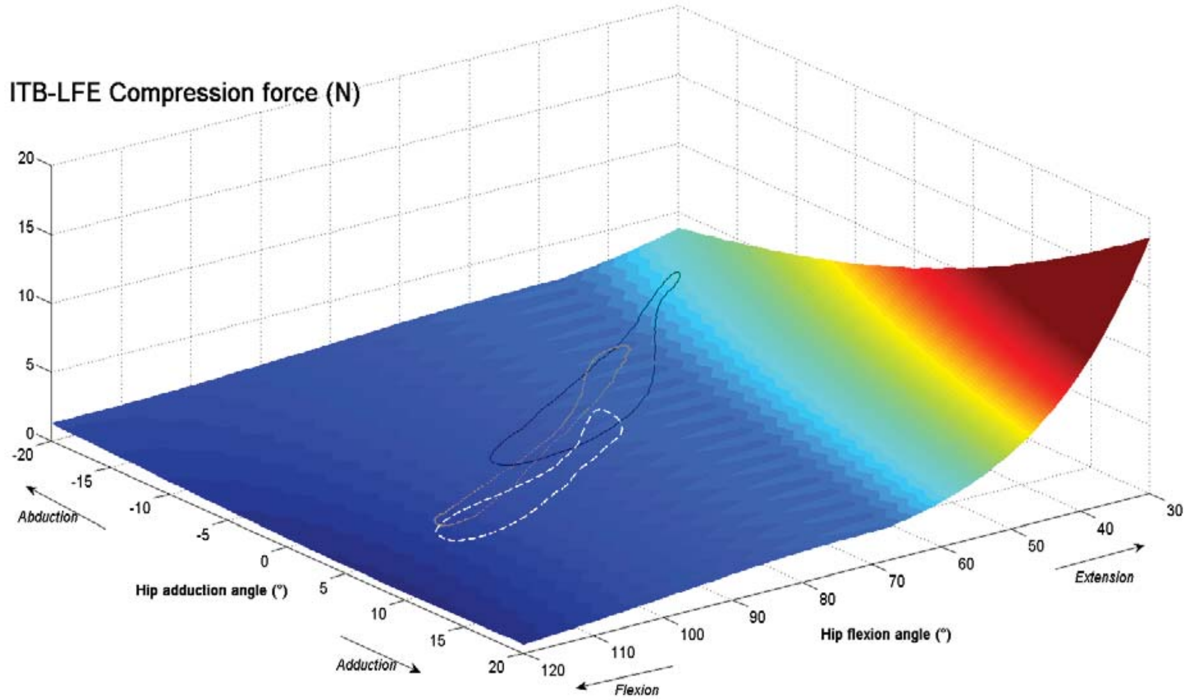

Figure 1: Simulation of ITB-LFE compressive force for combined hip flexion (120-30°) and hip adduction/abduction (20/-20°) angles. Solid black, dashed white and dotted grey lines illustrate the kinematics of participant 2, 5, and 8 respectively.

DISCUSSION: In order to better understand the influence of pedalling technique on ITBS in cycling, a musculoskeletal modelling was developed to analyse the ITB-LFE force during a pedalling cycle.

This study is the first one to calculate and report quantitative data of compression force between ITB and the femur (LFE). Given the biarticular nature of ITB, a simulation approach was then developed to investigate the combined influence of each degree of freedom on the compression force. Besides knee flexion angle, the simulation revealed a strong influence of knee rotation: for a 30° knee flexion, compression force can increase by 24% when associated with a 10° internal or external rotation.

Hip joint angles have an even stronger influence: for example, a 40° flexion (minimum flexion observed during a pedalling cycle) associated with a 10° adduction increases compression force by 100% (3.8 vs 7.6 N) in comparison to a 40° flexion associated with a 10° abduction (Figure 1).

Overall, the simulation highlights the necessity of studying the combined effect of all degrees of freedom of the hip and knee joint, rather than focusing on knee flexion solely. In order to assess the influence of individuals' pedalling technique, inter-individual kinematics difference was calculated. Maximal compression force occurred when knee flexion was minimal, i.e. approximately 30°, which corresponds to the joint posture that exacerbates pain in ITBS patients (Holmes, Pruitt, & Whalen, 1993).

Three representative participants were drawn over the simulation graphs to illustrate this finding, and show for example that participant 2 (solid black line) may be at a greater risk of developing ITBS than the other two. The participant had indeed a smaller hip adduction (Figure 1) - which is beneficial - but this was counteracted with detrimental higher hip extension and knee internal rotation, which lead to an overall greater ITB-LFE compression force.

In this perspective, the simulation brings biomechanical evidence that physical or manual therapy, such as osteopathic treatment for example, may also be useful to identify and decrease abnormal knee internal rotation and hip adduction.

CONCLUSION: The musculoskeletal modelling approach developed in this study gives new insights on the pathomechanism of ITBS in cycling: individual pedalling technique seem to play a critical role. Further studies should include longitudinal investigation of knee pain before and after pedalling kinematics correction to confirm those findings. In addition, whether these results could apply to other activities such as running and rowing is yet to be tested. Finally, this study highlights the importance of a thorough investigation of all the degrees of freedom crossed by an anatomical structure, and more generally the power of musculoskeletal simulation, to identify underlying pathomechanism and help for the treatment of cumulative trauma disorders.

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