HIP JOINT LOAD AND MUSCLE STRESS IN SOCCER INSIDE PASSING

Thomas Dupré[1], Kristian R. L. Mortensen[1, 2], Filip Gertz Lysdal[1, 2], Johannes Funken[1], Ralf Müller[1], Markus Braun[3], Hartmut Krahl[1], Uwe Kersting[2] and Wolfgang Potthast[1, 4]

Institute of Biomechanics and Orthopaedics, German Sport University Cologne, Cologne, Germany[1]
School of Medicine and Health, Aalborg University, Denmark[2]
Ballspielverein Borussia 09 e.V. Dortmund[3]
ARCUS Clinics Pforzheim, Pforzheim, Germany[4]

Studies investigating the mechanisms of adductor injuries in soccer have concentrated on full effort kicks. Purpose of this study was a kinetic analysis of the inside pass. Using infrared cameras and inverse dynamics, hip joint moments and adductor muscle stress was calculated during the swing phase of the pass. Moments in the transverse plane were nearly as high as in full effort kicks reported previously. Muscle stress in the m. gracilis reached up to 450 kPa. Considering the repetitive nature of inside passes in modern soccer, adductor muscles undergo high loads in matches and training. This might contribute to the explanation of the high incidences of adductor injuries. Practitioners should therefore consider the load-recovery-relation even in inside pass training. Specific strength training programs for the adductor and abductor muscle groups should be developed.

KEY WORDS: Footbonaut™, AnyBody, kinetics, injury risk, groin.

INTRODUCTION: One third of all injuries in professional soccer are muscle injuries of which the adductors are the second most injured muscle group (Ekstrand, Hägglund & Waldén, 2011) and they account for a disproportionate high amount of loss from training (Gilmore, 1998).
Therefore, it is important to understand the mechanisms behind these injuries. Next to running, kicking is the central action in soccer and is highly repetitive. Hölmich, Thorborg, Dehlendorff, Krogsgaard and Gluud (2014) found a significant higher injury rate in the adductor-muscles of the dominant leg compared to the non-dominant leg, which is presumably used more often for kicking and passing. They proposed, that high eccentric muscle loads in the swing phase of the kick exert high stress on the adductor muscles. Full effort instep and side-kicks have been studied extensively (Nunome, Asai, Ikegami, & Sakurai, 2002; Brophy, Backus, Pansy, Lyman & Williams, 2007; Katis & Kellis, 2010), while research on submaximal inside passing is underrepresented in the literature. But as today's soccer is becoming increasingly fast, utilizing more passes, with 'tiki-taka-football' being the most prominent example, the importance of the inside pass is increasing (Brophy et al., 2007). Therefore, the potential influence of inside passing on injury mechanisms in the groin region should be investigated. Information in this regard is important in terms of injury prevention, rehabilitation and training methods. Furthermore, this is of paramount importance in kids and youth soccer, where growing biological structures are more vulnerable than in adulthood. Particularly the musculo-skeletal loading in young players has to be better understood to avoid overload injuries.
Therefore, the purpose of this study was to examine the moments, developed at the hip, and the muscle stress of the adductors during the swing phase of submaximal inside passing.

METHODS: Ten healthy, male subjects (age = 23.4 ± 2.4 years; height = 180.6 ± 4.4 cm; mass = 77.70 ± 6.44 kg), from a semi-professional level were tested for this study. Each player gave his written consent to participate. All data were collected in a Footbonaut™. This is a 14x14m ball machine for soccer-players, where balls can be passed to a player from four different directions, in different angles and at different speeds. Subsequently, the player has to control the ball and then pass it to one of 64 target fields (1.3x1.3m, 32 ground level, 32 on top), located around him (Figure 1). For the current study, this allowed to measure a standardized series of passes. Subjects had to perform 2 sessions of two minutes each, contain-

ing 20 to 30 passes per session. They received the ball from a dispenser right in front of them: The target, where the ball had to be passed, was always in the subjects' peripheral line of sight. Every ball was dispensed by the machine at 45 km/h at a vertical angle between 0 and 5 degrees and had to be received and passed as quickly as possible.
Sixteen infrared cameras (MX-F40, Vicon, Oxford, UK) were used to collect kinematic data at 200 Hz. Sixty nine retro-reflective markers were attached to anatomical reference points on the subjects skin. Inverse dynamics and muscle force calculations were performed using AnyBody Modeling System (Version 6.0, AnyBody Technology, Aalborg, Denmark). A modified version of the Anatomical Landmark Scaled Model (Lund, Andersen, de Zee & Rasmussen, 2012) was used. Subsequently, data was processed using MATLAB R2015b (The MathWorks, Natick, Massachusetts). Muscle force data was used to calculate muscle stress based on the physiological cross-sectional area (PCSA) reported by Klein Horsman, Koopman, van der Helm, Prosé & Veeger (2007).

Figure 1: A - Inside of the Footbonaut™, B - Subject with attached Markerset

Swing phases of ten passes of each subject using their dominant leg were selected for further analysis. Start of the swing phase (toe-off) was defined as the MT5-Marker being 20 mm higher compared to its standing reference position. End of the swing phase was defined as the second peak in height of MT5. Therefore, it was the end of follow through (Brophy et al., 2007) after ball contact. Swing phases were time-normalized to toe-off being 0%.

RESULTS & DISCUSSION: This is the first study that investigated lower limb kinetics during submaximal inside passes. Further comparisons have to be made with studies investigating full effort kicks. Even here, only the study of Nunome et al. (2002) provides comparable data for all three planes of movement. In the present study, swing phase was extended, compared to Nunome et al. (2002). This was done in order to include the follow-through, defined by Brophy et al. (2007).
Peak hip moments found by Nunome et al. (2002) exceed the moments reported in this study, which are reported in Table 1. The calculated maximum extension moment for the inside pass was 69% of the one presented by Nunome et al. (2002) (3.42 N·m/kg). The adduction moment reported, was 60% of the one in Nunome et al. (2002) (1.91 N·m/kg). These results are not surprising, considering the fact that moments are smaller if the effort is submaximal. The peak moment in the transverse plane on the other hand, was 86% of the one calculated by Nunome et al. (2002), who found a peak value of 0.83 N·m/kg. This allows the conclusion, that inside kicking with submaximal effort reduces the loading in the transverse plane less than in the other movement planes compared to full effort kicking.
Nunome et al. (2002) showed, that moments in all planes tend to change directions shortly before ball impact. Using this information for further analysis, one can see, that the moments change direction at about 60% swing phase. This leads to the assumption that the peak moments were found in the middle of the leg cocking phase, further indicating, that the highest moments occurred in the transition between backward and forward swing.
To our knowledge, this is the first study to calculate muscle stress for inside passing. Adductor longus and gracilis showed the highest stress of all muscles in the adductor group. They

also reached their peaks within the first half of the swing phase, at around 40%, the same time as the joint moments, as seen in Figure 2. The stress endured by the gracilis was nearly three times higher than the stress of the adductor longus, due to its small pcsa of 4.9 cm^2. High adductor stresses might arise from a high external rotation angle in the hip while passing. This forces the adductor muscles to produce a bigger proportion of the force needed for the leg acceleration, otherwise done by the extensors.

Table 1
Means and standard deviations of the peak moments at the hip and adductor muscle stresses of 10 subjects

	Peak	Percent of swing phase [%]
Flexion moment [N·m/kg]	1.42 ± 0.37	84
Extension moment [N·m/kg]	2.37 ± 0.44	35
Adduction moment [N·m/kg]	1.38 ± 0.16	94
Abduction moment [N·m/kg]	1.14 ± 0.21	43
Internal rotation moment [N·m/kg]	0.71 ± 0.1	44
External rotation moment [N·m/kg]	0.39 ± 0.15	75 - 100
Adductor longus stress [kPa]	168.22 ± 27.21	37
Gracilis stress [kPa]	449.72 ± 51.25	40

Schache, Kim, Morgan and Pandy (2010) reported the hamstring muscle forces of a subject suffering an acute muscle strain while sprinting. Stress in the hamstrings of the injured leg, calculated with the PCSA data by Klein Horsman et al. (2007), was 768.6 kPa in the injury trial. While this was calculated for sprinting at maximum effort, a stress of 449.7 kPa for a submaximal pass puts considerable load on the muscle and the tendons. Furthermore, as passing is highly repetitive, adductor muscles have to endure such loads for hundreds of times during training. Stress at the insertion point of a muscle has to be even higher, as the muscle has a smaller cross sectional area at this point while the force stays the same.

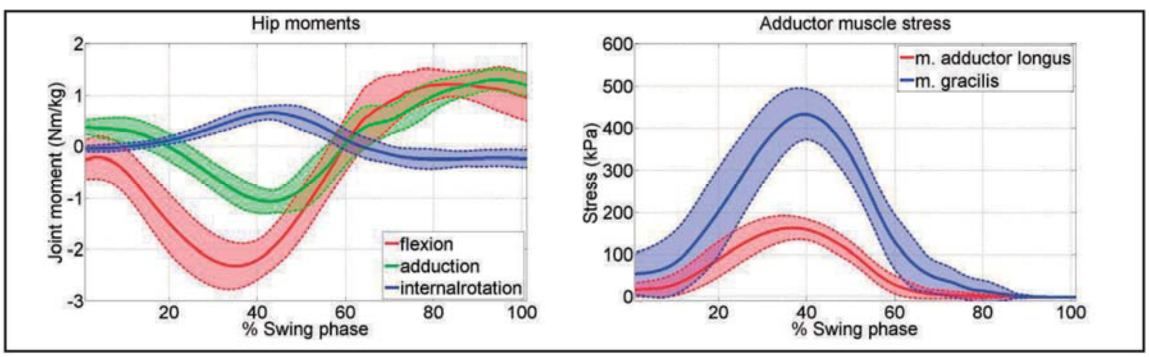

Figure 2: Mean curves and standard deviations for hip joint moments and tensile stress of the adductor longus and gracilis for the swing phase of inside passing for 10 subjects

Because 40% swing phase represents the second half of the leg-cocking (Nunome et al., 2002), it is assumed, that the peaks of the curves were around the transition between the backward and forward swing. Thus, the highest stress might have occurred while the adductors contracted eccentrically, reversing the movement of the thigh. High eccentric loads are considered to be a risk factor for strain injuries in the hamstring muscles (Schache et al., 2010). This might also be applicable for the groin muscles.

A limitation to this study was the use of PCSA data reported by Klein Horsman et al. (2007), since this is based on a 77 year old specimen. This might have led to an overestimation of muscle stress, as the subjects participating in the present study were much younger and active soccer players, who might have had bigger PCSAs.
Nevertheless, moments in the hip and the corresponding stress calculated in the adductor longus and gracilis were high and seem to be a reasonable explanation for high rates of groin injuries among soccer players. This applies especially for overuse injuries at the pubic bone, considering the small cross-sectional areas of the adductor muscles at their insertion point. Furthermore, these loads are highly repetitive due to the central importance of the inside pass in soccer. Therefore, practitioners should keep this in mind when using high amounts of pass training. Especially younger participants might need additional training for the adductor and abductor muscles, if experiencing high training loads.
Future studies should investigate, if adductor stress can be reduced by changes in the passing technique. This might be done by lesser external rotation in the first half of the swing phase. This way, more of the overall hip joint moment could be developed by the larger muscle groups of the leg, responsible for extension and flexion. Furthermore, the Footbonaut™ is only a model for showing the physical demands of modern training methods, athletes have to deal with. More methods and movements that put high loads on the athletes should be investigated.

CONCLUSION: High hip joint loads, in the transverse plane in particular, coupled with high stresses in the adductor muscles during submaximal inside passes might explain the high rates of groin injuries in football. Thus, it is important for practitioners, to dose pass training carefully, especially in kids and adolescent groups. Furthermore, those muscles might need isolated training.

REFERENCES:

Brophy, R. H., Backus, S. I., Pansy, B. S., Lyman, S., & Williams, R. J. (2007). Lower extremity muscle activation and alignment during the soccer instep and side-foot kicks. *Journal of Orthopaedic & Sports Physical Therapy*, 37, 260-268.

Ekstrand, J., Hägglund, M., & Waldén, M. (2011). Epidemiology of muscle injuries in professsional football (soccer). *The American Journal of Sports Medicine*, 39, 1226-1232.

Gilmore, J. (1998). Groin pain in the soccer athlete: fact, fiction and treatment. *Clinics in Sports Medicine,* 17, 787-793.

Hölmich, P., Thorborg, K., Dehlendorff, C., Krogsgaard, K., & Gluud, C. (2014). Incidence and clinical presentation of groin injuries in sub-elite male soccer. *British Journal of Sports Medicine*, 48, 1245-1250.

Katis, A., & Kellis, E. (2010). Three-dimensional kinematics and ground reaction forces during the instep and outstep soccer kicks in pubertal players. *Journal of Sports Sciences*, 28, 1233-1241.

Klein Horsman, M. D., Koopman, H. F. J. M., Van der Helm, F. C. T., Prosé, L. P., & Veeger, H. E. J. (2007). Morphological muscle and joint parameters for musculoskeletal modelling of the lower extremity. *Clinical Biomechanics,* 22, 239-247.

Lund, M. E., Andersen, M. S., de Zee, M. & Rasmussen, J. (2015). Scaling of musculoskeletal models from static and dynamic trials. *International Biomechanics*, 2, 1–11.

Nunome, H., Asai, T., Ikegami, Y., & Sakurai, S. (2002). Three-dimensional kinetic analysis of side-foot and instep soccer kicks. *Medicine and Science in Sports and Exercise*, 34, 2028-2036.

Schache, A. G., Kim, H. J., Morgan, D. L., & Pandy, M. G. (2010). Hamstring muscle forces prior to and immediately following an acute sprinting-related muscle strain injury. *Gait & Posture,* 32, 136-140.