ARE MUSCLE FORCES RELEVANT IN THE AGE RELATED RISE OF INJURIES IN ADOLESCENT SOCCER PLAYERS?

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The purpose of this study was the comparison of the kinematics and kinetics in soccer inside passes between three age groups (U12, U16, U23). Using 3D movement analysis and inverse dynamics, hip joint kinematics and adductor muscle forces were calculated. SPM analysis showed significant differences in adduction angle and velocity and in muscle forces of adductor longus and gracilis. Comparison of the muscle forces shows a rapid increase in muscle forces from the youngest children to the adolescents while the difference between the adolescents and adults is only minor. It seems reasonable, that the fast development of muscle forces in adolescents compared to the slower development of the tendons is a factor in the sudden rise in injury incidence at the beginning of puberty. Therefore, adolescent players should be trained with caution to avoid early injuries.

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

INTRODUCTION: Injury incidence in children is generally very low until the beginning of puberty around the age of 14. In a study by Backous, Friedl, Smith, Parr and Carpine (1988), the injury incidence for young soccer players doubled after the age of 14. This sudden rise has been shown for different types of injuries and different locations (Backous et al., 1988; Inklaar, 1994; Shea, Pfeiffer, Wang, Curtin & Apel, 2004; Volpi, Pozzoni & Galli, 2003). Some of the injuries considered in the studies above are minor injuries with no long-term effect. Others like injuries of the groin or ACL-ruptures can have tremendous effects on the person concerned because of their characteristics as being recurrent or often having consequential damages.
In soccer players, groin injuries are one of the most frequent type of injuries (Ekstrand, Hagglund & Walden, 2011) and are known to be more likely after their first appearance in a player with a longer absence from training after the second injury (Werner, Hagglund, Walden & Ekstrand, 2009). Sustaining a groin injury early in one's soccer career thereby leads to a higher susceptibility to re-injury and might induce an early end of the career. Therefore, understanding the mechanisms leading to the sudden rise in injury incidence is crucial for injury prevention and rehabilitation.
Previous work on the muscle forces in the groin during pass training showed high stresses in the adductor muscles (Dupré et al., 2016), indicating, that high amounts of pass training are associated to overuse injuries of the groin (e.g. adductor muscle strains). Knowledge on how these forces change during adolescence might provide information on the sudden rise in injury incidence in young soccer players.
Therefore, the purpose of this study was the comparison of the kinematics and kinetics (muscle forces) at the hip joint during soccer passes between different age groups.

METHODS: Sixty-one healthy, male subjects from three different age groups (U12, U16, U23) were tested for this study. The subject sample consisted of 14 players in U12 (11.07 ± 0.46 years, 38.29 ± 4.78 kg, 149.74 ± 7.76 cm), 31 players in U16 (14.58 ± 0.75 years, 62.18 ± 9.18 kg, 171.93 ± 7.43 cm) and 16 players in U23 (19.75 ± 0.9 years, 74.84 ± 7.35 kg, 179.28 ± 8.19 cm).
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. Subsequent-

ly, 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. Subjects had to perform one standardized session consisting of 32 passes. They received the ball from a random dispenser on floor level: The target, where the ball had to be passed, could be on each side of the Footbonaut™, but always on floor level. 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 (F40, Vicon, Oxford, UK) were used to collect kinematic data at 200 Hz. Seventy-one retro-reflective markers were attached to anatomical reference points on the subjects' skin. Inverse dynamics were performed using AnyBody Modeling System (Version 6.0, AnyBody Technology, Aalborg, Denmark). A modified version of the Anatomical Landmark Scaled Model (Lund, Andersen, Zee & Rasmussen, 2015) was used. Muscle forces were calculated using a simple Hill-model provided in AnyBody and a polynomial muscle recruitment criterion of the power 3. Subsequently, data was processed using MATLAB R2016a (The MathWorks, Natick, Massachusetts).
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 crossing 60 mm above floor level. End of the swing phase was defined as ball contact which was obtained visually for each trial. Therefor each ball in the Footbonaut™ was prepared with retro-reflective foil to make it visible for the Vicon cameras.
Statistical tests for differences were performed using Statistical Parametric Mapping (SPM) (Friston, 2007) in Matlab R2016a. Due to non-normal distributed data, the specific test used was a nonparametric permutation test (Nichols & Holmes, 2002) with α=0.05. In the case of a significant result, SPM nonparametric two-sample t-tests were performed for the three comparisons with a bonferroni-corrected level of significance.

RESULTS & DISCUSSION: Hip adduction curves (Figure 1) are similar to those reported by Levanon and Dapena (1998). Although, hip adduction angular velocity can only be roughly

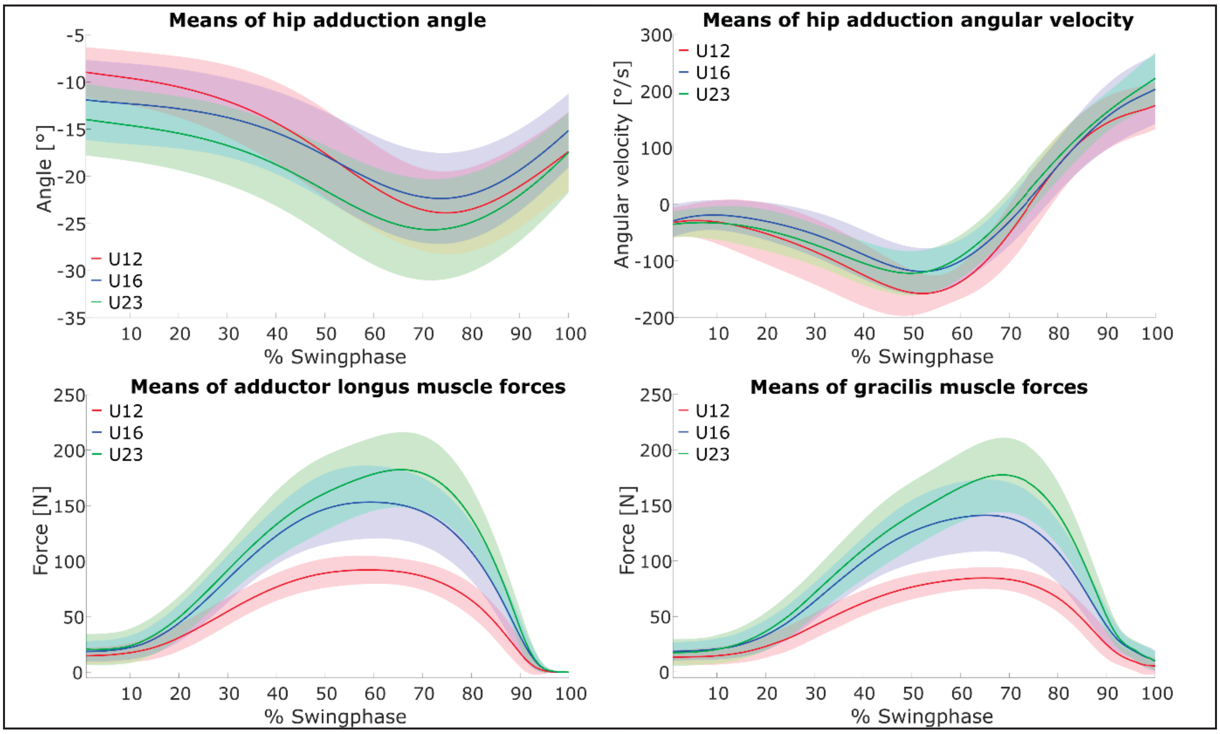

Figure 1: Means and standard deviations of the four parameters for the three groups. Solid lines represent time normalized mean curves, shaded areas represent means ± standard deviation. For adduction angle and angular velocity, positive values indicate adduction.

Table 1
SPM results for significant parameters. The left side of the table shows results for the permutation test, the right side shows the results for pairwise comparisons.

Parameter	p-value	Significant differences [% swing phase]	Group comparisons	p-value	Significant differences [% swing phase]
Hip abduction angle	0.01	0-39	U16 vs. U12	> 0.017	-
			U23 vs. U12	< 0.001	0-29
			U23 vs. U16	> 0.017	-
Hip abduction velocity	0.027	55-62	U16 vs. U12	0.008	55-59
			U23 vs. U12	0.005	56-62
			U23 vs. U16	> 0.017	-
Adductor longus	< 0.001	22-91	U16 vs. U12	< 0.001	23-89
			U23 vs. U12	< 0.001	22-91
			U23 vs. U16	0.007	72-81
Gracilis	< 0.001	24-97	U16 vs. U12	< 0.001	25-96
			U23 vs. U12	< 0.001	24-96
			U23 vs. U16	0.004	69-83

compared to Nunome, Asai, Ikegami and Sakurai (2002), curves reported there seem to be similar to the ones shown in Figure 1. Results for muscle forces are lower than reported before (Dupré et al., 2016) which is due to the usage of a different muscle recruitment criterion. Using a criterion of the power 3 distributes muscle forces more evenly over all muscles involved. Hip adduction curves (Figure 1) are similar to those reported by Levanon and Dapena (1998). Although, hip adduction angular velocity can only be roughly compared to Nunome et al. (2002), curves reported there seem to be similar to the ones shown in Figure 1. Results for muscle forces are lower than reported before (Dupré et al., 2016) which is due to the usage of a different muscle recruitment criterion. Using a criterion of the power 3 distributes muscle forces more evenly over all muscles involved.

Results of the kinematic analysis show a significant lower abduction angle at the start of the swing phase for U12 and a significant higher abduction velocity for U12. This shows that younger players tend to start from a narrower position when passing the ball, and therefore have to abduct the kicking leg more quickly to reach the same abduction angles as older players.

Results for muscle forces of the adductor longus show significant differences between each group, with muscle forces increasing with age (Table 1). An increase in muscle forces with increasing age is not surprising. The moments of inertia rise with increasing body height and weight, demanding more muscle force to reach similar velocities. More interesting are the differences in muscle force compared to the differences in age that lie between the groups: Force of the adductor longus, increases by 67% in 3.5 years from a mean maximum of 98.22 N in the U12 to a mean maximum of 164.18 N in the U16. The increase of force in the 5.5 years from U16 to U23 is comparatively small with a 16% increase to a mean maximum of 191.43 N. Increases of force in the gracilis are similar to 68% between U12 (89.29 N) and U16 (150.42 N) and 22% between U16 and U23 (183.87 N).

During the adolescent growth spurt, the bodies segment lengths can increase at high rates, increasing segment moments of inertia as well, thereby leading to the shown increases in muscle forces. This raises the question, whether all structures in the adolescent body can adapt fast enough to the higher forces. Slower adaption of tendons (Waugh, Blazevich, Fath & Korff, 2012) might promote the development of tendonitis and osteitis pubis, especially if the training frequency is increased during this vulnerable phase in adolescent growth which is common in soccer training.

The kinematic analysis also shows a possible approach to reduce the high stresses on the adductor muscles. As the younger kids have a narrower stance just before toe-off, they have

to abduct their leg faster to reach the same abduction angle as the older players. Therefore, when decelerating the abduction, they have to use relative higher adductor muscle forces than older players. This means that the simple instruction of taking a broader stance when passing should reduce the necessity of faster hip abduction and should therefore also reduce the muscle forces in the adductor longus and gracilis.
Although the calculation of muscle forces from kinematic and anthropometric data cannot provide results completely free of doubt, the presented data gives a reasonable explanation for the sudden rise in injury incidence around the time of the adolescent growth spurt. This has important implications for the training of young soccer players: It is very likely, that the body is more vulnerable to overuse injuries during the growth spurt because of fast changes of the body's proportion's and different speeds in the structural adaptations. Players experiencing the growth spurt should therefore be treated with care while training. Sudden increases of training frequency, especially in pass training should be avoided. Further studies should investigate the influence of the growth spurt on the adolescent body to prevent early overuse injuries in young athletes.

CONCLUSION: Muscle forces in adductor longus and gracilis increase at high rates during adolescence. This increase in muscle force might be faster than the related tendons can adapt, leading to an increased risk of an early injury. Training intensity of young soccer players experiencing the adolescent growth spurt should therefore be reduced to avoid early overuse injuries.

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