RELATIONSHIP BETWEEN MUSCLE VOLUME AND STRENGTH ASYMMETRY IN ELITE ATHLETES: INVESTIGATION OF THE QUADRICEPS FEMORIS AND HAMSTRING MUSCLES

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The purpose of this study was to examine the relationship between muscle volume asymmetries and strength asymmetries of the lower extremity. 26 highly trained athletes underwent isometric and isokinetic strength tests at different speeds (60, 180, 0 °/s) and magnetic resonance imaging (MRI) to analyse quadriceps femoris and hamstring muscle volume. Pearson's correlation coefficients revealed significant correlations between both the quadriceps volume asymmetries and the maximum knee extension asymmetries (r = .60 to r = .72) as well as the hamstring volume asymmetries and the maximum knee flexion asymmetries (r = .39 to r = .52). It is assumed that bilateral differences in muscle volume in part explain the existence of strength asymmetries and that unilateral resistance training of the lower extremity could reduce strength asymmetries by increasing muscle size.

KEY WORDS: strength, imbalances, asymmetries, deficits, muscle volume

INTRODUCTION: Studies revealed that bilateral strength asymmetries of the leg muscles represent an internal risk factor for injuries of the lower extremity (Bonci, 1999; Croisier, 2004; Freckleton & Pizzari, 2012; Knapik, Bauman, Jones, Harris, & Vaughan, 1991). Such strength deficits can be the result of numerous factors including the specific requirements of a given sport (Zvijac, Toriscelli, Merrick, Papp, & Kiebzak, 2014), laterality (Jones & Bampouras, 2010) and especially preinjuries (Schiltz et al., 2009). The underlying neuromuscular reasons have not been investigated so far. Therefore a theory of the efficacy of a specific preventative intervention is lacking. The present study aims to resolve this grievance by analysing the relationship of morphological properties of the quadriceps femoris (QF) and hamstring muscles (H) and the strength asymmetries. Based on these results guidance for prevention and rehabilitation in competitive sports should be derived to counteract strength asymmetries of the knee extensors and flexors and thus raise the health status of highly trained athletes.

METHODS: 13 female and 13 male highly trained athletes of different sports were included in the study (age: 20.5 ± 2.9 years; height: 176.5 ± 8.6 cm; body mass: 74.2 ± 11.3 kg). All subjects gave their informed consent to the procedure of the study. None of the subjects had acute knee or muscle injury and all participated in normal training and competition.

Isokinetic and isometric strength testing

Bilateral strength of quadriceps femoris and the hamstring muscles was tested by isometric and isokinetic maximum voluntary contractions (MVC) at different speeds (60, 180, 0 °/s) with an isokinetic dynamometer (IsoMed 2000, D&R Ferstl GmbH, Hemau, Germany). For all MVC maximum moment of force and contraction work (integral of torque over angular position) were calculated. Measurements were always performed in the same order after a 10 min, 80 W warm-up on a cycle ergometer (wattbike pro, Nottingham, UK) starting with the right leg (Fig. 1). Data were analysed using the ISA software (CSI, Bad Schönborn, Germany).

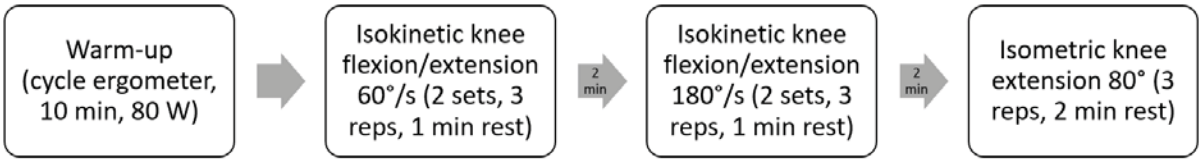

Figure 1: Strength testing procedure.

Muscle resonance imaging
Morphological properties of the muscles were determined by magnetic resonance imaging (MRI). Lying in the supine position with the knees extended both thighs of each subject were scanned. A 1.5-T MRI scanner (Magnetom Avanto, Siemens Healthcare GmbH, Erlangen, Germany) was used to obtain a series of axial slices from the superior border of the patella to the anterior superior iliac spine encompassing the entire quadriceps femoris and hamstring muscle group. The images were produced using 1-cm-thick T1-weighted axial with a 50-cm field of view. Measurement parameters: time to echo: 13 ms, repetition time: 626 ms, matrix size: 512 x 336. Images were transferred to a personal computer in the digital imaging and communications in medicine (DICOM) file format. The scan files were imported into the OsiriX software (Pixmeo SARL, Bernex, Switzerland) for further analysis. For each axial slice the cross-sectional area (CSA) of the quadriceps femoris and hamstring muscle group was manually outlined with a graphic tablet (Cintiq 22 HD, Wacom, Kazo, Japan) as a region of interest. The same investigator performed each analysis. The CSA of each axial slice were then multiplied by the distance between slices and summed across slices. These values represent quadriceps and hamstring muscle volume, respectively.
Statistics
Strength asymmetries and asymmetries of the muscle volume were determined by calculating the limb symmetry indices ($LSI = \frac{left-right}{maximum} * 100$). Correlations between muscle volumes and strength asymmetries were determined by using the Pearson correlation coefficient. The critical level for statistical significance was set at 5%. The data are presented as means ± S.D. SPSS Statistics 22 software (IBM, Armonk, US) was used for statistical analysis.

RESULTS: LSI of muscle volume averaged 3.67% (LSI V_{QF}) and 5.26% (LSI V_H). In addition strength asymmetries on average ranged from 7.43% to 8.80% (MVC_{Flex}) and 7.52% to 11.58% (MVC_{Ext}), respectively. There were significant positive correlations between muscle volume asymmetries and strength asymmetries. Correlation coefficients between LSI V_H and the analysed parameters of MVC_{Flex} ranged from r = .39 to r = .52. In contrast LSI V_{QF} highly correlated with all strength asymmetry variables of MVC_{Ext} (r = .60 to r = .72).

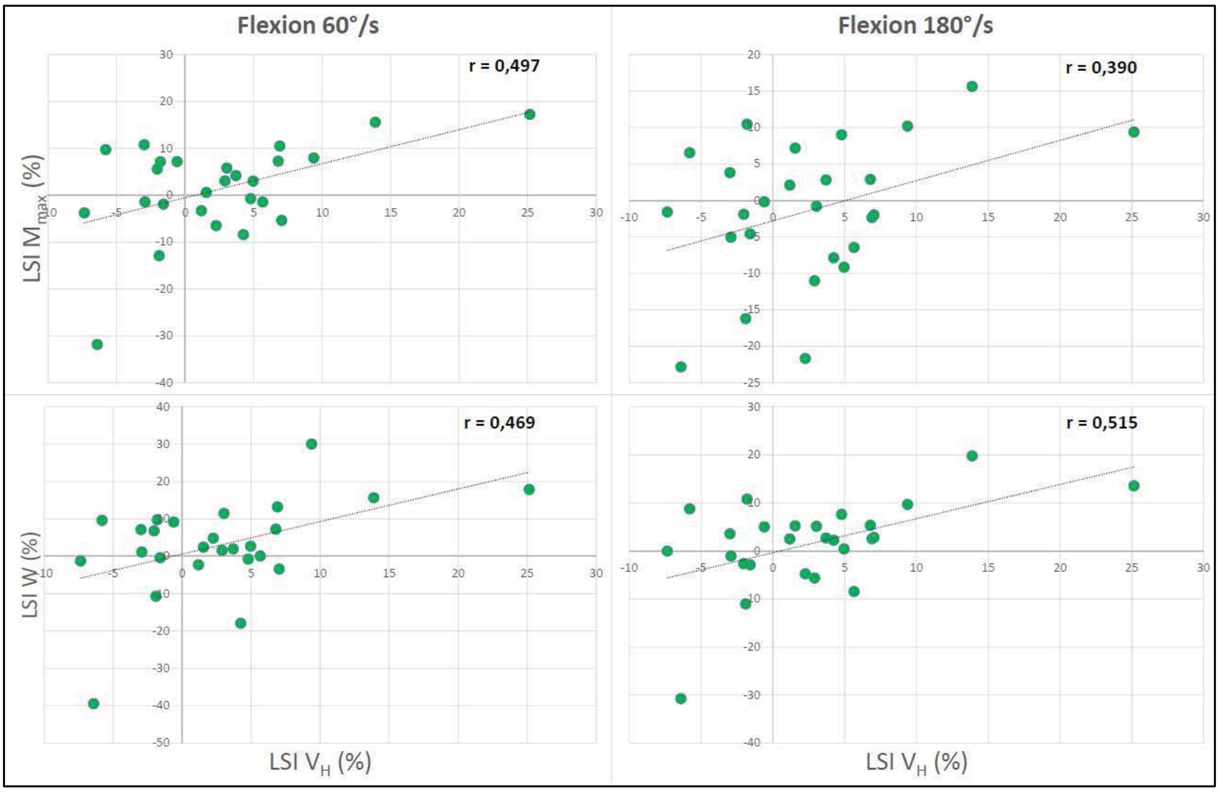

Figure 2: Correlations between hamstring muscle volume asymmetries and strength asymmetries. LSI: limb symmetry index; V_H: volume of hamstring muscles; W: work; M: moment of force.

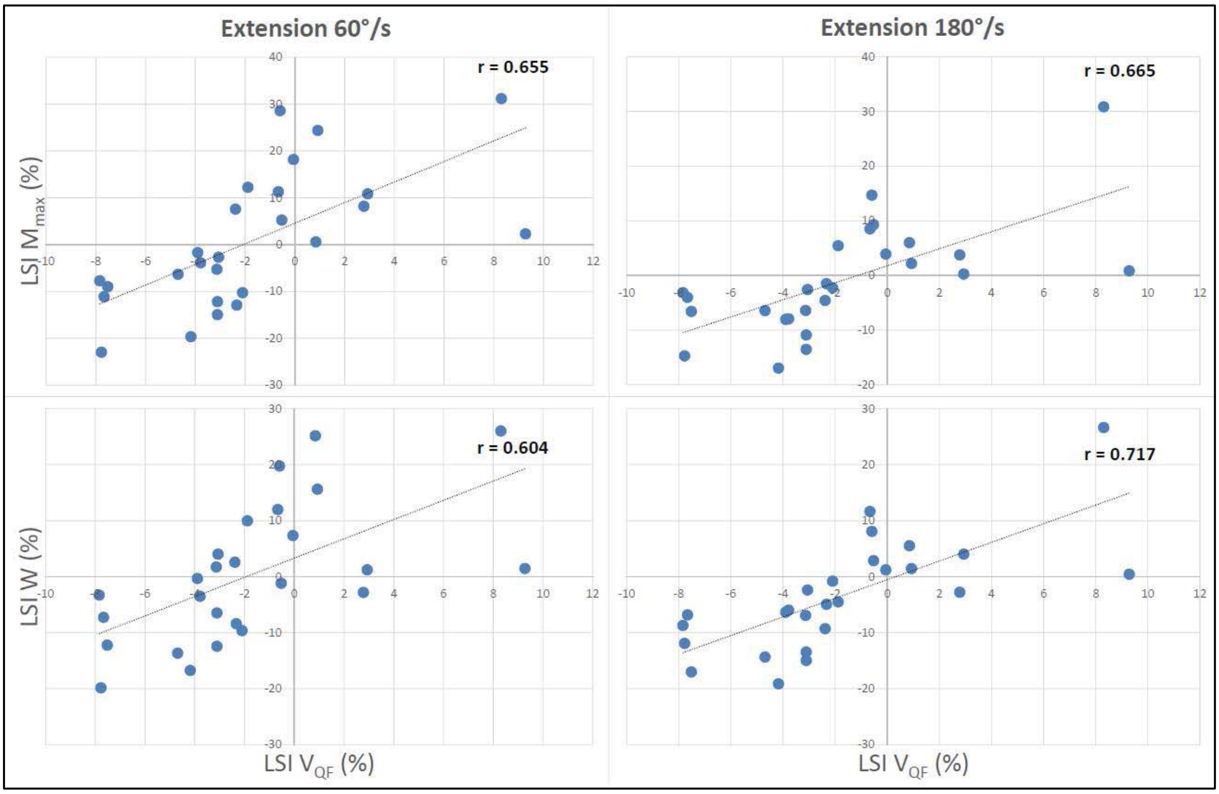

Figure 3: Correlations between quadriceps femoris volume asymmetries and strength asymmetries. LSI: limb symmetry index; V_{QF}: volume of quadriceps femoris; W: work; M: moment of force.

DISCUSSION: Taken into account that bilateral strength asymmetries of the leg muscles of more than 10% increase the risk of injury in competitive sports (Bonci, 1999; Croisier, 2004; Freckleton & Pizzari, 2012; Knapik et al., 1991) the LSI of maximum knee flexion and especially the LSI of maximum knee extension seem pretty high in this sample. The main findings of the present study are the significant correlations between muscle volume asymmetries and strength asymmetries. The general relationship between muscle mass and maximal strength is well-known and beyond question (Cormie, Mcguigan, & Newton, 2011; Folland & Williams, 2007; Housh, Housh, Johnson, & Chu, 1992; Masuda, Kikuhara, Takahashi, & Yamanaka, 2003; Thomas, Wojtys, Brandon, & Palmieri-Smith, 2015). The present results indicate that muscle volume asymmetries strongly affect strength asymmetries. Although we acknowledge correlation does not imply causality, these findings suggest muscle asymmetries to be at least one important source for strength asymmetries. The fact that the correlation is much higher for the quadriceps femoris and the maximum knee extension than for the hamstring muscles and the maximum knee flexion could in part be explained by human anatomy. Despite the hamstring muscles there are other muscles supporting the knee flexion (e.g. m. sartorius, m. gracilis, m. gastrocnemius). In contrast by investigating the quadriceps femoris every muscle acting as a knee extensor has been analysed. As morphological properties of the muscles are not the only factors which determine muscle strength (Häkkinen, Alen, Kallinen, Newton, & Kraemer, 2000; Ivey et al., 2000; Mizner, Petterson, Stevens, Vandenborne, & Snyder-Mackler, 2005), future studies should consider additional factors such as muscle activation or neural drive.

CONCLUSION: Strength asymmetries of the lower extremities is a big issue in competitive elite sports. The underlying neuromuscular reasons can be manifold. As shown in the present study differences in the quantity of the musculature mostly explains bilateral strength asymmetries in highly trained athletes. We assume that unilateral high resistance training of the lower extremity could reduce strength asymmetries by increasing muscle size. Further investigations should evaluate this treatment strategy and include neuronal factors, which could additionally account for strength deficits.

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