**MAIN DOCUMENT  
TITLE:** A new field-test for assessing the medial and lateral hamstring strength at long-muscle length

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This research investigates the influence of tibial rotations with knee flexion (KF) on the electromyographic (EMG) activities of hamstring muscles (HM) groups and the strength ratio between the medial and lateral rotation of the tibia. A cross-sectional design was employed to assess muscle activity, isometric strength and reliability. The research was conducted in a controlled laboratory environment. Thirty-six amateur male athletes were recruited as volunteers. The measures included peak muscle activity of thesemitendinosus and biceps femoris long head, the knee flexors’ isometric strength ratio and reliability. The isometric strength ratios of medial (MR) to lateral (LR) tibial rotations were 0.94 ± 0.17 at 90°, and 0.93 ± 0.10 at both 60° and 30° of KF angulation. Tibial position significantly influenced knee flexion strength as well as HM activity, irrespective of KF angulation. Specifically, biceps femoris activity increased by 33.6% in LR compared to MR, while semitendinosus activity increased by 22.6% in MR compared to LR. The Knee-Rotation test (KR-test) can be a valuable tool for evaluating both HM groups (ICC > 0.87), and identifying the primary target for strengthening purposes during the injury prevention process. It provides insights for effective rehabilitation and training interventions.

**Keywords:** *hamstrings, surface electromyography, reliability, isometric strength*

1. **Introduction**

The hamstring muscles (HM) have a high rate of injuries especially on the football field (12-15%) (Opar et al. 2012; Ekstrand et al. 2016) and represent as much as 50% of all injuries on the track and field (Alonso et al. 2012; Yeung et al. 2009). These injuries lead to major financial costs and negative impacts on both individual and global team performance. During the swing phase of sprinting when most of injuries occur, significant eccentric force magnitude reach up to nine times body-weight with high HM activity, rapid leg movement speeds (> 700°/s at the hip) and the muscle-tendon-unit (MTU) length increasing up to 13% (Dorn et al. 2012). HM injuries (HMI) are unevenly distributed between the medial (MH) and lateral (LH) HM groups, with 80% of the cases located in the upper third of the biceps femoris long head (BFlh), especially near the myotendinous junction (MTJ) (Verrall et al. 2003). This probably results from different muscle-tendon unit architecture compared to other hamstring muscles (Fiorentino et al. 2014; Kalkhoven et al. 2023). Despite concentrated efforts to prevent or rehabilitate hamstring injuries over the last decade, HMI significant incidence remains high in both competition and training, with a high re-injury rate (18-30%) (Ekstrand et al. 2016).

From a rehabilitation perspective, the strength assessment of the HM is crucial for detecting any strength weakness that could potentially increase the risk of HMI (Van der Horst et al. 2017). For this purpose, current evaluation methods use an isokinetic dynamometer (Croisier et al. 2004, 2008), hand-held dynamometer (Lahti et al. 2020) or functional tests such as the single leg hamstring bridge test or force-velocity-power profiling and kinematic analysis during sprinting (Freckleton et al. 2014; Lahti et al. 2020; Bramah et al. 2024). However, these traditional evaluations do not provide insights into the intramuscular synergistic behaviour of MH and LH muscle groups, nor do they indicate their relative contribution to the strength results during the assessment. This highlights the practical difficulty of estimating the relative contribution to strength outcomes of MH and LH hamstring muscle groups in an athlete’s leg (Kalkhoven et al 2023).

Various authors have emphasized that the greater the imbalance of muscular activation between hamstring muscle groups, the lower the performance, and the higher the intrinsic risk of HMI (Avrillon et al. 2018; Schuermans et al. 2016). Potential compensatory mechanisms developed by the contralateral HM group may effectively mask weakness, especially in long muscle lengths (>90° of hip flexion with moderate knee flexion angle), even when strength results appear to be “balanced” across various tasks such as sprinting (Areia et al. 2019; Higashihara et al. 2019), jumping (Jankaew et al. 2023) or strength exercises such as the nordic curl (Blandford et al. 2018b). Specific deficits may persist go unnoticed (Blandford et al. 2018b) with current assessment tests (Georgoulis et al. 2023; Presland et al. 2021).

Therefore, it is useful to develop clinical strength tests that assess the different HM groups more selectively, avoiding missing a specific MH or LH muscle group weakness. Some studies have found that medial (MR) and lateral (LR) tibial rotations increased the ipsilateral HM group recruitment when associated with isometric contractions at different knee flexion angles (Beuchat et al. 2019; Beyer et al. 2019). However, to our knowledge, only few researches (Jónasson et al. 2016; Beyer et al. 2019) have described the isometric strength ratio of MR/LR and the MH/LH muscle activation ratio in healthy amateur male athletes for prevention purposes.

The primary purpose of this study was to analyze the influence of tibial rotation on the MH/LH muscle recruitment and the isometric strength ratio of MR/LR at three knee flexion angles to propose normative values. The second objective of this study was to assess the reliability of the Knee-Rotation test (KR-test) in these different positions. It is hypothesized that tibial rotations influence the global knee flexion strength production and the recruitment of hamstring muscle groups, favoring the ipsilateral HM group recruitment and disfavoring the contralateral HM group.

1. **Material and Methods**

volunteers

Thirty-six healthy males volunteers (23.2 ± 3 years old, 178.0 ± 6 cm, body mass 71.6 ± 6 kg) with a dominant right leg were included in this study. The sample size was determined using G-Power (3.1; http://www.gpower. hhu.de) (effect size = 0.25; alpha significant level = 0.05 and power = 0.80; with F-test and repeated-mesures ANOVA with within-between interaction) (Beuchat et al. 2019; Beyer et al. 2019; Serdar et al., 2021; Kang et al. 2021; Jónasson et al. 2016). The volunteers had to be regularly (between three to eight hours of sport per week) active in a variety of explosive sports (soccer and rugby) with particular emphasis on the lower limbs. Exclusion criteria were to have no previous or current injuries in the lower back or lower limbs leading to minimum three weeks without sport participation. Moreover, all volunteers were asked not to practice any intensive sport two days preceding the test. The Medical Ethics Committee of the University Hospital of Liège approved the study, and all volunteers signed an informed consent form beforehand.

Experimental procedure

The experimental procedure consisted of two sessions (pre- and post-test) the same day, with a thirty-minutes break interval. An initial warm-up was performed, consisting of three sets of isometric knee flexions contractions for a total of 20 repetitions (each repetition lasting between 3 to 5 seconds), at low then moderate intensities. For the duration of the tests, the volunteers were seated on a chair with 90° of hip flexion (Figure 1A). The contralateral leg was kept at 90° of knee flexion and the arms crossed in front of the torso, as to avoid any body compensations.

During the strength tests using a hand-held dynamometer (HHD; MicroFET2, Hoggan Industries, Inc., West Jordan, UT, USA), surface electromyography (sEMG) values were measured simultaneously for biceps femoris long head (BF) and semitendinosus (ST) muscles. Prior to the placement of sEMG sensors on BF and ST muscles, the skin was shaved, sanded with sandpaper and cleaned with alcohol. The recording electrodes were placed on the muscle bellies, which were identified by palpation based on sEMG recommendations (Barbero et al. 2012). sEMG activity of these muscles were recorded using Delsys Trigno Sensors with silver-contact wireless bipolar bar electrodes and 10mm fixed inter-electrode spacing (Delsys Inc, Natick, MA, USA). The maximal voluntary activity (MVA) of each muscle was then measured during maximal voluntary isometric contraction (MVIC) in standard seated position on a chair with 90° of hip flexion and knee flexion. To do this, each volunteer was asked to complete three trials of isometric contraction (five seconds during which they had to maintain the contraction before relaxing out the sixth second).

Strength for the Knee-Rotation test was evaluated using the HHD, solidly attached to a fixed system of metal bars (Figure 1A). The HHD was positioned in a standard localisation (Buckinx et al. 2017) on the Achilles tendon 3 cm above the external malleolus. We recorded the peak strength expressed in newtons and measured the arm lever (lateral condyle of the knee to dynamometer application point distance) as to expressed the peak strength in newtons per meter (N.m). The better of two trials at each randomized knee flexion positions (30, 60 and 90°) and each knee rotation (medial, neutral, and lateral; Figure 1B) was kept for further analyses. A fixed model with 30° medial and lateral rotations was drawn on the floor and an independent observer constantly impose the volunteer to keep a constant range of motion for each tibial rotation (Figure 1B). During the entire task, the volunteers were supported by verbal encouragements. Rest periods of 30 seconds were also granted between each trial to avoid fatigue.

data processing

The EMG signal was first band pass filtered (20 - 500 Hz, zero-phase 4th order Butterworth) and then processed using a root-mean-square (RMS) algorithm (Castelein et al. 2015; Schwartz et al. 2017). Then, the average EMG envelope over a time window of 500ms (moving average filter) was calculated during each MVIC trial for each muscle (Delsys Trigno software, Delsys Inc, Natick, MA, USA). The EMG signals were then normalized with respect to the values obtained during the maximum voluntary isometric contraction test (MVIC) in order to obtain the activation level percentage of the MVA (%MVA) for each of the muscles assessed.

data analysis

Statistical analyses were performed using JASP (JASP team software, version 0.9.1.0, University of Amsterdam) and R (R Core Team 2021; package psych 1.0.12 and Rcmdr 1.7-1). The Shapiro-Wilk test was applied to the peak strength and sEMG values of HM to confirm the normality of the distribution. After its confirmation, the mean values and the standard deviation (SD) were then calculated. In addition, the reliability of strength and sEMG results in each tested position was estimated by comparing the two trials and calculating the Intraclass Coefficient Correlation (ICC; Two-way mixed effects, absolute agreement, single rater/measurement based on Koo et al. 2016) with 95% confidence interval (95% CI) and Minimal Detectable Change (MDC). We considered an ICC over 0.90 as very high, from 0.70 to 0.89 as high and finally from 0.50 to 0.69 as moderate (Denegar et al. 1993). Paired-Student t-tests were used to compare the first and second session for strength and EMG data.

Repeated measures analysis of variance (ANOVA) was used to analyse the effect of tibial rotation (TR) and Knee flexion (KF) angulation on isometric peak strength and for each hamstrings muscle group activity. A Bonferroni adjustment was used for post-hoc tests when the ANOVA results showed a statistically significant effect (with significance level set at *p* < 0.05). We considered a Cohen’s d effect size over 0.8 as large, from 0.5 to 0.79 as medium to large, from 0.2 to 0.49 as small to medium and finally from 0.0 to 0.2 as small (Lakens et al. 2013).

1. **Results**

Peak strength analysis

The peak strength data analysis showed high to very high reliability (ICC 0.87 - 0.97; Table 1). No statistical difference was found between the first and second test, except for the 90° knee flexion associated with a neutral tibial position (*p* = 0.043), as the peak strength was significantly greater in the second test (75.1 N.m ± 17.6) compared to the first test (73.5 N.m ± 18.2) (Table 1).

The repeated measures ANOVA showed no effect on isometric peak strength of knee flexion angle (p = 0.72) and the interaction of angle vs tibial rotation position (p = 0.461). However, repeated measures ANOVA showed a significant influence on isometric peak strength of tibial rotation position (p = 0.027), with Bonferroni post hoc showing there was a superior isometric peak strength in neutral position in comparison to medial rotation (p = 0.023), but in small to moderate proportions (mean difference of 9.1 N.m with Cohen’d = 0.261). Bonferroni post hoc showed no significant difference between lateral and medial rotation (p = 0.293) or between neutral position and lateral rotation (p = 0.899) (Table 2). Finally, the isometric strength ratio of MR/LR were 0.93±0.10 at 30°, 0.93±0.10 at 60° and 0.94±0.17 at 90° of knee flexion angle (Table 3).

sEMG analysis

Tables 4 and Figure 1 A and B represent sEMG activity of semitendinosus and biceps femoris at the three knee flexion angulations and different tibial positions.

sEMG activities for BF and ST muscles were found to be low to moderately reliable between the first and second trial for each tibial rotation at all knee flexion angulation (ICC 0.22 – 0.73; Table 4).

For BF muscle, Repeated measures ANOVA with Bonferroni post hoc showed the mean value of maximal recruitment at the three knee flexion angulation increased in LR (+ 19.2%; p < 0.001; Table 5) and decreased in MR (- 23.0 %; p < 0.001; Table 5) compared to neutral position (NP). However, the repeated measures ANOVA showed no effect on the mean value of maximal recruitment of knee flexion angle (p = 0.111) or angle vs position (p = 0.282; Table 5).

For ST muscle, the repeated measures ANOVA with Bonferroni post hoc showed the mean value of maximal recruitment at the three knee flexion angulation decreased in LR (- 20.7%; p = 0.001) in comparison to NP and MR (p<0.001), but did not differ significantly between MR and NP (p = 1.0; Table 6). In MR, ST muscle recruitment did not significantly differ between the three knee flexion angles. However in LR and NP, there was a superior activation at 90° compared to 30° (p < 0.001) and 60° (p = 0.044), but not between 60° and 30° (p = 0.404; Table 6).

1. **Discussion**

This study aimed to analyze the ability of the Knee-Rotation test (or KR-test) to specifically measure a hamstring muscle group maximal isometric strength at 90 degrees of hip flexion. The main findings were that 1) lateral and medial rotation could be used to assess the isometric strength ratio of MR/LR independently from the knee flexion angle, allowing better isolation of each hamstring muscle group recruitment from its counterpart. 2) Neutral position appeared to result in the greatest isometric strength. 3) The KR-Test showed high reliability (ICC > 0.87) for assessing the MR/LR isometric strength of knee flexion using the hand-held dynamometer.

Overall, our data support the idea that the hamstring muscle groups should be considered as two separate entities from an assessment perspective, as tibial rotation significantly influence their recruitment. Results showed that tibial rotation indeed change the global hamstring muscle strength production independently from the knee flexion angle, with small to moderate effect size. There were significant differences in isometric strength between MR and NP at every knee flexion angle, with an average of 12% lower result associated with MR. This mean difference is comparable to the results of Jónasson et al. (2016), who found the strength to be 9.1% higher in NP compared to MR. Although the relevance of this small difference in strength between MR and NP remains questionable, it may be considered clinically relevant after injury (Croisier et al. 2004, 2008). These findings may be due to increased mechanical disadvantage in MR and altered relationships between the lengths of muscle-tendon units, thereby reducing strength generation. The normal active MR range of motion (ROM) in healthy volunteers is on average between 24° to 32° (Slichter et al. 2018). Conversely, higher strength in NP and LR may result from optimal joint position and muscle fiber tension, enhancing strength production while the normal ROM of LR averages between 39° and 41° (Slichter et al. 2018). The difference in strength between MR and NP is in contrast to the study by Armour et al. (2004), who found no significant modifications of the hamstring isometric strength function due to tibial rotation. The result may be because the movements tested in Armour’s study relied on tibial rotation strengths rather that knee flexion strength in tibial rotation position.

sEMG analysis revealed different activation patterns between the semitendinosus and biceps femoris muscles in MR, NP and LR. In the present study, it was found that LR to significantly increased the BFlh by up to 19.2%, and conversely, MR decreased the BFlh activation by up to 23.0% compared to NP, which is consistent with previous results (Jónasson et al. 2016; Beyer et al. 2019). These changes in muscle activity may hinder overall knee flexion function and strength production, as we found that 12% less strength was produced in MR than in NP. We also observed that the mean values of maximal ST muscle recruitment at the three knee flexion angles did not differ between NP and MR. This is consistent with Beyer et al. (2019) and Jónasson et al. (2016), who suggested that a neutral tibial position could already predispose a healthy volunteer to optimally recruit the ST muscle compared to MR (Jónasson et al. 2016; Beyer et al. 2019). Furthermore, unlike Jónasson et al. results (2016), who found no statistical difference between MR and LR for ST muscle activity (p=0.085), our study revealed that ST muscle activity decreased by up to 20.7% in LR compared with MR, especially at long muscle length (LML) (30° of knee flexion; p<0.001). The results may be attributed to methodological considerations as Jónasson et al. only studied a 40° knee flexion position.

Furthermore, two studies (Lynn et al. 2009; Beuchat et al. 2019) have shown that changes in tibial rotation during various common strengthening exercises can reduce the activity of the contralateral HM group, thereby proportionally increasing the contribution of the ipsilateral counterpart. Additionally, from a strengthening standpoint, muscle activation represents an important factor for muscular hypertrophy, as several studies have demonstrated similarities between the recruitment patterns of the HM groups during hamstring strengthening exercises and adaptations resulting from their long-term use (Bourne et al. 2017). Therefore, hamstring exercises are often classified as short, medium, or long muscle length (Marušič et al. 2021; Vatovec et al. 2021), hip or knee dominant, or depending on which muscle group is preferentially activated (MH versus LH) (Hegyi et al. 2019). However, it remains difficult in everyday practice to estimate the relative contributions of the MH/LH muscle groups due to significant interindividual variability, conflicting evidence, and confounding factors (e.g. relative intensity, muscle length, and total time under tension) influencing the mechanisms underlying their effects (Hegyi et al. 2019; Wolf et al. 2023).

Among athletes who have undergone ACL reconstruction (ACLR) or a BFlh muscle injury, limitated flexibility in MR after ACLR (Brandenbourg et al. 2018; Boguszewski et al. 2016) or activation deficit in different injury situations such as ACLR and BFlh muscle injury (Georgoulis et al. 2023; Presland et al. 2021) can be long-lasting (Oleksy et al. 2023; Sherman et al. 2021) during explosive movements or eccentric contractions (Opar et al. 2013; Presland et al. 2021; Higashihara et al. 2019; Fyfe et al. 2013; Angelozzi et al. 2012; Oleksy et al. 2023). This can mask weakness even when strength outcomes appear “balanced” in jumping (Jankaew et al. 2023), sprinting (Areia et al. 2019) or strengthening exercises such as Nordic Curl (Blandford et al. 2018b). Although they may not initially have clinical consequences in specific activities of daily living or in athletic conditions (Blandford et al. 2018a), these compensatory mechanisms can disrupt progress and effectiveness of the rehabilitation process (Ekstrand et al. 2016; Della Villa et al. 2021), while also increasing the reinjury risk (Opar et al. 2014; Timmins et al. 2014). Consequently, “compensatory mechanisms” should not be considered a substitution strategy to a specific focus on BFlh/ST assessment. Other muscles with unique functional properties cannot replace the specific role of HM groups, and will never perfectly compensate for neuromuscular inhibition, strength loss, or insufficient fatigue/tissue tolerance, because one cannot be interchangeable with another (Schuermans et al. 2014; Avrillon et al. 2018).

Finally, some limitations are present in this study. Firstly, further studies should be specifically performed on athletes who have previously sustained an anterior cruciate ligament reconstruction or a biceps femoris muscle injury, as our results were limited to healthy athletes. Secondly, it should be noted that discomfort for the athletes could results from the maximal tibial rotation positions that create articular shear forces (Slichter et al. 2018). However, as the athletes did not reach maximal knee extension, we thought that an adapted warming-up would be sufficient, as no volunteers complained about discomfort in our experimentation.

1. **Conclusion**

This study demonstrated that lateral and medial tibial rotation could be used to determine the isometric strength ratio of MR/LR independently of knee flexion angle, with the KR-test showing high reliability (ICC >0.87) to assess this isometric strength ratio using a hand-held dynamometer. Our findings indicate that lateral and medial rotations preferentially activate the medial and lateral hamstring muscle groups, allowing for targeted assessment and revealing that the neutral position resulted in the highest isometric strength. Tibial rotation significantly affects hamstring muscle recruitment, highlighting the importance of considering the hamstring muscles as separate entities during assessment. The KR-test provides a valuable tool for selectively targeting specific hamstring muscle groups, which is particularly useful for rehabilitation and training interventions. By using the isometric strength ratio of MR/LR, practitioners could better detect deficiencies in specific muscle groups in athletes with previous injuries, thereby improving the rehabilitation process before their return to sports. Further research should focus on evaluating the isometric strength ratio of MR/LR in specific populations, such as those recovering from hamstring injury or anterior cruciate ligament reconstruction, to validate these findings and improve rehabilitation processes.

1. **Conflict of interest**

The authors have no conflicts of interest that are relevant to findings of this manuscript.

1. **Data availability and integrity**

The data used for this article are available on request from the corresponding author. All authors have read and approved the final version of the manuscript and had full access to all the data in this study and take complete responsibility for the integrity of the data and the accuracy of the data analysis.

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**Table 1.** Mean ± SD strength results and reliability in 30, 60 and 90 degrees of knee flexion with the hand-held dynamometer during the first and second tests in healthy male volunteers

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | NP 90° | | MR 90° | | LR 90° | | NP 60° | | MR 60° | | LR 60° | | NP 30° | | MR 30° | | LR 30° | |
|  | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test |
| Mean (N.m) | 73.5 | 75.1 | 62.8 | 64.0 | 70.2 | 71.0 | 73.4 | 73.6 | 64.2 | 65.1 | 70.4 | 70.8 | 74.1 | 74.6 | 63.6 | 64.0 | 69.3 | 69.3 |
| SD (N.m) | 18.2 | 17.6 | 15.0 | 13.7 | 15.5 | 15.8 | 13.7 | 13.2 | 15.0 | 15.2 | 12.7 | 12.5 | 17.8 | 17.5 | 14.7 | 14.7 | 14.6 | 13.6 |
| MDC (N.m) | 9.7 (13.2%) | | 7.6 (11.7%) | | 16.7 (23.7%) | | 12.2 (16.8%) | | 9.5 (14.6%) | | 9.1 (12.7%) | | 11.1 (14.9%) | | 7.7 (11.9%) | | 6.8 (9.8%) | |
| ICC (95% CI) | 0.97 (0.93-0.98) | | 0.97 (0.94-0.98) | | 0.87 (0.76-0.93) | | 0.91 (0.83-0.95) | | 0.95 (0.89-0.97) | | 0.94 (0.88-0.96) | | 0.95 (0.91-0.97) | | 0.96 (0.93-0.98) | | 0.97 (0.94-0.98) | |
| *p*-value | **0.043** | | 0.10 | | 0.20 | | 0.83 | | 0.14 | | 0.56 | | 0.44 | | 0.33 | | 0.69 | |

*SD = standard deviation; MDC = minimal detectable change; ICC = intraclass coefficient correlation ; 95% CI = 95% confidence interval; MR = medial rotation; LR = lateral rotation; NP = neutral position*

**Table 2.** Results for repeated measures ANOVA with Bonferroni post hoc comparison of peak strength production in tibial rotations, and mean difference with 95%CI for mean difference with the hand-held dynamometer in NP, LR and MR

|  |  |  |  |
| --- | --- | --- | --- |
|  | Mean Diff (N.m)  with 95% CI | Cohen's d | p bonf |
| NP vs LR | 3.5 (-4.7 ; 11.7) | 0.100 | 0.899 |
| NP vs MR | 9.1 (0.9 ; 17.4) | 0.261 | **0.023** |
| LR vs MR | 5.6 (-2.6 ; 13.8) | 0.161 | 0.293 |

*Mean diff = mean difference ; 95%CI = 95% confidence interval of mean difference with lower and upper results ; Cohen’s d = effect size ; p bonf = p-value of Bonferroni post hoc ; MR = medial rotation; LR = lateral rotation; NP = neutral position*

**Table 3.** Mean ±SD isometric strength results (of the 1st and 2nd tests) in MR and LR, and isometric strength MR/LR ratio at 30, 60 and 90 degrees of knee flexion with the hand-held dynamometer in healthy male volunteers

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | MR 90° | LR 90° | MR 60° | LR 60° | MR 30° | LR 30° |
| Mean ± SD (N.m) | 63.4 ± 14.4 | 70.6 ± 15.7 | 64.7 ± 15.1 | 70.6 ± 12.6 | 63.8 ± 14.7 | 69.3 ± 14.1 |
| MR/LR ratio | 0.94±0.17 |  | 0.93±0.10 |  | 0.93±0.10 |  |

*SD = standard deviation; MR = medial rotation; LR = lateral rotation*

**Table 4**. sEMG activation values for biceps femoris and semitendinosus in NP, MR and LR at 30, 60 and 90 degrees of knee flexion during first/second test in healthy male volunteers

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Biceps Femoris | | | | | | | | | | | | | | | | | | |
|  | NP 90° | | MR 90° | | LR 90° | | NP 60° | | MR 60° | | LR 60° | | NP 30° | | MR 30° | | LR 30° | |
|  | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test |
| Mean (%MVA) | 73.8 | 77.3 | 58.0 | 59.1 | 89.0 | 88.5 | 68.9 | 71.4 | 59.0 | 57.0 | 81.0 | 85.6 | 68.5 | 64.9 | 57.3 | 55.1 | 79.5 | 82.7 |
| SD (%MVA) | 18.1 | 15.4 | 17.8 | 17.4 | 13.5 | 13.2 | 19.9 | 19.4 | 22.4 | 19.4 | 13.0 | 13.1 | 25.3 | 19.2 | 20.3 | 18.5 | 16.7 | 14.4 |
| MDC (%MVA) | 41.7 | | 43.7 | | 36.7 | | 52.3 | | 56.8 | | 35.8 | | 60.0 | | 51.6 | | 53.2 | |
| ICC (95% CI) | 0.25 (-0.08-0.53) | | 0.61 (0.36-0.78) | | 0.43 (0.10-0.66) | | 0.63 (0.38-0.79) | | 0.66 (0.43-0.81) | | 0.22 (-0.08-0.50) | | 0.64 (0.41-0.80) | | 0.56 (0.29-0.75) | | 0.62 (0.37-0.79) | |
| *p*-value | 0.20 | | 0.38 | | 0.42 | | 0.25 | | 0.29 | | 0.06 | | 0.20 | | 0.26 | | 0.34 | |
| Semitendinosus | | | | | | | | | | | | | | | | | | |
|  | NP 90° | | MR 90° | | LR 90° | | NP 60° | | MR 60° | | LR 60° | | NP 30° | | MR 30° | | LR 30° | |
|  | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test | 1st test | 2nd test |
| Mean (%MVA) | 80.0 | 85.1 | 76.9 | 78.7 | 67.6 | 67.6 | 72.9 | 77.5 | 72.7 | 76.0 | 61.7 | 62.7 | 68.1 | 64.9 | 73.3 | 67.9 | 55.2 | 56.7 |
| SD (%MVA) | 18.9 | 17.1 | 18.1 | 17.3 | 23.1 | 20.1 | 19.7 | 21.5 | 19.1 | 17.1 | 17.2 | 19.5 | 21.8 | 21.9 | 19.5 | 18.4 | 19.8 | 18.8 |
| MDC (%MVA) | 47.7 | | 45.0 | | 56.1 | | 54.5 | | 49.1 | | 50.5 | | 59.1 | | 50.3 | | 53.0 | |
| ICC (95% CI) | 0.43 (0.13-0.66) | | 0.51 (0.23-0.72) | | 0.73 (0.53-0.85) | | 0.58 (0.31-0.76) | | 0.49 (0.20-0.70) | | 0.54 (0.27-0.74) | | 0.61 (0.36-0.78) | | 0.47 (0.17-0.69) | | 0.59 (0.33-0.77) | |
| *p*-value | 0.09 | | 0.32 | | 0.49 | | 0.15 | | 0.18 | | 0.38 | | 0.22 | | 0.10 | | 0.34 | |

*SD = standard deviation; MDC = minimal detectable change, ICC = intraclass coefficient correlation ; 95% CI = 95% confidence interval ; MR = medial rotation; LR = lateral rotation; NP = neutral position ; %MVA = percentage of maximal vountary activation*

**Table 5.** Results of repeated measures ANOVA with Bonferroni post hoc for sEMG activation values of biceps femoris for knee flexion angulation in comparison to tibial position, with mean difference and 95%CI for mean difference

|  |  |  |
| --- | --- | --- |
|  | F | p |
| Knee | 2.219 | 0.111 |
| Knee vs tibia | 1.272 | 0.282 |
| Tibia | 36.380 | **< 0.001** |

|  |  |  |  |
| --- | --- | --- | --- |
|  | Mean Diff (%MVA) with 95% CI | Cohen's d | p bonf |
| NP vs LR | -12.0 (-19.6 ; -4.3) | -0.367 | **< 0.001** |
| NP vs MR | 14.8 (7.1 ; 22.4) | 0.453 | **< 0.001** |
| LR vs MR | 26.7 (19.1 ; 34.3) | 0.819 | **< 0.001** |

*Mean diff = mean difference ; 95%CI = 95% confidence interval of mean difference with lower and upper results; Cohen’s d = effect size ; p bonf = p-value of Bonferroni post hoc ; MR = medial rotation; LR = lateral rotation; NP = neutral position ; knee = angle of knee flexion ; tibia = position of tibial rotation ; %MVA = percentage of maximal vountary activation*

**Table 6.** Results of repeated measures ANOVA with Bonferroni post hoc for sEMG activation values of semitendinosus muscle for tibial rotation in comparison of knee flexion angulation, with mean difference and 95%CI for mean difference

|  |  |  |  |
| --- | --- | --- | --- |
|  | Mean Diff (%MVA) with 95% CI | Cohen's d | p bonf |
| 30° vs 60° | -3.5 (-9.2 ; 2.1) | -0.144 | 0.404 |
| 30° vs 90° | -9.3 (-14.9 ; -3.6) | -0.381 | **< 0.001** |
| 60° vs 90° | -5.8 (-11.4 ; -0.1) | -0.237 | **0.044** |

|  |  |  |  |
| --- | --- | --- | --- |
|  | Mean Diff (%MVA) with 95% CI | Cohen's d | p bonf |
| NP vs LR | 12.0 (4.1 ; 19.9) | -0.144 | **0.001** |
| NP vs MR | -1.0 (-9.0 ; 6.9) | -0.381 | 1.0 |
| LR vs MR | -13.0 (-20.9 ; -5.1) | -0.237 | **< 0.001** |

*Mean diff = mean difference ; 95%CI = 95% confidence interval of mean difference with lower and upper results; Cohen’s d = effect size ; p bonf = p-value of Bonferroni post hoc ; MR = medial rotation; LR = lateral rotation; NP = neutral position*

**Figure 1** A. Fixed model with volunteer’s position at 90 degrees of hip and 60 degrees of knee flexion. B. 30° of lateral and medial rotation

  

Figure 1A Figure 1B