Quadriceps femoris cross-sectional area and specific leg strength: relationship between different muscles and squat variations

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Background. The aim was to determine the relationship between the cross-sectional area of the quadriceps femoris and strength performance in the deep and parallel barbell squat.

Methods. The sample included 16 university students (7 female, 24.1±1.7 years). Muscle strength was expressed as external load, including the one-repetition maximum and the body mass segments involved (calculated according to Dempster's method). The cross-sectional area of the quadriceps femoris muscles was determined using ultrasound, while leg muscle mass was measured using the Bioelectrical Impedance method.

Results. The cross-sectional areas of the three vastii muscles and leg muscle mass showed moderate to strong correlation with external load in both squat types (r=0.509-0.873). However, partial correlation (cross-sectional area of quadriceps femoris muscles were controlled) showed significant association only between leg muscle mass and deep squat (r=0.64, p<0.05). The cross-sectional area of the vastus lateralis showed a slightly higher correlation with external load in the parallel than in the deep squat (r=0.67, p<0.01 vs. r=0.59, p<0.05). The regression analysis extracted the vastus medialis cross-sectional area as the most important factor in manifesting strength (parallel squat: R^2=0.569; deep squat: R^2=0.499, both p<0.01). The obtained results suggest that parallel squat strength depends mainly on the cross-sectional area of the vastii muscles, while it seems that the performance in the deep squat requires an additional engagement of the hip and back extensor muscle groups.

1 **Quadriceps femoris cross-sectional area and specific**
2 **leg strength: relationship between different muscles**
3 **and squat variations**

Abstract

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Introduction

24 The squat is one of the most popular and important exercises for developing strength and power

25 and is often integrated into strength and conditioning training (Toutoungi, Lu, Leardini, Catani,

26 & O'Connor, 2000; Escamilla, 2001). The exercise is performed in a closed kinetic chain

27 involving the hip, knee, and ankle joints and requires a significant level of hip and ankle mobility

28 as well as stability of the lumbar spine (Kritz, Cronin, & Hume, 2009). It is generally believed

29 that the quadriceps femoris (QF) muscles, assuming 4 pennate muscles (rectus femoris-RF,

30 vastus intermedius-VI, vastus medialis-VM and vastus lateralis-VL), make the greatest

31 contribution to the squat motion, while the hip extensors, hip abductors, and ankle plantar flexors

32 also play important roles (Schoenfeld, 2010).

33 In resistance training, there are numerous variations of the squat, such as the foot position, the

34 position of the dumbbell (load), or the range of motion (Schoenfeld, 2010; Clark, Lambert, &

35 Hunter, 2012). The range of motion (ROM) during the squat, known as the knee flexion angle, is

36 frequently modified in practice, with three types of squats most commonly used: 1) partial squat

37 with ROM of 0 - 45 degrees (°), 2) parallel squat with knee flexion around 90°, and 3) deep squat

38 with ROM over 100° (Clark et al., 2012). It has been shown that different ROM squat variations

39 produce different dynamic and kinematic changes (Drinkwater, Moore, & Bird, 2012), possibly

40 indicating that engagement of upper-leg muscles could be dependent on movement amplitude

41 prescription. The studies on the variability of muscle activation during different ROM squat

42 variations mostly utilized electromyographic (EMG) analyses, and these reports are mostly

43 inconclusive. While some findings indicate that a change in the amplitude of flexion does not

44 cause changes in QF muscle activity (Contreras, Vigotsky, Schoenfeld, Beardsley, & Cronin,

45 2016; da Silva et al., 2017), others indicate a change in EMG activity of different QF muscle

46 groups as a function of squat ROM (Caterisano et al., 2002; Marchetti et al., 2016). For example,

47 Contreras et al. (2016) reported similar EMG responses of VL and the hip extensor muscles

48 (gluteus maximus and biceps femoris) during both parallel and deep squats in resistance-trained

49 females. However, in resistance-trained males, shorter variants of the squat (partial and parallel)

50 elicited greater involvement of the VL, VM and RF muscles, while conversely the EMG

51 amplitude of the gluteus maximus was greater during deep squats (Caterisano et al., 2002;

52 Marchetti et al., 2016). The shortcoming of the aforementioned studies is that the contribution of

53 the VI muscle is neglected because estimation of the EMG signals of the deep muscles, such as

54 VI, cannot be performed directly with surface electrodes. The exception is the distal portion of

55 the VI muscle, which is the only area available for surface EMG but can only be used for

56 isometric contraction at low force levels (Watanabe & Akima, 2011). In addition, the majority of

57 EMG studies have measured total muscle electrical activity and have not determined the partial

58 contribution of the muscular and neural components. Considering that different squat modalities

59 could accentuate intramuscular hypertrophy of the quadriceps (Earp, Newton, Cormie, &

60 Blazevich, 2015; Kubo, Ikebukuro, & Yata, 2019), which in turn could lead to different

61 performance adaptations (Mangine et al., 2014; Wilhelm et al., 2014; Methenitis et al., 2016) and

62 alter potential knee injury risks (Zebis, Andersen, Bencke, Kjaer, & Aagaard, 2009; Toumi et al.,

63 2013; Mangine et al., 2014a), it is extremely important to evaluate and confirm the relationship

64 between the development of different quadriceps muscle parts and squat strength in two

65 fundamental ROM variations (i.e. parallel vs. deep squat).

66 Although there are a considerable number of studies in the current literature that investigated the

67 relationship between lower-body muscle size and squat strength (Häkkinen et al., 1998; Secomb

68 et al., 2015; Seitz et al., 2016), most of them measured the outer thigh volume and did not

69 provide data on the contribution of each quadriceps muscle parts in different ROMs squat

70 performance. It should also be noted that previous research has assessed squat strength by one-

71 repetition maximum test (1RM), which only reflects the weight lifted and does not take into

72 account the mass of the other segments of the body (i.e., head, trunk, and upper-leg). Hence, this

73 could be a confounding factor when determining total QF muscle resistance, and incorporating

74 both lifted weight and body segments would be more a reliable indicator of external load.

75 Therefore, the aim of the study was to evaluate the relationship between the cross-sectional area

76 of four quadriceps femoris muscles and external load measured during two major squat

77 variations: deep squat and parallel squat. We hypothesized that different parts of the quadriceps

78 muscle will have a different relationship with maximum strength in squats and that contribution

79 of vastii muscles (VM, VL and VI) would be greater during parallel compared to deep squat.

80

Materials & Methods

82 **Sample and study design**

83 The sample included 16 university volunteers (9 males and 7 females) with no experience of

84 resistance training. During the sample selection, the study was advertised to all departments at

85   the university (Table 1). Both sexes were included to reduce gender sampling disparity in sports

86   science and medical research (Costello, Bieuzen, & Bleakley, 2014).

87   **INSERT TABLE 1 HERE**

88

89   Participants were not professional athletes and did not suffer from leg or back injuries. All

90   participants voluntarily participated in the study and previously signed a written informed

91   consent regarding the experimental procedure and potential risks. The study was approved by the

92   Ethics Committee of the Faculty of Sport and Physical Education, University of Belgrade

93   (protocol number: 2316/19-2) and conducted in accordance with the Declaration of Helsinki.

94   The strength tests were performed on two separate days, with the deep barbell squat on the first

95   day and the parallel barbell squat on the second day. Before strength testing, two familiarization

96   sessions were performed, where subjects received instructions on the proper squat technique for

97   the deep and parallel squat exercises. During familiarization sessions, the subjects performed 2

98   controlled sets with 8 to 10 reps of both squat variants with barbell on the shoulders, while being

99   continuously monitored and corrected by experienced coach. Both squat variations were

100   performed with the feet at shoulder width and with toes pointed forward or slightly outward. The

101   barbell was placed in the high bar position across the shoulders on the trapezius, slightly above

102   the acromion. To eliminate the negative impact of fatigue, the tests took place 48 hours apart.

103   Both tests were performed at approximately the same time of day (12-14h). Between each test

104   and retest session, the subjects had 48h of rest, in order to avoid the effects of fatigue.

105   Anthropometry, body composition and quadriceps femoris (QF) cross-sectional measures were

106   taken two days prior to first strength testing. Subjects were advised to avoid any form of physical

107   activity 48 hours prior to the testing, as well as not to consume alcoholic or caffeinated

108   beverages 12 hours before testing. The study protocol is shown in Figure 1.

109

110   **INSERT FIGURE 1 HERE**

111

112   **Variables and protocols**

113   Strength in both squat variations was assessed by one-repetition maximum test (1RM) using the

114   standardized testing protocol (Baechle & Earle, 2008). The test was preceded by a 10-minute

115   warm-up (light running and warm up exercises), followed by 8-10 repetitions of the exercise

116 with a load of 50% 1RM and 2-3 repetitions of the exercise with a load of 60-80% 1RM. Each

117 subject had 5 attempts to lift the maximum weight. Rest intervals between trials were set at 3

118 minutes. Deep squat was performed with maximum amplitude of flexion in the knee joint. The

119 required knee angle in this position was 45 degrees (Contreras et al., 2016; Kubo et al., 2019),

120 with the lumbar spine kept neutral. The height of the deep squat was measured for each

121 participant individually. An elastic band was then stretched, which the participants had to touch

122 during the squat to achieve the required angle of 45 degrees at the knee. Parallel squat was

123 performed in a position where the femurs were parallel to the ground when the trochanter mayor

124 and lateral epicondyle of the femur were at the same level (Figure 2; Earp et al., 2015; Contreras

125 et al., 2016; da Silva et al., 2017). External load was calculated as the sum of 1RM and mass of

126 body segments (head, trunk, arms and thighs) using the model proposed by Dempster &

127 Gaughran (1967). To determine the repeatability of the strength measurement, test-retest was

128 conducted on ten participants on the two separate days.

129

130   **INSERT FIGURE 2 HERE**

131

132 Body height was measured with a Martin's portable anthropometer (Siber-Hegner, Switzerland)

133 to an accuracy of 0.1 cm. Body composition variables, including skeletal muscle mass (SMM),

134 percent body fat (PBF), and dominant leg muscle mass (LSMM), were measured with In-Body

135 720 (Biospace Co., Seoul, Korea) using Direct Segmental Multi frequency–Bioelectrical

136 Impedance Analysis (DSM–BIA method). Prior to testing, the subjects were instructed not to eat

137 anything in the morning, avoid any kind of exercise 24 before body composition analyze and

138 perform all physiological needs before the measurement. Subjects were in the standing position

139 for at least 5 minutes prior to measurement for redistribution of body fluids. During the

140 measurement all subjects were in light sport clothing and had no metal accessories. The subjects

141 individually picked their dominant leg, based on the question "Which leg would you use to shoot

142 the ball?" (van Melick et al., 2017) and that variable was used for further analysis.

143 Image acquisition was performed by the experienced and previously trained radiology specialist.

144 The cross-sectional area (CSA) was measured using an ultrasound scanner (Siemens Antares,

145 Erlangen, Germany), with a linear probe of 7.5 MHz and expressed in square millimetres (mm²).

146 The 2D ellipse diagnostic method was applied. Imaging was conducted after about 10 min rest in

147   supine position on right leg in full extension. The ultrasound probe was transversally placed on

148   the skin with minimal compression with conductive gel used for acoustic coupling on the skins

149   surface. The CSA of the rectus femoris (RF) was measured at the level of the three-fifths of the

150   distance from the anterior superior iliac spine to the superior patellar border (Seymour et al.,

151   2009), while the vastus intermedius (VI) CSA measurement was performed at one-half between

152   spina iliaca anterior superior and the proximal border of the patella (Haaf et al., 2017). The VL

153   muscle CSA was measured at 50% of femur length, defined as the distance of 50% between the

154   greater trochanter and the lateral condyle (Franchi et al., 2018). The vastus medialis (VM) was

155   measured at the level of the distal portion above the medial side of patella. To determine the

156   repeatability of the ultrasound measurement, test-retest was conducted on ten participants on the

157   two separate days.

158

159   **Statistics**

160   The Shapiro-Wilk and Levene'ş tests were used to assess the normality of the distribution and

161   the homogeneity of variances, respectively. Reliability of the strength and ultrasound measures

162   were accessed using the intra-class correlation coefficient (ICC). The independent samples t-test

163   was used to determine the differences between male and female CSA of muscles and LSMM. To

164   analyse the effects of sex and differences between external load of deep squat and parallel squat,

165   the 2-way ANOVA (model: Mixed between-within subjects) was used. Pearson's moment

166   correlation was used to examine the association between external load, LSMM and CSA of 4

167   muscles forming QF (RF, VI, VM and VL). A partial correlation (controlling for QF muscles

168   size) was performed to determine the influence of other lower-body muscle groups, except QF,

169   on external load during both squat variations. The relationships were classified as trivial (< 0.4),

170   moderate (0.4 – 0.6), strong (0.6 – 0.8), very strong (0.8 – 1.0), and perfect correlation (1.0)

171   (Dancey & Reidy, 2007). For discussion purposes, the correlation coefficients were directly

172   compared with their 95% confidence intervals (Vigotsky et al., 2019). Additionally, to find the

173   best predictive model of the quadriceps muscles for the external load of deep and parallel squat,

174   a backward multiple regression was applied. Statistical analysis was performed using the IBM

175   SPSS Statistics software package (Version 21, SPSS Inc, Chicago, IL, USA). All data are

176   presented as means ± SD, where p≤0.05 was considered a statistically significant determinant.

177

178 **Results**

179 Excellent reliability was observed for both ultrasound (RF: ICC = 0.997, CI = 0.990-0.999, p <

180 0.001; VI: ICC = 0.995, CI = 0.979-0.998, p < 0.001; VM = 0.997, CI = 0.987-0.999, p < 0.001;

181 VL: ICC = 0.996, CI = 0.982-0.999, p < 0.001) and strength (parallel squat: ICC = 0.997, CI =

182 0.987-0.999, p < 0.001; deep squat: ICC = 0.997, CI = 0.990-0.999, p < 0.001) measurements.

183 As expected, the CSA of QF muscle and LSMM was higher in males than females (t = 3.449, df

184 = 14, p = 0.004, ES = 1.75 and t = 5.824, df = 14, p = 0.000, ES = 2.89, respectively). Males

185 demonstrated significantly higher CSA of RF (t = 2.238, df = 14, p = 0.042, ES = 1.11), VI (t =

186 3.626, df = 14, p = 0.003, ES = 1.89) and VM (t = 3.283, df = 14, p = 0.005, ES = 1.71). A

187 significant difference was not found only for VL (t = 1.749, df = 14, p = 0.102, ES = 0.92),

188 although in females the average CSA of VL was lower for about 55 mm^2 (Table 2).

189

190   **INSERT TABLE 2 HERE**

191

192 Male subjects achieved significantly higher external load for deep and parallel squat (F = 24.882,

193 df = 1, p =0.000, ES = 1.33). Subjects of both sexes demonstrated significantly higher external

194 load for parallel compared to deep squat (F = 44.136, df = 1, p = 0.000, ES = 1.77). As the

195 interaction between sex and squat variation was not statistically significant (F = 0.036, df = 1, p

196 = 0.852, ES = 0.05), this proves that strength manifests in the same manner in both genders

197 (Figure 3).

198

199   **INSERT FIGURE 3 HERE**

200

201 Both deep squat (p = 0.014) and the parallel squat (p = 0.004) were significantly related to QF

202 CSA, but the correlation was stronger for the parallel squat (see Table 3). VM and VL showed

203 the strongest correlation with parallel squat (p = 0.001 amd p = 0.005, respectively), followed by

204 VI (p = 0.029). For deep squat, the strongest correlation was observed with VM (p = 0.002),

205 followed by VL (p = 0.014) and VI (p = 0.044). Only CSA of RF showed no significant

206 association with external load measured during deep and parallel squat (p = 0.267 and p = 0.104,

207 respectively; Table 3). LSMM was significantly correlated with both squat variation (p = 0.000).

208   Even when a CSA of QF was controlled, LSMM was significantly correlated with deep (r =

209   0.641, p = 0.026), but not with parallel squat (r = 0.530, p = 0.076).

210

211   **INSERT TABLE 3 HERE**

212

213   Further regression analysis revealed that of the four predictors of quadriceps muscles, the best-fit

214   model highlighted VM as the most important factor in the manifestation of strength in both squat

215   variations. For external load of parallel squat, VM explained about 57% of variance (R^2 = 0.569,

216   p = 0.001), with the equation for this model: y = 0.3349x + 61.365. On the other hand, the VM

217   model explained about 50% of the external load deep squat (R^2 = 0.499, p = 0.002), with the

218   equation: y = 0.3114x + 58.609 (Figure 4).

219

220   **INSERT FIGURE 4 HERE**

221

222   **Discussion**

223   The study was conducted with the aim to determine contribution of quadriceps muscle parts in

224   manifestation of strength during deep and parallel barbell squat. The present results indicate that

225   there is a significant correlation between the CSA of QF and 1RM strength in both squat

226   variations, but a stronger association was found with PS. Squat performance is largely dependent

227   on the CSA of all three vastii muscles, with VM dimensions playing a significant role in the

228   manifestation of strength in both squat variations. The contribution of VL CSA appears to be

229   more pronounced in the parallel compared to the deep squat.

230   We observed a significant association between lower-body muscle size and maximal strength in

231   both squat variations. In addition, males demonstrated larger CSA of QF muscles and LSMM, as

232   well as higher values of external load for both squat types. This implies that larger muscle sizes

233   in males are the fundamental reason for significantly higher strength for deep and parallel squat.

234   Pearson correlation coefficient revealed moderate to strong association between muscle size and

235   squat strength (r=0.58-0.68). Similar results were obtained by Suchomel & Stone (2017) (r=0.64)

236   and Häkkinen et al. (1998) (r=0.56-0.64) for males and females, indicating that QF muscle mass

237   plays an important role in squat strength performance, however additional factors are also

238   important (i.e. other muscle groups, neural activity, muscle architecture). These statements are

239 further confirmed by our results, as squat external load is more related to total leg muscle mass

240 compared to the QF CSA. Moreover, QF CSA showed a rather stronger relationship with parallel

241 than with deep squat (r=0.68, p<0.01 vs. r=0.59, p<0.05, respectively), while conversely, when

242 CSA of QF was controlled, LSMM was significantly correlated only with deep squat.

243 Considering that ROM significantly determines strength output in the squat (Drinkwater et al.,

244 2012), we can assume that in addition to the QF, the other leg muscle groups are also

245 significantly involved in the performance of squats with larger ROMs. Previous training studies

246 with deep and half squats, showed that performing deep squats (ROM 0º-140º) influence higher

247 relative increases in squat 1RM and significantly affect the volume of adductor and gluteus

248 maximus muscles, in comparison to half squats (Kubo et al., 2019). However, the level of

249 quadriceps hypertrophy was similar in both groups. On the other hand, Bloomquist et al. (2013)

250 demonstrated greater QF hypertrophy after full ROM squats (0º - 120º) compared to partial (0º-

251 60º). These partial disagreements could be explained by different squats ROM prescription,

252 which might affect the level of stimulus on different leg muscle groups.

253 In contrast to the vastii muscles, RF showed no significant association with 1RM in either squat

254 variation. Apart from knee extension, RF acts as a hip flexor (Robertson, Wilson, & St Pierre,

255 2008), and it is quite possible that single-joint knee extension exercises are more suitable for

256 training the RF (Ema, Sakaguchi, Akagi, & Kawakami, 2016; Kubo et al., 2019). The CSA of

257 the VM showed the highest correlation with both deep and parallel squat, indicating a crucial

258 role of VM muscle size in squat performance. From a practical point of view, this is of great

259 importance considering that knee stability depends primarily on VM function and that VM

260 asymmetry, as well as VM atrophy, lead to various knee problems including patelo-femoral pain

261 syndrome (Toumi et al., 2013). The relationship between the CSA of VL and parallel squat was

262 stronger compared to deep squat (r=0.65, p<0.01 vs. r= 0.55, p<0.05), explaining why the CSA

263 of total QF was more strongly correlated with the external load of parallel squat. In addition,

264 both Brechue & Abe (2002) and Secomb et al. (2015) reported that the thickness of VL was a

265 strong predictor of 1RM in back squat and squat jump performance, while Earp et al. (2010)

266 indicated that leg power production and jumping performance were strongly dependent on the

267 architecture of the gastrocnemius lateralis muscle rather than VL. Nimphius, McGuigan, &

268 Newton (2012) showed a moderate relationship between VL muscle thickness and relative squat

269 1RM and emphasized that the performance of the muscle is strongly dependent on its

270 architecture, including muscle fascicle length and pennation angle. The complexity of the leg

271 strength and power performance phenomenon in multi-joint movements consisting of hip, knee,

272 and ankle is even greater when the total EMG activity during squat variations is analysed. Using

273 the muscle EMG approach in squat analysis, Contreras et al. (2016) and Caterisano et al. (2002)

274 reported that the EMG values of VL and VM showed no significant differences during DS, PS

275 and front squat. Moreover, EMG measurements support the importance of the hip extensors,

276 especially the gluteus maximus in DS strength output, whose EMG amplitude showed a

277 significant increase with squat depth (Caterisano et al., 2002).

278

279 **Strengths and limitations of the study**

280 The main strength of this study is that this is the first study to evaluate the contribution of each

281 quadriceps muscle part in different ROMs of squat performance. Most previous studies only

282 measured outer thigh volume and did not provide this information. Moreover, we were able to

283 evaluate the contribution of the VI, which was neglected in previous studies. Another strength of

284 this study is that it provides more accurate information about muscle strength by calculating the

285 exact external load, taking into account the mass of the other body segments in addition to the

286 1RM. This is very important when calculating muscle strength as it could be a confounding

287 factor in determining total QF muscle strength.

288 A limitation of the present study investigating CSA and strength in deep and parallel squat

289 includes the lack of data on the neural contraction component and muscle architecture. In

290 addition, the CSA of all three vasti muscles (VI, VM and VL) was measured in the distal region.

291 Previous studies have shown that CSA varies depending on the measurement position (Noorkoiv,

292 Nosaka, & Blazevich, 2010), so there is a possibility of partial variation in results, and we

293 recommend that future studies include measurement of QF in the proximal, middle, and distal

294 regions. The second limitation refers to the strength testing protocol, as the order of the tests was

295 fixed, which could have resulted in increased fatigue from the first test session influencing

296 strength in the second session. Therefore we strongly encourage that future studies apply a

297 randomised strength testing design. Also, it should be noted that this is cross sectional research,

298 based on correlation analysis, and longitudinal training studies are required to better explore how

299 specific hypertrophy of QF regions is affected by squat depth variations. In addition, subjects

300 require optimal hip and ankle mobility to perform deep squat safely and successfully, so this type

301 of exercise is not suitable for everyone in practice (Contreras et al., 2016). Therefore,

302 standardization of depth during deep squat is difficult to establish among the subjects, mainly

303 due to varying levels of joint mobility and muscle flexibility. We instructed our subjects to go as

304 deep as possible and reach 45º in the knees while keeping the lumbar spine neutral, which was

305 quite difficult task for some subjects.

306

307 Conclusions

308 In conclusion, the results prove that the external load in the parallel and deep squat is highly

309 dependent on the CSA of the quadriceps femoris, while a slightly stronger association was found

310 in the parallel squat. The CSA of the VM has a fundamental role in manifesting strength in both

311 types of squat and the highest correlation with both squat variations. VL showed a slightly higher

312 correlation with parallel squat external load. The vastus intermedius showed an intermediate

313 correlation with both variants of the squat, but slightly lower than VM and VL. We can assume

314 that muscle strength during the parallel squat depends mainly on the CSA of three vastii muscles,

315 while the deep squat performance requires additional function of other muscle groups, especially

316 the hip and back extensors. From a practical point of view, the inclusion of both squat variations

317 in resistance training program might be the best possible approach, while supplementary

318 exercises should be implemented for optimal training of the rectus femoris due to the multi-joint

319 function of this muscle.

320

321

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444

Sample characteristics.

BH- body height; BM- body mass; BMI- body mass index; SMM- skeletal muscle mass; PBF percent body fat; LSMM- dominant leg skeletal muscle mass

1   Table 1:

2   Sample characteristics.

Variables	Mean±SD
Age (years)	24.1±1.7
BH (m)	1.75±0.08
BM (kg)	70.4±12.03
BMI (kg/m²)	22.7±2.3
SMM (kg)	33.23±7.60
PBF (%)	16.48±7.30
LSMM (kg)	9.3±1.32

3   BH- body height; BM- body mass; BMI- body mass index; SMM- skeletal muscle mass; PBF

4   percent body fat; LSMM- dominant leg skeletal muscle mass

Cross-sectional area of quadriceps muscles and leg muscle mass between males and females.

*- indicates a significant gender difference ($p<0.05$); **- indicates a significant gender difference ($p<0.01$)

1   Table 2:

2   Cross-section area of quadriceps muscles and leg muscle mass between males and females.

Muscles	Males Mean±SD	Females Mean±SD
Rectus Femoris (mm^2)	383.67±79.73*	285.71±95.49
Vastus Intermedius (mm^2)	333.44±83.20**	205,71±46.59
Vastus Medialis (mm^2)	337.11±67.57**	242,29±39.69
Vastus Lateralis (mm^2)	374.67±72.45	321.00±40.59
Quadriceps Femoris (mm^2)	1428.89±223.04**	1054.71±204.48
LSMM (kg)	10.68±1.02**	7.52±1.15

3   *- indicates a significant gender difference ($p<0.05$);

4   **- indicates a significant gender difference ($p<0.01$)

Correlation between external load and cross- section area of Quadriceps Femoris muscles.

1 Table 3:

2 Correlation between external load and cross- section area of Quadriceps Femoris muscles.

Muscles	Parallel Squat		Deep Squat	
	r	p	r	p
Rectus Femoris	.408	.117	.315	.235
Vastus Intermedius	**.546**	**.029**	**.509**	**.044**
Vastus Medialis	**.754**	**.001**	**.706**	**.002**
Vastus Lateralis	**.669**	**.005**	**.598**	**.014**
Quadriceps Femoris	**.672**	**.004**	**.599**	**.014**

Figure 1

Study protocol
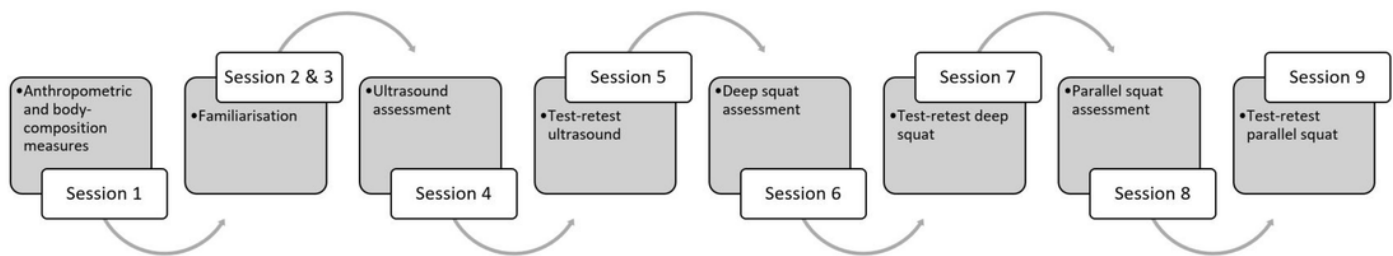
Figure 2

Illustration of participants performing the deep squat and parralel squat.
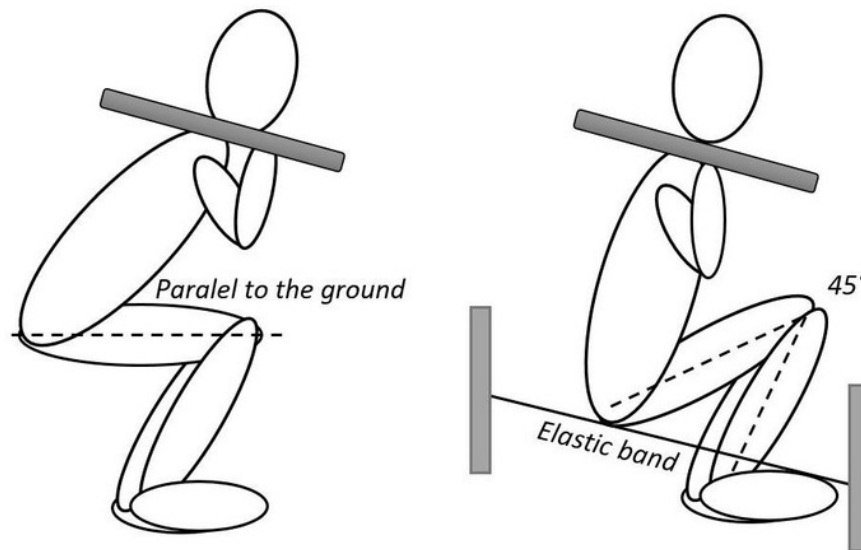
Figure 3

Deep squat and parallel squat external load values for males and females.

**- indicates a significant squat variation difference (p<0.01); #- indicates a significant gender difference (p<0.01).
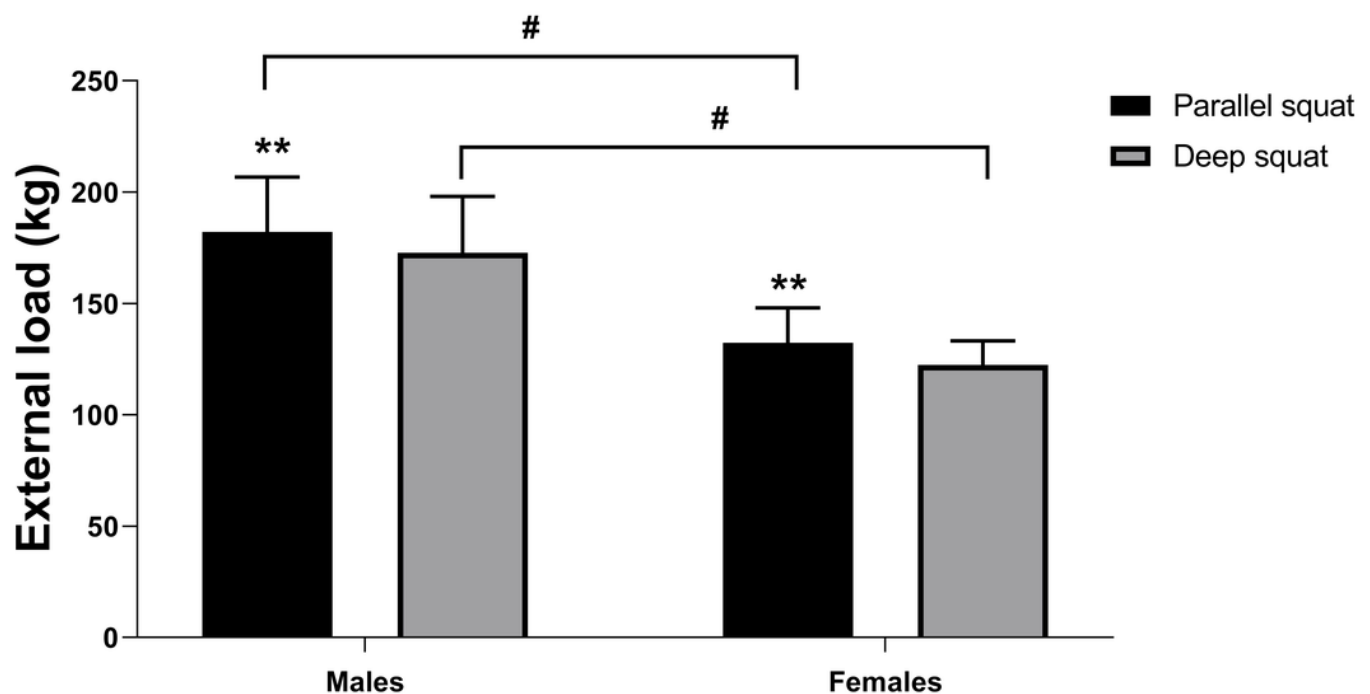
Figure 4

External load prediction for parallel (panel A) and deep squat (panel B) based on the cross-section area of vastus medialis.

VM - vastus medialis.