

1 **The variation in pressures exerted by commercially available compression garments**

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3 Original Investigation
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61 **Abstract**

62 Commercially available compression garments (CGs) demonstrate the enhanced recovery from exercise in
63 some, but not all studies. It is possible that in some cases the degree of compression pressure (ComP) exerted is
64 not sufficient to produce any physiological benefit. The aim of this investigation was to identify the levels of
65 ComP exerted by commercially available CGs. This study was composed of two parts. In part A 50 healthy,
66 physically active individuals (n=26 male, n=24 female) were fitted with CGs according to manufacturer's
67 guidelines. ComP was measured in participants standing in the anatomical position with a pressure measurement
68 device inserted between the skin and the garment. Data were compared to 'ideal' pressure values proposed in
69 the literature. In part B ComP in three different brands of CG were compared in a population of 29 men who all
70 wore a medium sized garment. A one way ANOVA indicated that there was a significant difference ($P < 0.05$)
71 between observed pressure and ideal pressure at the quadriceps for males and females and in the calf for the
72 female population. There was no significant difference ($P > 0.05$) between observed and ideal pressures in the
73 calf of the male population. No significant differences in pressure ($P > 0.05$) were observed between CG brands
74 at the quadriceps or calf. In conclusion a large number of individuals may not be experiencing an adequate
75 ComP from CG, and this is true for all 3 of the major brands of CGs tested in this investigation.

76
77 Keywords: Recovery, Stockings, Tights, Sports, Athletes
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80 **Introduction**

81 The use of commercially available compression garments (CGs) is becoming increasingly popular within an
82 athletic setting [1-3]. It is claimed that CGs can improve performance, reduce fatigue and enhance recovery
83 [4]. However, the known studies show mixed results, with some supporting the use of CGs [5-8] and others
84 observing no benefits [9]. Compression pressure (ComP) seems to be one of the major factors that potentially
85 determines their efficacy.

86
87 Manufacturers recommend that lower limb CGs (tights) are fitted according to the height and mass of an
88 individual [10], however, the variation in limb size and tissue structure within a given population is likely to
89 affect the fit, particularly when standard sizing categories are used [11]. Thus wide inter-individual variation
90 may exist in the ComP exerted by CGs [12]. Ashdown [13] also indicated that sizing systems used to create
91 'ready to wear' garments are flawed, due to the lack of size variation available to fit the wide range of body
92 types within a population. A large number of studies do not specifically measure the ComP exerted by the CGs
93 used within their study. These studies either fail to report the level of ComP altogether [8, 14-16], report the
94 ComP indicated by the manufacturers of the product, or reference ComP reported in previous research that has
95 used the same brand of garment [11, 17-20]. It has been suggested that the measurement of interface pressure
96 between the skin and the garment is essential in evaluating the efficacy of a garment [21]. Consequently, the
97 ComP should be measured for each individual because the degree of compression exerted by a garment is
98 dependent on the individual size and shape of the body [20] and not necessarily on the height and mass.

99
100 To date, the ideal ComP required to be beneficial to performance and recovery has not been defined. CGs,
101 particularly lower limb garments, are purported to be graduated, with the highest ComP exerted at the ankle and
102 decreasing towards the thigh, thereby creating a pressure gradient [22]. Reported (but not specifically verified)
103 levels of ComP exerted by CGs used in recent research range from 10-12 mmHg [19] to 18-22 mmHg [11].
104 Clinical grade CGs exerting pressures of 30-60 mmHg are frequently prescribed for a range of medical purposes
105 [23]. It has been suggested that for compression to be effective in modulating haemodynamic factors, the ComP
106 must be sufficient to cause a narrowing of the superficial blood vessels; and in order for this to occur the
107 compression must be greater than intravenous pressure [24]. In a supine position, venous pressure in the lower
108 limb is approximately 10-15 mmHg, however these pressures are much higher when standing (30-90 mmHg)
109 [24]. This indicates that the level of compression required to be of benefit may be dependent upon body
110 position. Compression pressures of 10-15 mmHg have been shown to be effective in reducing the diameter of
111 superficial veins in a supine position, however much higher pressures are required to achieve the same results
112 when standing [24]. In contrast, Watanuki and Murata [25] observed improved cardiac output and venous
113 return with ComP of 20 mmHg at the thigh and 25 mmHg at the calf. The authors of this study estimated that
114 the minimum ComP required to improve venous return is 17.3 mmHg at the calf, decreasing to 15.1 mmHg at
115 the quadriceps. Hypothetically, if individuals are not receiving a physiologically effective ComP, the CGs may
116 have no effect on recovery or performance.

121 Ali et al [26] investigated the effects of different grades of compression garments with high (32mmHg at the
122 ankle and 23mmHg at the knee) low (15mmHg at the ankle and 12mmHg at the knee) and no compression, on
123 40 minute running performance. Although no benefits of the compression garments were observed on
124 performance or recovery, participants found the low grade compression garments more comfortable. Whilst
125 there are no studies that indicate optimal levels of compression in the sporting field, clinical research had found
126 positive results with ComP of 15-30 mmHg at the ankle dissipating at the thigh [26-28]. Research has also
127 indicated that high ComP (approximately 30 mmHg at the calf) may impair blood flow and restrict venous
128 return [29]. With this in mind the ComP observed in this study is compared to the ComP suggested by
129 Watanuki and Murata [25].
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131
132 Current evidence for the benefits of using CGs remains equivocal or weak at best. This may be because the
133 popular commercially available garments do not exert sufficient enough pressure to be of benefit. Defining the
134 exact ComP achieved with CGs would enable detailed investigations into the optimum ComP required to affect
135 performance and recovery, and will improve our ability to interpret research findings [12]. Therefore the
136 primary aim of this investigation was to identify the ComP exerted by commercially available lower limb CGs
137 across a representative sample of physically active male and female population. The secondary aim was to
138 identify whether there was consistency in the amount of ComP exerted between different brands of similar
139 products.
140

141 **Methodology**

142 **Participants**

143 This study was composed of two parts.
144

145
146 Fifty participants, having different body sizes (male: n=26; female: n=24), were recruited to participate in part A
147 of the study, in order to establish ComP exerted by commercially available garments. Twenty nine male
148 participants were recruited to participate in Part B of the study, in order to investigate variability in ComP for
149 different product brands. A medium sized garment from 3 different brands was selected (participant
150 characteristics can be seen in table 1). All participants were healthy, physically active and exercised minimum 3
151 times per week. Procedures were approved by the University ethics committee, in accordance with the
152 Declaration of Helsinki and all participants gave written, informed consent and completed a health screening
153 questionnaire. Participants were asked to refrain from heavy exercise in the 48 h preceding the testing session
154 and were excluded from the study if they had a chronic illness or if they were experiencing any musculoskeletal
155 pain or discomfort.
156

157 **Procedures**

158 Anthropometric data were collected from all participants including height and weight; waist, hip and gluteal
159 circumference; thigh, calf and ankle girth and skinfold measurements from 7 sites (bicep, tricep, subscapular,
160 supraspinale, abdomen, front thigh and medial calf). All girth and skinfold measures were taken from the right
161 leg, in accordance with ISAK guidelines. All measures were taken by a level 2 anthropometrist. The technical
162 error of measurement (TEM) for each anthropometric variable is reported in Table 2.
163

164
165 Following anthropometric data collection, male and female participants in part A of the study were fitted with a
166 pair of CGs from one brand (2XU, MA1551b men's compression tights or WA1552b women's compression
167 tights, Melbourne, Australia). Garments were fitted based upon the height and weight of the participant,
168 according to manufacturer guidelines. All participants were either a small, medium or large in traditional
169 garment size (none of the participants required a tall sized garment).
170

171 Part B involved a comparison between 3 different brands of CGs in male participants only. Garment A (2XU,
172 MA1551b men's compression tights) fitted participants in a height and weight range of 150-185cm and 65-90kg
173 respectively, garment B (Skins, A400 men's compression tights, Campbelltown, Australia) fitted participants in
174 a height and weight range of 170-190cm and 70-85kg respectively and garment C (Linebreak, men's velocity
175 compression tights, Sydney, Australia) fitted participants in a height and weight range of 157-190cm and 65-
176 75kg respectively. Garments A, B and C were fitted, in a randomised order, to all male participants who met the
177 manufacturer's fitting criteria (the characteristics for each group can be seen in Table 3). Garments A, B and C
178 were selected for use in this study as they were the most frequently used garments for known research studies
179 investigating the efficacy of lower limb compression tights on sport performance and recovery [5,10-11,15-16].

180 Of the 20 studies, garment A was used in 3 studies, garment B was used in 11 studies and garment C was used
181 in 4 studies.

182 The ComP was measured using a pressure measuring device (Kikuhime, TT Medi Trade, Søleddet, Denmark)
183 that has previously been validated for use with compression clothing [12]. The device was calibrated at the
184 National Physical Laboratory using a pressure vessel (OerLikon Leybold Vacuum, GmbH, Cologne, Germany)
185 attached to a digital pressure controller (DPI 500, Digital Pressure Controller, Druck Ltd, Leicester). The ComP
186 was measured at 3 sites: the midpoint between the inguinal crease and the superior aspect of the patella of the
187 front thigh; the medial aspect of the calf at the site of maximal girth; and 2 cm above the centre of the medial
188 malleolus of the ankle. The seam on the ankle of the garment was positioned below the distal border of the
189 malleolus. All measurements taken with the pressure measuring device were clear of the seam on the lower
190 edge of the garment and clear of the vertical seam on the garment. ComP measurements were taken with the
191 participant standing in the anatomical zero position with their weight evenly distributed on both feet.
192 Measurements were repeated 3 times with the mean value recorded. Technical error of measurement (TEM) was
193 0.48 and 0.92 mmHg at the quadriceps and calf, respectively. The pressure measuring device displays values to
194 the nearest 1 mmHg.

195 196 **Data Analysis**

197 Data collected in part A were analysed using one-way analysis of variance (ANOVA). In the absence of a
198 defined optimal ComP, compression at the quadriceps and calf for a male and female population compared to
199 the minimum recommended ComP of 17.3 and 15.1 mmHg as suggested by Watanuki and Murata, (1994). Data
200 collected in part B were analysed using a one-way ANOVA. A Pearson correlation was also carried out to
201 identify whether any of the measured anthropometric characteristics were related to the ComP at the quadriceps
202 and calf. Where significant differences were observed a *post-hoc* test with a Fisher least significant difference
203 (LSD) adjustment was used to highlight where the differences occurred. Data is presented as a mean value and
204 standard deviations. Significance was set at $p \leq 0.05$.

205 206 **Results**

207 The anthropometric characteristics of the participants are reported in tables 1 and 3. A one-dimensional
208 ANOVA indicated that there was a significant group difference ($F_{2,77}=92.644$, $p < 0.001$) for ComP achieved at
209 the quadriceps. Further *post-hoc* analysis indicated that ComP in the male population was significantly lower
210 ($p < 0.001$) than the recommended minimum pressure. ComP at the quadriceps was 9.9 ± 2.9 mmHg, failing to
211 meet the minimum recommended ComP of 15.1 mmHg by 34.4% (Figure 1). ComP achieved in the female
212 population was also significantly lower than the recommended ComP ($p < 0.001$). The average ComP of 7.9 ± 1.7
213 mmHg fell short of the recommended ComP by 47% (Figure 1).

214
215 A significant group difference was also observed for ComP achieved at the calf ($F_{2,77}=11.535$, $p < 0.001$). Post
216 hoc analysis indicated that there was no significant difference ($P=0.605$) between ideal ComP and ComP at the
217 calf in the male population. Pressure fell short of the recommended level of 17.3 mmHg by 2.9%. There was
218 however, a significant difference between ideal ComP and ComP at the calf in the female population ($p < 0.001$).
219 The mean ComP observed at the female calf was 13.9 ± 2.3 mmHg failing to meet the suggested minimum ComP
220 by 19.7% (Figure 1). Individual compression values for the quadriceps and calf can be seen in figure 2.

221
222 The second part of the investigation revealed no significant difference in ComP between garment brands at the
223 quadriceps ($p=0.638$) and the calf ($p=0.318$). Compression at the quadriceps fell short of the ideal minimum
224 pressure by 33.2, 28.9 and 30.5% for brands A, B and C respectively; ComP at the calf did not achieve the ideal
225 minimum pressure by 10.5, 13.5 and 4.2% for brands A, B and C respectively (Figure 3). There were no
226 significant correlations ($p > 0.05$) between any anthropometric variable measured and ComP at the quadriceps
227 and calf.

228 229 **Discussion**

231 The primary aims of this investigation were to 1) ascertain the level of ComP exerted by a commercially
232 available CGs when applied to the lower limb in a population of active participants; and 2) to identify whether
233 there was consistency in ComP between different popular brands. Results indicated that there was a large
234 degree of variability in ComP when garments were fitted according to manufacturer's guidelines. In part A,
235 ComP ranged from 4-16.7 mmHg at the quadriceps and from 10.3-25 mmHg at the calf. In part B ComP ranged
236 from 8-15 and 10.3-15 mmHg for garment A, 7.7-16 and 9-22 mmHg for garment B and 6-15 and 10.7-22
237 mmHg for garment C at the quadriceps and calf respectively.

238
239 In addition, ComP fell short of the minimum pressure, suggested by Watanuki and Murata [25], in both the male
240 and female populations at the quadriceps. ComP also fell short of the minimum pressure in the female
241 population at the calf. When three different brands of CG were compared there were no significant differences
242 in ComP at the quadriceps or the calf. It should also be noted that a medium sized CG in three different brands
243 does not fit the same sized population. Garment A was the smallest fitting a height and weight range of 157-
244 190cm and 65-75kg, followed by garment B fitting a height and weight range of 170-190cm and 70-85kg, and C
245 was the largest fitting a height and weight range of 150-185cm and 65-90kg. The difference in populations can
246 be observed in Table 3.

247
248 Previous research has caused concerns over whether standardised size categories are effective due to the large
249 variations in anthropometric characteristics within a given population [11]. MacRae et al. [30] indicated that
250 people categorised into one garment size classification, will vary in body shape and size. Indeed this is true of
251 the participants who took part in this study. For example, those fitted with garment brand A exhibited a thigh
252 and calf circumference that ranged from 46.1-56.3 and 33.0-39.5 cm respectively, despite them all meeting the
253 manufacturers recommendations for fitting a medium size garment. It should be acknowledged that some
254 manufacturers now offer bespoke garments, fitted with greater precision by using more surface measurements or
255 using a body scanning device. It is likely that these approaches will improve garment fit and possibly increase
256 the level and consistency of ComP.

257
258 The findings of this investigation support concerns identifying that there is wide variation in body morphology
259 and ComP exerted by the CGs tested here. ComP ranged from 4-16.7 mmHg at the quadriceps and 10.3-25
260 mmHg at the calf in the male population and 5-12.7 mmHg at the quadriceps and 10.3-18.7 mmHg at the calf in
261 the female population. This observation indicates that the suggested minimum pressures of 15.1 mmHg at the
262 quadriceps and 17.3 mmHg at the calf were not being met for the majority of individuals. Individual ComP
263 observed in figure 2 demonstrate the large range in pressure received amongst participants at the quadriceps and
264 calf. Individual data was used for the correlational analysis, the fact that there were no correlation between any
265 anthropometric variable and quadriceps or calf ComP indicates there is a more complex interaction between
266 various anthropometric characteristics and ComP applied by the CGs. This is supported by Troynikov et al [4],
267 who highlighted the need for further investigation into the interaction between the CG and the body of the
268 individual using the garment.

269
270 There is no current consensus on how much ComP is required in order to improve indices of performance and
271 recovery. Many of the observed improvements in haemodynamics and subsequent recommendations on the
272 application of compression are derived from clinical studies [28,31]. Brandages et al [31] used CGs that exerted
273 a ComP of 40 mmHg at the ankle decreasing to 21 mmHg at the calf and Ibegbuna et al. [28] used CGs with a
274 reported range of 18-24 mmHg. These ComP appear to have crossed over into the sporting arena with little
275 evidence to suggest the ComP levels are optimum or even effective. It may therefore be possible that the levels
276 of ComP used to treat clinical conditions may not be necessary in an athletic setting [2,32]. Ali et al [2]
277 investigated the effects of three different grades of below the knee, lower limb CGs, low (12-15 mmHg),
278 medium (18-21 mmHg) and high (23-32 mmHg). This study observed that jump height was improved,
279 following a bout of endurance exercise, when participants wore the low and medium grade garments, but not the
280 high grade garment. The authors suggest that muscle function was better maintained in the low and medium
281 grade trials but more research is needed to understand why no improvement was observed in the high grade trial.
282 These findings highlight the importance of understanding factors affecting CG fit, particularly in a performance
283 setting.

284 285 **Conclusion**

286 A large number of individuals are using CGs to enhance performance or recovery [6], however this investigation
287 demonstrates that the majority of people who use these garments may not be receiving adequate levels of ComP
288 to be of benefit. In addition to this there is a large variation in the range of ComP received from the same brand
289 of garment across a population. This has implications for individuals who wish to use CGs and indicates the
290 need to measure the exact amount of ComP exerted by a CG on each individual.

291
292
293 Knowledge on the ComP individuals receive from these garments is key to interpreting the findings from studies
294 investigating the efficacy of CGs [12], and a greater level of rigour is needed in order to define the ComP
295 achieved in studies of compression garments in sports applications. Given the large range in ComP observed in
296 this study, it is possible that whilst some individuals are receiving insufficient ComP to be of benefit, perhaps
297 others are receiving excessive ComP. This highlights the need to measure ComP pressure in all individuals and

298 may explain why literature investigating the efficacy of CGs is inconsistent, particularly as the majority of the
299 research failed to report the ComP applied to the limb. Future research should 1) measure and control for the
300 pressures exerted by commercially available CGs; 2) investigate whether bespoke fitted garments improve
301 ComP and consequently recovery; 3) identify the effects of different levels of ComP on indices of performance
302 and recovery.
303

304 **Conflict of Interest**

305 The authors declare they have no conflict of interest.
306
307

308 **References**

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410 **Table 1.** Anthropometric characteristics of participants. Values are reported as mean±SD.

411

		Age (yrs)	Height (cm)	Mass (kg)	Sum of Skinfold (mm)	Waist Circumference (cm)	Hip Circumference (cm)	Thigh Girth (cm)	Calf Girth (cm)
Part A	Males (n=26)	31.8±8.3	178.3±4.9	78.5±9.3	65.4±23.4	79.3±13.8	98.3±5.3	55.3±4.3	39.1±5.5
	Females (n=24)	29.8±5.2	168.1±8.3	65.4±10.6	101.2±26.6	74.0±7.8	98.2±8.8	53.2±5.0	37.5±3.0
Part B	Males (n=29)	24.5±7.0	177.7±5.1	77.0±6.1	59.8±17.3	81.4±5.6	96.8±6.3	52.8±3.5	38.5±5.1

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414 **Table 2.** Technical error of measurement (TEM) for anthropometric measures.

Circumference Measures (cm)							
	Waist	Hip	Thigh	Calf	Ankle		
TEM (%)	0.4	0.4	0.3	0.4	0.6		
Skinfold Measures (mm)							
	Bicep	Tricep	Sub-scapular	Supra-spinal	abdominal	Thigh	Calf
TEM (%)	2.8	1.6	2.0	1.9	1.9	2.2	2.1

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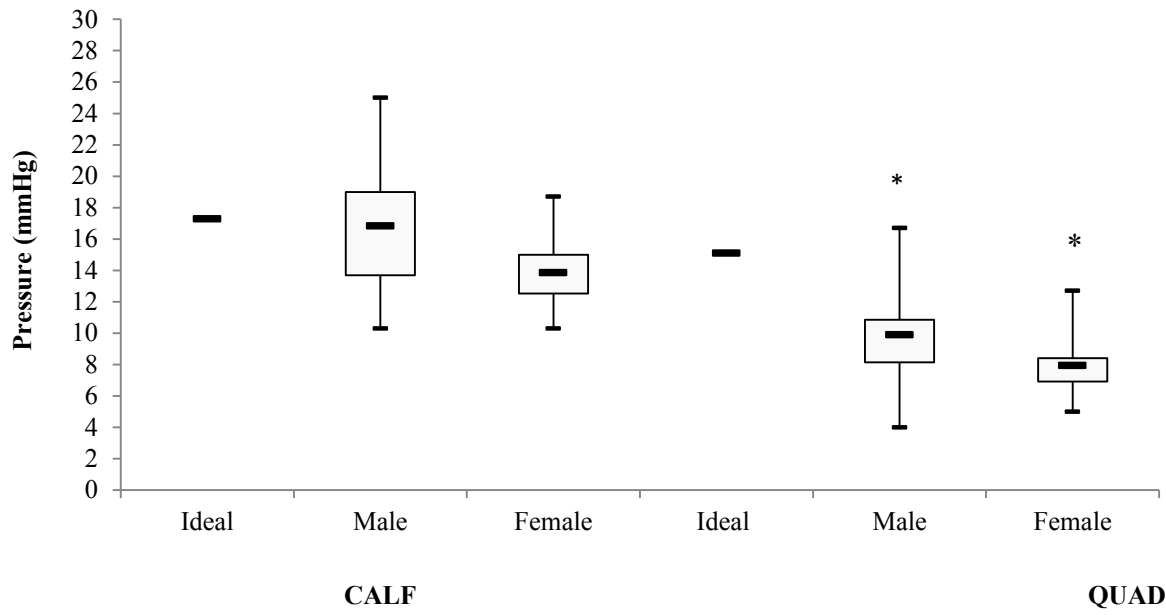
417 **Table 3.** Anthropometric characteristics of participants in each of the medium sized garment trials. Values are reported as mean±SD.

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	Age (yrs)	Height (cm)	Mass (kg)	Sum of Skinfold (mm)	Waist Circumference (cm)	Hip Circumference (cm)	Thigh Girth (cm)	Calf Girth (cm)
Garment A (n=19)	23.7±5.5	178.1±5.0	80.2±4.3	65.6±17.9	82.4±4.5	99.4±3.8	54.1±3.1	38.3±1.7
Garment B (n=23)	22.5±4.6	177.9±5.3	77.8±3.9	62.7±17.7	82.2±5.5	97.2±6.1	53.0±3.0	37.7±1.7
Garment C (n=22)	24.3±7.1	178.1±5.0	74.4±4.2	58.0±18.4	80.0±5.5	95.0±6.1	51.6±2.8	37.0±1.7

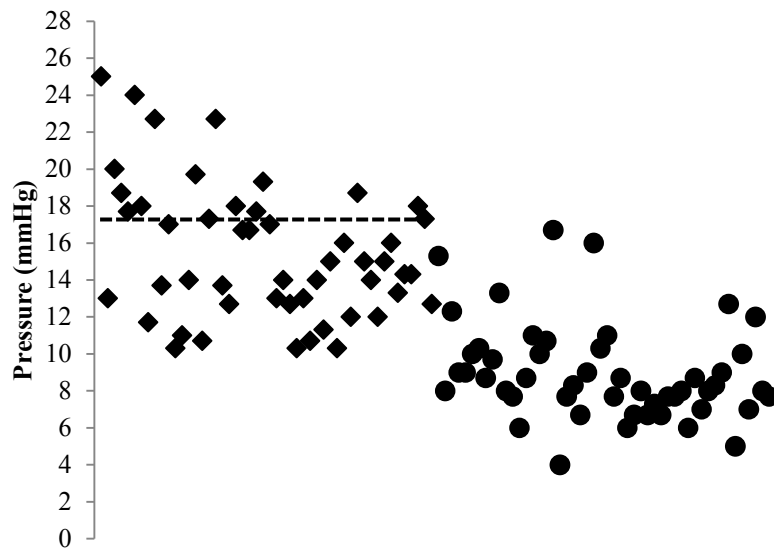
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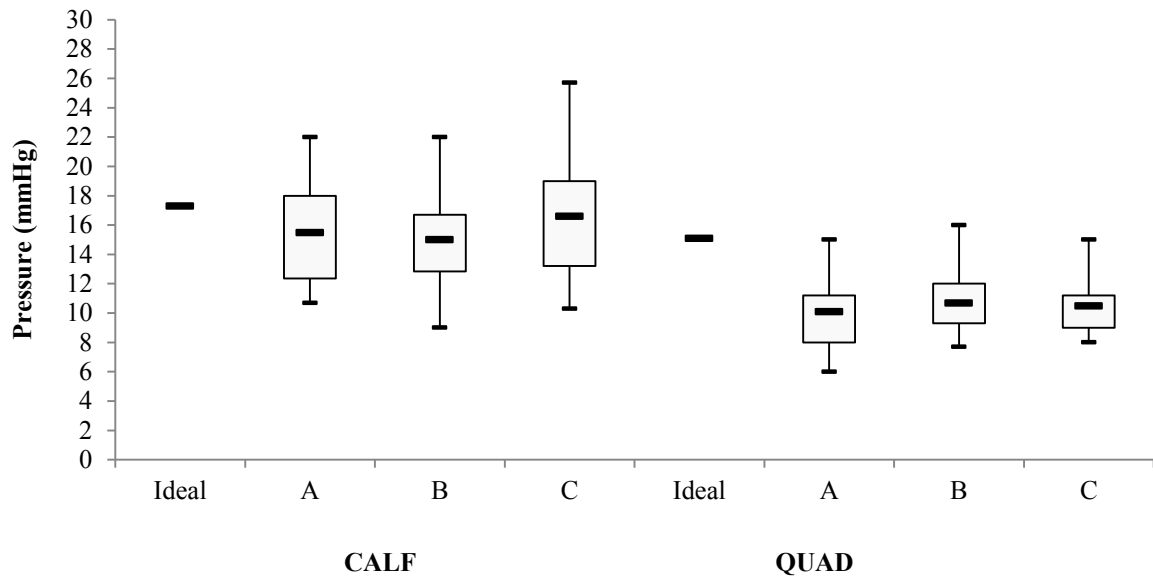
421
 422 **Figure 1.** Box plots representing the mean, maximum, minimum and upper and lower quartiles for pressure
 423 exerted at the calf and thigh for males and females and compared to the ideal pressure suggested by Watanuki
 424 and Murata (1994). * denotes significantly different from ideal pressure ($p < 0.05$).
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Figure 2. Scatter plot representing the compression pressure received by each individual. Diamonds represent pressure at the calf and circles represent pressure at the quadriceps. Horizontal lines represent the ideal pressure values suggested by Watanuki and Murata (1994) at the calf and quadriceps.



432
 433 **Figure 3.** Box plots representing the mean, maximum, minimum and upper and lower quartiles for pressure
 434 exerted at the calf and thigh in 3 different brands of compression garment and compared to the ideal pressure
 435 suggested by Watanuki and Murata (1994).
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