Influence and reliability of lower-limb arterial occlusion pressure at different body positions.

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1 **Abstract**

2

3 **Background:** Total arterial occlusive pressure (AOP) is used to prescribe pressures for

4 surgery, blood flow restriction (BFRE) and ischemic preconditioning (IPC). AOP is often

5 measured in a supine position; however, the influence of body position on AOP

6 measurement is unknown and may influence of the level of occlusion in different

7 positions during BFR and IPC. The aim of this study was therefore to investigate the

8 influence of body position on AOP. **Methods***:* Fifty healthy individuals (age $= 29 \pm 6$ y)

9 underwent AOP measurements on the dominant lower-limb in supine, seated and

10 standing positions in a randomised order. AOP was measured automatically using an

11 automated pneumatic tourniquet system, with each measurement separated by 5 minutes

12 of rest. **Results***:* AOP was significantly lower in the supine position compared to the

13 seated position (187.00 ± 32.5 vs 204.00 ± 28.5 mmHg, p<0.001) and standing position

14 (187.00 ± 32.5 vs. 241.50 ± 49.3 mmHg, p<0.001). AOP was significantly higher in the

15 standing position compared to the seated position (241.50 ± 49.3 vs. 204.00 ± 28.5

16 mmHg, p<0.001). **Discussion***:* AOP measurement is body position dependent, thus for

17 accurate prescription of occlusion pressure during surgery, BFR and IPC, AOP should be

18 measured in the position intended for subsequent application of occlusion.

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20 Keywords: Blood flow restriction exercise, Ischemic Preconditioning, Occlusion, Limb

21 occlusion pressure,

1 Introduction

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3 The technique of occluding limb blood flow using pneumatic tourniquet cuffs is applied

4 in various settings, such as during surgery (Bussani & McEwen, 1988), blood flow

5 restriction exercise (BFRE) (Hughes et al., 2017) and ischemic preconditioning (IPC)

6 (Griffin et al., 2017). The level of occlusion achieved by an applied pressure is considered

7 to be an important factor for effective creation of a bloodless surgical field (Bussani &

8 McEwen, 1988), driving physiological adaptations and preventing full occlusion of

9 arterial blood flow during BFRE (Fahs et al., 2012; Lixandrão et al., 2015), and

10 effectiveness of the IPC stimulus (Cunniffe et al., 2016). The required pressure to reach

11 a desired level of occlusion is influenced by several factors, such as cuff width, limb

12 circumference and blood pressure (Loenneke et al., 2015; Jessee et al., 2016), which

13 makes standardisation of occlusion level difficult using arbitrary pressures. The use of

14 arbitrary pressures in BFRE may influence the amount of fatigue observed during

15 exercise and thus potential adaptations. Furthermore during IPC a standard pressure of

16 200 – 220 mmHg is widely used prior to exercise, irrespective of upper- or lower- limb

17 application, which may influence the potential benefit of this technique due to different

18 limb circumference and blood pressure within individuals (Bailey et al., 2012; Barbosa

19 et al., 2014; Patterson et al., 2015). Calculation of arterial occlusive pressure (AOP)

20 involves determination of the pressure required to fully occlude arterial flow to the

21 involved limb (AORN Recommended Practices Committee., 2007). This is most often

22 achieved using doppler ultrasound (Bezerra de Morais et al., 2017) and can be used to

23 prescribe pressure at a relative percentage of AOP to standardise the level of occlusion

24 across cohorts (Laurentino et al., 2012; Hughes et al., 2017; Patterson et al., 2017) .

25

26 Occlusion of blood flow is typically applied in one of three positions: supine, seated/semi-

27 recumbent or standing (Loenneke et al., 2012). However, within the literature it is evident

28 that only a small number of studies measure AOP in the same position that the occlusion

29 stimulus is subsequently applied (Staunton et al., 2015); this may not account for postural

30 influences on hydrostatic pressure (Wilkins, Halperin, & Litter, 1950; Eiken, 1988). For

31 example, movement of the lower-limb into a dependent position causes changes in

32 hydrostatic pressure, deformation of the vascular bed and an increase in blood flow and

33 pressure within the limb (Trinity et al., 2010). Systolic blood pressure has been identified

34 as a major predictive variable of AOP in the upper limbs (Loenneke et al., 2015); Jessee

35 et al., 2016), whereas thigh circumference is the largest predictor in the lower body

36 (Loenneke et al., 2015), thus it is conceivable that posture-induced changes in blood flow

37 and pressure may affect the pressure required for absolute occlusion of blood flow in that

38 limb.

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40 To date, only one study has investigated the influence of body position on AOP

41 measurement (Sieljacks et al. 2018), however this was only in the supine and seated

42 position. Furthermore the reliability of AOP in each of these body positions is unknown.

43 This is problematic as it may result in under/over-estimation of the required pressure,

44 which may have implications for effectiveness in application of an occlusion stimulus.

45 Additionally, heterogeneous changes in AOP between individuals may lead to variation

46 in occlusion stimulus even when prescribed relative to AOP. Thus, the aim of this study

47 was to investigate the influence of different postural positions on AOP measurement. A

48 further aim was to examine the test-retest reliability of AOP at different body positions.

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Materials & Methods

Participants

Fifty participants (37 males and 13 females) volunteered to participate in the study. Overall mean ± SD for age, mass and stature were 29 ± 6 y, 77.3 ± 14.2 kg and 175.9 ± 8.4 cm, respectively. All were healthy, active non-smokers free from cardiovascular (CV), pulmonary and metabolic diseases and musculoskeletal injuries in the past 12 months. Participants were asked to refrain from strenuous exercise, caffeine and alcohol in the 24 hours prior to each testing session. All participants provided signed informed consent in compliance with the Declaration of Helsinki, 7th version, October 2013 (World Medical Association, 2013). All protocols were approved by St Mary's University ethical committee (SMEC_2016-17_121).

Experimental design and procedure

To examine the influence of body position on AOP, participants attended the laboratory on one occasion. Upon arrival, participant's mass and stature were recorded to the nearest 0.1 kg and 0.1 cm, respectively. Participants rested for 5 minutes in the supine position on a portable treatment bed, then blood pressure was measured at the brachial artery (Omron M5, Omron Healthcare, Europe B.V., the Netherlands, 14 x 48 cm). Thigh circumference (cm) of the dominant lower-limb was measured at the midpoint of the distance between the greater trochanter and the lateral condyle of the femur in accordance with International Society for the Advancement of Kinanthropometry (ISAK) guidelines using a flexible steel tape (Lufkin W606PM). Additionally, skinfold thickness (ST) was measured (mm) at this point using skinfold calipers (Harpenden skinfold callipers, British

77 Indicators Ltd, UK). For the experimental procedure, participants underwent AOP

78 measurements in the dominant leg in a supine, seated and standing position in a within-

79 subjects randomised design. The randomisation was carried out by assigning each

80 participant a number and using publicly available software to allocate the order of

81 conditions (http://www.randomization.com/). Prior to each measurement, participants

82 rested in the required position for 5 minutes to ensure restoration of homeostasis after any

83 movement. For the supine position, participants lay on a portable treatment bed with their

84 arms relaxed by their sides. For the seated position, participants sat upright with their legs

85 straight and the hip flexed at a 90° angle, assessed using a goniometer. For the standing

86 position, participants stood in the standard anatomical position. Prior to each

87 measurement, participants rested in the required position for 5 minutes to ensure

88 restoration of normal blood flow after any movement (Jessee et al., 2016).

89 AOP measurement
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92 Restriction of blood flow in the lower-limb was achieved using the Delfi Easy-fit variable

93 contour tourniquet cuff (11.5 cm x 86 cm x 5 mm), connected to a pneumatic cuff inflator

94 (Delfi PTS, Delfi Medical, Vancouver, BC, Canada). The pneumatic tourniquet was

95 equipped with the capability of automatically measuring AOP and calculating the

96 personalised tourniquet pressure, comprised of a dual-purpose personalised tourniquet

97 cuff and a personalised tourniquet instrument containing AOP calculation sensors and

98 software. The pneumatic system connected to the tourniquet cuff increased the cuff

99 pressure in stepwise increments, analysing the pneumatic pressure pulsations in the cuff

100 bladder by the arterial pressure pulsations at each cuff pressure increment, and used these

101 characteristics to determine AOP (McEwen et al., 2015). AOP measurement using this

cuff was found to not be clinically or statistically different from using the gold standard

doppler technique (+0.08 mmHg [95%CI -2.66 to 2.82] for lower limbs) across 257 pairs

of AOP measurements taken from upper and lower limbs in 143 pre- and post-surgical

patients aged 17-86 (McEwen et al., 2015; Masri et al., 2016). This technique of

measuring AOP was found to have clinically acceptable accuracy compared to the distal-

sensor-based method of automatic AOP measurement, which measures AOP using a

sensor located on the most distal phalange of the involved limb (McEwen, Inkpen, &

Younger, 2002). The variable-contour cuff was placed on the most proximal portion of

the participant's dominant lower limb directly onto the skin and connected to the

pneumatic tourniquet with airtight hose tubing. After 5 minutes of rest, the device was

turned on to calculate AOP in the manner described above. The AOP displayed on the

pneumatic tourniquet device was recorded for each of the three positions.

Test-retest reliability

To assess the reliability of the pneumatic tourniquet, 10 subjects visited the laboratory at

the same time of day, on a second occasion, one week later during which the experimental

procedure for the AOP measurement was repeated with the order of positions tested in

the same order as they had previously been tested.

Statistical analysis

Due to non-normal distribution of the supine body position data ($p<0.05$) which persisted

after log transformations, a non-parametric Friedman test was used to determine if there

were differences in AOP across the three different body positions. For any significant

differences, Wilcoxon signed-rank pairwise comparisons were performed with

130 Bonferroni correction. Within-subject coefficient of variation (COV) was calculated, and

131 an intraclass correlation coefficient (ICC) test with a two-way mixed effects model was

132 used to determine absolute agreement to examine the reliability and reproducibility of

133 AOP measurements with the pneumatic tourniquet system. The COV was calculated from

134 the ratio of the standard deviation (SD) and the mean of the two AOP measurements (CV

135 = ((SD/mean) x 100)), followed by calculation of the mean (Bezerra de Morais et al.,

136 2017).

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138 **Results**

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140 Participants

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142 All 50 participants completed the study with no adverse events. Participants' blood

143 pressure, resting heart rate, thigh circumference and ST are presented in Table 1.

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145 ***Insert Table 1 here***

146
147 AOP
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149 Data are presented as mean ± SD. AOP was statistically significantly different in the

150 different body positions, $x^2(2) = 90.04$, p<0.001. Post-hoc analysis revealed that AOP in

151 the supine position was significantly lower compared to the seated position (187.00 ±

152 32.5 vs 204.00 ± 28.5 mmHg, respectively, p<0.001), and the standing position (187.00

153 ± 32.5 vs. 241.50 ± 49.3 mmHg, respectively, p<0.001). Additionally, AOP in the seated

154 position was significantly lower than in the standing position (204.00 ± 28.5 vs 241.50 ±

155 49.3 mmHg, respectively, p<0.001).

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157 Test-retest reliability
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160 For the supine position, the ICC for assessing reliability of the device across two repeated

161 measurements was 0.982 (95% CI: 0.932 to 0.995) with a COV of 2.94% (95% CI: 1.90

162 to 3.98%). For the seated position, the ICC for assessing reliability of the device across

163 two repeated measurements was 0.975 (95% CI: 0.932 to 0.994) with a COV of 1.82%

164 (95% CI: 0.95 to 2.69). For the standing position, the ICC for assessing reliability of the

165 device across two repeated measurements was 0.953 (95% CI: 0.822 to 0.988) with a

166 COV of 2.97% (95% CI: 0.89 to 5.05).

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172 **Discussion**

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174 This study investigated the influence of body position on AOP measurement. The main

175 findings were that lower-limb arterial AOP is body-position dependent. For absolute

176 occlusion of lower -limb arterial blood flow, it appears that higher pressures are required

177 in a seated compared to supine body position, and higher pressures are required in a

178 standing compared to seated and supine body position.

179

180 The pressure required to fully restrict arterial blood flow to the lower-limb increased from

181 187 mmHg to 204 mmHg to 241 mmHg in the supine, seated and standing positions,

182 respectively. This reflects literature demonstrating increases in peripheral blood flow to

183   the extremities (Goetz, 1950) and changes in hydrostatic pressure with different body

184   positions (Wilkins et al., 1950; Eiken, 1988). Elevation of the heart above the limbs when

185   comparing an seated to supine position results in an increase in peripheral blood flow and

186   pooling of blood in the lower limbs due to gravitational forces (Olufsen et al., 2005).

187   Increases in lower-limb local hydrostatic pressure (Wilkins et al., 1950), mechanical

188   deformation of the vascular bed and stimulation of group III afferent fibres (Trinity et al.,

189   2011) triggers peripheral vasodilation, causing a rise in peripheral blood flow. As there

190   is greater elevation of the heart again in a standing position and a larger effect of gravity,

191   these changes in peripheral blood flow and pressure may be amplified further in a

192   standing position (Olufsen et al., 2005). Studies examining factors influencing AOP in

193   the upper-limb support this, with systolic blood pressure identified as one of the major

194   predictive variables of AOP in the upper-limb (Loenneke et al., 2014; Jessee et al., 2016).

195

196   Implications for BFRE

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198   These observations suggest that measurement of AOP and application of the occlusive

199   stimulus in different positions would result in undesirable levels of occlusion, which has

200   important implications for application. For example, if AOP is measured whilst standing

201   but occlusion is applied in a seated or supine position, the individual may be exposed to

202   higher levels of occlusion than necessary. Within BFRE, higher pressures have been

203   shown to cause greater CV responses to exercise (Rossow et al., 2012) and may result in

204   full restriction of arterial inflow to the working muscle. It has been speculated that this

205   may increase the risk of ischemic reperfusion injury, peripheral nerve injury or

206   concerning hemodynamic alterations (Kacin et al., 2015, Loenneke et al., 2011, Jessee et

207 al., 2016), particularly when BFRE is used in patients with blood-related conditions such

208 as hypertension and heart disease (Madarame et al., 2010; Cezar et al., 2016).

209 Additionally, although the focus of this study was not on the physiological responses to

210 BFR, higher pressures are known to increase discomfort responses to BFRE (Jessee et

211 al., 2017; Mattocks et al., 2017) and thus could impact upon the clinical utility of BFRE

212 training and patient adherence to clinical rehabilitation programmes Therefore, accurate

213 calculation of AOP for pressure prescription is required for selection of the minimum

214 occlusion pressure required to elicit a positive change. It is of note that optimal occlusion

215 pressure is not fully understood, and may vary in different contexts. However, current

216 literature suggests that light-load BFRE (<30% 1RM) training protocols benefit from

217 higher occlusion pressures (80% vs 40%) (Lixandrão et al., 2015), which would support

218 the importance of accurate AOP measurement for prescription of relative pressures. In

219 contrast when loads are $\geq$ 30% 1RM there does not appear to be a need to exercise at

220 higher percentages of AOP (Counts et al., 2016).

221

222 On the contrary, measurement of AOP in a supine position and subsequent application of

223 BFRE in a seated or standing position may result in a lower level of occlusion than

224 desired, or a lack of venous occlusion altogether in situations where low pressures are

225 used (Kubota et al., 2011). Furthermore higher pressures during BFRE result in greater

226 accumulation of metabolic byproducts (Yasuda et al., 2010) hypothesised to be one of the

227 major driving forces of hypertrophic adaptations to light load BFR training (Pearson &

228 Hussain, 2015; Hughes et al., 2017). Insufficient levels of restriction due to inaccurate

229 pressure prescription confounded by body position may reduce the metabolic stress

230 stimulus, which may dampen the hypertrophic BFR stimulus and partially explain reports

231 of ineffectiveness of BFRE. Furthermore AOP may be influenced by time of day, with

232 increased pressure observed as the day progresses, likely brought about by oscillatory

233 changes in changes in blood flow and pressure ((Ingram et al., 2017). Therefore

234 measurement position and time of day should be considered by those using BFRE over

235 repeated applications.

236

237 Implications for IPC

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239 When performing IPC before exercise, the lower or upper limb is occluded at a set

240 arbitrary pressure between 200 and 220mmHg (Bailey et al., 2012; Barbosa et al., 2014;

241 Patterson et al., 2015). Furthermore when applying this pressure, participants are either

242 supine (Patterson et al 2015) or in a seated position (Marocolo et al., 2017) which may

243 influence the amount of occlusion observed. In the current study the average pressure

244 observed in the supine position was < 200 mmHg, however in the seated position this

245 increased to 204 mmHg. This suggests that the normal arbitrary pressures of 220 mmHg

246 should be sufficient to fully restrict blood flow prior to this intervention. However in

247 some studies the pressure used has been 200mmHg (Barboasa et al., 2014) and as low as

248 180 mmHg (Cunniffe et al., 2016). In the current investigation 28% and 18% of the

249 participants would not be fully occluded at 200 and 220mmHg in the supine position,

250 respectively. Furthermore, in the seated position, this number would rise to 60% and 28%

251 for 200 and 220 mmHg, respectively. Therefore we recommend the use of AOP to

252 standardise pressures during IPC due to the wide variance in participants and also the

253 wide array of cuffs used to occlude individuals.

254

255   Reliability

256 When measuring AOP automatically, it is important that the device used is reliable and

257 consistent across repeated measures to ensure correct prescription of pressure. In this

258 study, the pneumatic tourniquet system appeared to have high reproducibility (> 0.953)

259 with a COV of less than 2.97% across all the body positions examined. These findings

260 are similar to a recent study examining the reliability of doppler ultrasound for calculating

261 total AOP in the upper limbs (Bezerra de Morais et al., 2017). The authors calculated

262 AOP using doppler ultrasound in 13 male volunteers across three repeated measures,

263 reporting an ICC of 0.795 and a COV of 5.6%. Although the present study was in the

264 lower-limbs, we observed greater ICC scores and smaller COVs, suggesting

265 measurement of AOP using the pneumatic tourniquet system may be more reliable than

266 doppler ultrasound. This is may be attributed to the absence of human error; however,

267 this is speculative at present. Nevertheless, other studies have demonstrated similar

268 results.. The results of the present study suggest the pneumatic tourniquet system is highly

269 reproducible for measuring lower-limb arterial AOP due to the high ICC values and lower

270 COV scores compared to similar studies in the upper- limb (Bezerra de Morais et al.,

271 2017).

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274

275 **Conclusion**

276 The findings of the present study have several important clinical implications. Firstly, it

277 appears that AOP is body position-dependent. In BFRE and IPC, AOP must therefore be

278 calculated in the position of exercise to ensure accurate occlusion, while minimising the

279 risk of an adverse CV/neurological event or application of an insufficient BFRE stimulus.

280 Secondly, it appears that the pneumatic tourniquet system can be used to reliably calculate

281 lower-limb AOP. Previously, we highlighted that AOP may change across the duration

282 of a BFRE training study due to various tissue adaptations, such as increases in muscle

283 mass and vasculature adaptations, thus it is important to continually monitor AOP to

284 ensure prescription of the correct pressure (Hughes et al., 2017). Doppler ultrasound tools

285 can be expensive, and repeated measurement of AOP using this technique prior to weekly

286 BFRE training sessions would likely be time-consuming and require considerable skill.

287 This may be exacerbated in a clinical rehabilitation setting such as the NHS where

288 rehabilitation exercise classes are already time-constrained. However, the pneumatic

289 tourniquetsystem provides a simple and quick alternative for calculating AOP, and may

290 be implemented on a session-to-session basis. We propose that an actual measurement of

291 AOP is obtained at rest, prior to BFRE, and a percentage of that measurement is used

292 provide a more reliable stimulus (Laurentino et al., 2012; Hughes et al., 2017; Patterson

293 et al., 2017) as this method is still under-utilised by practitioners (Patterson & Brandner

294 2017).

295

296 In conclusion, the results of this study indicate that for accurate prescription of occlusion

297 pressure in BFRE and IPC applications, body position must be accounted for an AOP

298 measured in the position that the occlusion stimulus will be subsequently applied.

299 Moreover, the pneumatic tourniquet system appears to have high reproducibility for

300 automatic measurement of AOP in the lower-limbs.

301

302 **Acknowledgments**

306 **Conflicts of interest**

307 None.

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Table legends

Table 1 Participant anthropometric characteristics (Mean ± SD)