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# Quadriceps strength and functional performance after anterior cruciate ligament reconstruction in professional soccer players at time of return to sport

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26 **QUADRICEPS STRENGTH AND FUNCTIONAL PERFORMANCE FOLLOWING ACLR IN**  
27 **PROFESSIONAL FOOTBALLERS AT TIME OF RETURN TO SPORT**

28 **Introduction**

30 A recent systematic review of outcome from anterior cruciate ligament reconstruction (ACLR) in elite sports  
31 people reported pooled return to sport (RTS) rate was 83% (95% confidence interval 77-88%) (14). Six out of  
32 nine studies included in the review, which had a non-injured control group found no deterioration in athletic  
33 performance following ACLR in elite sports performers. When assessing return to elite soccer Walden et al.  
34 (21) reported greater than 90% of professional football players returned to play, with 2/3 still playing at the  
35 same level 3 years post-surgery. Zaffagnini et al. (25) reported a similar level of return (95%) with 71% still  
36 playing at the same level, whilst Erickson et al. (8) reported a slightly lower level of return (77%).  
37 Unsurprisingly, these levels of return to sport are higher than those reported for non-elite/professional  
38 populations with Ardern et al. (2) reporting the figure to be around 55%. The reasons for the disparity appear to  
39 be obvious, full time professionally supervised rehabilitation and higher baseline (pre-operative) levels of fitness  
40 and strength, alongside the financial imperative to return to play. These reports on return to play come from  
41 retrospective audits of injury data, what is current lacking in the literature, is data on the physical status of these  
42 athletes when they return to play, and if they have superior physical qualities compared to those previously  
43 reported for non-elite patients which have supported these achievements.

44  
45 Individuals who have undergone ACLR frequently been found to have deficits in quadriceps activation (level of  
46 inhibition) and rate of force development (RFD) which can persist for greater than 1 to 2 years post-surgery  
47 (3,9). These deficits in muscle function (activation, strength and RFD) have been linked to decreased  
48 performance both in the sporting environment and also in activities of daily living and quality of life (7,9).  
49 Furthermore, poor muscle function has been linked to poor movement quality during landing tasks, walking ,  
50 running and cutting performance which exposes the athlete to increased risk of further ACL injury (12) and  
51 osteoarthritis (1,7). What is currently unclear in the literature is if the higher levels of RTS in professional  
52 footballers could be attributed to overcoming these deficits. The first stage in possibly improving the outcome  
53 for non-elite ACLR patients then might be to understand the performance characteristics and physical qualities  
54 of elite athletes at RTS. Then from this information inform and define goals for rehabilitation for all ACLR  
55 patients.

57 Logerstedt et al. (16) commented that both short-term and long-term outcomes after ACLR require attention and  
58 action, because of the relatively poor outcomes with less than 55% of non-elite athletes making a full recovery  
59 (2) and greater than 50% developing significant osteoarthritis (OA) within a decade of surgery (6). Despite the  
60 relative advances in surgical techniques in the last 10 years the outcomes for the patients have remained  
61 unchanged (20). The rehabilitation undertaken by the patients post reconstructive surgery is regarded as equally  
62 important as the surgery itself in defining the patient's outcome (18), but this has altered relatively little in this  
63 period and no consensus still exists on the optimal strategies to rehabilitate these patients post ACLR (11).

64

65 Culvenor et al. (7) clearly identified, in their review, the relationship between poor quadriceps strength and the  
66 increased risk of symptomatic and functional deterioration of the knee during activities of daily living and sport-  
67 recreational activities. Furthermore, persistent quadriceps dysfunction, both in terms of strength and activation  
68 pattern, following ACLR has been identified as a risk factor for re-injury, contralateral knee joint injury and pre-  
69 mature progression to degenerative knee joint changes (1,6,7). The absolute levels of quadriceps strength  
70 (strength normalized to bodyweight) as opposed to limb symmetry index are rarely reported in the literature on  
71 outcome from ACLR. The most frequently reported variable is the limb symmetry index (LSI), thus making it  
72 difficult to understand the absolute levels of quadriceps performance. One of the few papers reporting strength  
73 found it to be a more significant predictor of outcome than LSI (19). The use of the contralateral leg as a  
74 performance comparison using metrics such as limb symmetry index (LSI) has been questioned, because it may  
75 underestimate the true level of deficit, because the contralateral leg of an ACLR patient is often significantly  
76 weaker when compared to a control limb in non-injured individuals. (5).

77

78 The aim of this study, therefore, was to assess the concentric, eccentric and isometric quadriceps strength, and  
79 level of inhibition (central activation ratio (CAR)), of elite professional footballers at the time of RTS, to  
80 identify their level of performance in relation to their quadriceps muscles. Alongside direct measures of  
81 quadriceps performance standard hop tests were assessed as a proxy for functional performance (12, 13,18) As  
82 these athletes have returned to sport it may then provide an insight into the physical qualities (measurable  
83 performance metrics) required to return to sport. It was hypothesized that these athletes would show LSI >90%  
84 and not have significant performance deficits between limbs, due to lower levels of strength in the ACLR limb.

85

86 **Method**

87 **Experimental Approach to the Problem**

88 An observational cross-sectional design was used to determine the level of quadriceps strength and central  
89 activation ratio, of professional soccer players, at the time of return to sport, and to compare between affected  
90 and unaffected limbs to determine if any asymmetry was evident.

91

92 **Participants**

93 Fifteen full-time professional footballers (age  $22.3 \pm 3.1$  years, body mass  $81.0 \pm 11.5$  kg, height  $1.75 \pm 0.1$  m,  
94 and a global KOOS questionnaire score of  $89.9 \pm 5.1$  at time of assessment), playing for clubs in the English  
95 premiership or championship divisions, who had undergone an ACLR participated in the study. Participants  
96 were recruited via orthopaedic surgeons or directly from their football teams, following an invitation letter to  
97 participate in the study. An initial screening of the volunteers was undertaken to exclude any individuals who  
98 had received more than primary ACL reconstructive surgery. Assessment was performed on all volunteers who  
99 met the inclusion criteria, between the period January 2015 - February 2017 (24 months). All participants had  
100 undergone ACL reconstruction (time since surgery  $7.8 \pm 1.3$  months). All participants had been medically  
101 cleared to return to sport and undertaken and passed functional return to play testing at their clubs and all their  
102 rehabilitation had been undertaken on a full-time basis within their professional club environment supervised by  
103 a sports physiotherapist, sports physician and Orthopaedic surgeon. Ten of the 15 had received a hamstring  
104 autograft and 5 had received a patella tendon autograft. All surgery had been undertaken by experienced  
105 orthopaedic surgeons using standard procedures, with none of the cases having any secondary procedures,  
106 beyond the primary ACLR. At the time of surgery none of these athletes had any significant meniscus lesions or  
107 chondral damage reported (as assessed either from MRI or by the orthopaedic surgeon at the time of surgery).  
108 Ethical approval was provided by the University's ethical committee and written informed consent was attained  
109 from all participants.

110

111 **Procedures**

112 Tests were undertaken in the following order: isokinetic test, isometric test, quadriceps activation test; hop tests  
113 with a 10 minute rest between each group of tests, to minimize any effect of fatigue.

114

115 **Isokinetic quadriceps strength test**

116 Isokinetic eccentric and concentric strength of the quadriceps was assessed using a Biodex isokinetic  
117 dynamometer (Biodex Medical Systems, Shirley, NY, USA). The test was conducted at an angular velocity of  
118  $60^{\circ}.\text{sec}^{-1}$  through a range of  $0\text{-}90^{\circ}$  knee flexion. The participant performed five practice repetitions followed  
119 three minutes later by five maximal repetitions of consecutive maximal effort eccentric, followed by concentric,  
120 quadriceps actions, the best trial (highest peak torque) was recorded from the five repetitions for the eccentric  
121 and concentric efforts, respectively. All data were gravity corrected and normalised against body mass (absolute  
122 torque / body mass: Nm/kg).

123

#### 124 **Isometric quadriceps strength test**

125 The isometric test of quadriceps strength was performed with the participants seated in an isokinetic  
126 dynamometer and positioned in  $90^{\circ}$  hip flexion  $90^{\circ}$  knee flexion (13,25). The participant performed five  
127 practice repetitions followed by five maximal (3-5 s) repetitions, the highest peak torque was recorded from the  
128 five repetitions and normalised against body mass.

129

#### 130 **Quadriceps central activation ratio**

131 The muscular inhibition of the quadriceps (central activation ratio (CAR)) was assessed, during a maximal  
132 isometric contraction (MVIC) of the quadriceps with the interpolated twitch technique (21). The participants  
133 were seated in an isokinetic dynamometer and positioned in  $90^{\circ}$  hip flexion  $90^{\circ}$  knee flexion. Two electrodes  
134 (proximal:  $50\times 130$  mm, distal:  $7.5\times 100$  mm) (Axelgaard, Fallbrook, Ca, USA) were placed on the quadriceps  
135 muscle at one-third and two-thirds from the distance between the anterior superior iliac spine and the upper  
136 border of the patella. Arthrogenic muscle inhibition measurements were taken using a Digitimer high voltage  
137 stimulator (DS7AH Digitimer Ltd, Hertfordshire, England). The participant undertook a maximal voluntary  
138 isometric contraction, 5 seconds. During the MVIC contraction two single pulses of  $200\ \mu\text{s}$  duration, 200 Volt  
139 and 120 mA were triggered three times (beginning, mid and end of the contraction; approximately at 1, 3 and 5  
140 seconds) manually by the investigator when the MVIC force had plateaued on the monitor. Thus, electrical  
141 twitches were evoked at rest and added during a MVIC. Before CAR analysis, torque data was low-pass filtered  
142 at 150 Hz using a second-order Butterworth filter. CAR was quantified by calculating the difference between the  
143 stimulus-evoked torque during MVIC to the stimulus-evoked torque at rest and expressed in %: activation  
144 deficit (AD) at 100% MVIC. The smaller the deficit, the less the inhibition, whereby an inhibition of 0% means  
145 that the subject was able to fully recruit the muscle without showing any signs of inhibition.

146 **Hop tests:** the assessment of single hop for distance (SHD) and cross over hop for distance (CHD) was  
147 undertaken (11,17). For the single hop, subjects were required to hop forwards as far as possible along the line  
148 of the standard tape measure and land on the same limb. In the crossover hop subjects maximally hopped  
149 forward 4 times, alternately crossing two parallel lines 15 cm apart, therefore participating in two medial and  
150 two lateral direction landings. In both cases distance was measured from the start line to the rear of the foot  
151 upon final landing. The distance hopped was then normalized to a percentage of leg length, by dividing the  
152 distance hopped by the participant's leg length (distance anterior superior iliac spine to medial malleolus) and  
153 multiplying by 100. The participants performed 3 practice trials and then a test trial as per the method of Munro  
154 and Herrington (18).

155

### 156 **Statistical Analyses**

157 **Reliability of measures:** Eight uninjured semi-professional footballers (age  $20.1 \pm 5.3$  years, body mass  $85.0 \pm$   
158  $10.1$  kg, height  $1.73 \pm 0.2$  m, and a global KOOS questionnaire score of  $94.8 \pm 4.3$  at time of testing), undertook  
159 all the tests on two separate occasions to assess the reliability of the tests. The reliability of the tests was  
160 assessed using intraclass correlation coefficient (ICC model 2,1), standard error of measurement (SEM) and  
161 coefficient of variance (%CV). Intraclass correlation coefficients were interpreted using established criteria (3)  
162 as follows: Poor -  $<0.40$ ; Fair -  $0.40-0.70$ ; Good -  $0.70-0.90$ ; and excellent  $>0.90$  and %CV  $<10\%$  were regarded  
163 as acceptable (3).

164 **Main analysis:** Data were assessed for normality using Shapiro-Wilkes test. For each test ACLR and  
165 contralateral limb performance was then compared using individual paired t-tests with Cohen's *d* effect sizes  
166 calculated and interpreted with 0.5 and below being a small effect size; greater than 0.5 being a medium effect  
167 size; 0.8 and above being a large effect size (3). Limb symmetry index was calculated by dividing the ACLR  
168 limb performance by the contralateral limb performance and multiplying by 100 to give a percentage.

169 *A priori* power analysis (\*G\* Power, Version 3.1.7) with mean differences between two dependent means were  
170 used to calculate the required sample size, with an effect size of 2.53 (peak isometric force, ACLR and non-  
171 injured knee) and an alpha level of  $p \leq 0.05$ , 10 subjects were required to obtain power of 1.0

172

### 173 **Results**

174 The global KOOS score for the ACLR group was  $89.9 \pm 5.1$ , whilst the score from the uninjured group used for  
175 the reliability study was  $94.8 \pm 4$ .

176 **Table 1: Reliability of dependent variable**

Test	ICC (95% CI)	SEM*	%CV
Knee extensors eccentric peak torque (Nm.kg <sup>-1</sup> )	<b>0.76</b> (0.52-0.91)	<b>0.48</b>	<b>14.3</b>
Knee extensors concentric peak torque (Nm.kg <sup>-1</sup> )	<b>0.87</b> (0.66-0.95)	<b>0.45</b>	<b>13.0</b>
Knee extensors Isometric peak force (Nm.kg <sup>-1</sup> )	<b>0.97</b> (0.91-0.99)	<b>0.23</b>	<b>6.9</b>
Central activation ratio (%)	<b>0.89</b> (0.7-0.96)	<b>2.3</b>	<b>9.8</b>
Single hop for distance (% leg length)	<b>0.85</b> (0.61-0.95)	<b>7.9</b>	<b>7.8</b>
Cross over hop for distance (% leg length)	<b>0.8</b> (0.-0.93)	<b>19.7</b>	<b>8.5</b>

ICC = intraclass correlation coefficient; CI = confidence interval; SEM = standard error of measurement; \*SEM is presented for absolute units; CV = coefficient of variation

177

178 All tests show good reliability, however eccentric and concentric knee extensor strength exceeded the acceptable  
 179 levels of variability (Table 1).

180 Medium to large significant differences in quadriceps strength (eccentric, concentric and isometric) were found  
 181 between and the difference was greater than the SEM, with the uninjured limb performing consistently better  
 182 than the ACLR limb. There was a large and significant difference in the CAR between limbs which was greater  
 183 than the SEM. Single hop distance showed a medium and significant difference between limbs, but only had a  
 184 64% chance of being superior based on the medium effect size, with a the difference being greater than the  
 185 SEM. There was a small yet significantly greater CHD in the contralateral limb, with a difference greater than  
 186 the SEM.

187

188 **Table 2: Comparison between ACLR and non-injured legs across tests**

Test	Limb	Mean (SD)	Range	<i>p</i>	<i>d</i>
Knee extensors eccentric peak torque (Nm.kg <sup>-1</sup> )	ACLR	3.28 (0.79)	1.89-4.72	<b>0.0001</b>	<b>0.84</b>
	Non-injured	3.97 (0.83)	2.48-5.5		
Knee extensors concentric peak torque (Nm.kg <sup>-1</sup> )	ACLR	2.76 (0.55)	1.76-4.31	<b>0.0001</b>	<b>0.99</b>
	Non-injured	3.37 (0.68)	2.15-5.0		
Knee extensors Isometric peak force (Nm.kg <sup>-1</sup> )	ACLR	2.9 (0.2)	2.6-3.7	<b>0.0001</b>	<b>2.53</b>
	Non-injured	3.7 (0.4)	3.0-4.8		
Central activation ratio (%)	ACLR	18.8 (7.9)	11.1-32	<b>0.0038</b>	<b>2.14</b>
	Non-injured	4.6 (5.1)	0-13		
Single hop for distance (% leg length)	ACLR	183.9 (26.1)	141-226	<b>0.0001</b>	<b>0.53</b>
	Non-injured	197.7 (26.1)	145-247		



<b>Cross over hop for distance (% leg length)</b>	<b>ACLR</b>	<b>692.0 (128.7)</b>	<b>550-974</b>	<b>0.0002</b>	<b>0.38</b>
	<b>Non-injured</b>	<b>741.1 (129.6)</b>	<b>560-1012</b>		

189  
190 The limb symmetry index (LSI) percentages for all tasks along with the percentage of players, who achieved a  
191 LSI greater than the typical 90% cut off, are presented in table 3, highlighting that with the exception of the two  
192 hops tests low percentages of the players achieved the recommended level of LSI i.e. greater than 90%.

<b>Test</b>	<b>Mean (SD) %</b>	<b>Range %</b>	<b>Percentage players LSI &gt;90% (n=)</b>
<b>Knee extensors eccentric peak torque</b>	<b>82.8 (10)</b>	<b>59.7-98.3</b>	<b>20 (3)</b>
<b>Knee extensors concentric peak torque</b>	<b>83 (13.7)</b>	<b>52.1-101.1</b>	<b>20 (3)</b>
<b>Knee extensors Isometric peak force</b>	<b>80.7 (7.8)</b>	<b>63.7-96.8</b>	<b>13 (2)</b>
<b>Single hop for distance</b>	<b>93.2 (7.4)</b>	<b>71.4-105.3</b>	<b>67 (10)</b>
<b>Cross over hop for distance</b>	<b>93.6 (7.6)</b>	<b>66.9-113.8</b>	<b>73 (11)</b>
<b>Central activation ratio</b>	<b>85.1 (5.6)</b>	<b>75.5-92.1</b>	<b>13 (2)</b>

193  
194  
195 **Discussion**

196 This study has presented quadriceps strength and hop performance data from a group of professional footballers  
197 following ACLR who had all been cleared to return to play. This is the first time data of this type has been  
198 present for such high level professional footballers. Because of the unique nature of this group, data from un-  
199 injured players is limited or not available. This study's data has been presented with effect sizes for the  
200 differences and the SEM for all tests, in order to give the findings some context. Despite being cleared to play,  
201 the majority of these individuals showed moderate to large significant deficits in both their quadriceps strength  
202 and hop performance when compared to the uninjured leg. These differences are also reflected in the high  
203 percentage of individuals who failed to achieve a 90% LSI score for the tests. Gokeler et al. (9) using similar  
204 test battery on a more general population of ACLR patients, found that for hop tests 78.5% patients passed  
205 LSI>90% for SHD, but only 39.3% passed LSI>90% for quadriceps concentric contraction, whilst only 35.7%  
206 patients had >3.0Nm.kg<sup>-1</sup> isometric quadriceps strength for the involved ACLR limb. Wellsandt et al. (22)  
207 reported that 23% of ACLR patients assessed at 6 months post operation failed to have isometric quadriceps  
208 strength LSI greater than 90%, with 26% on SHD and 17% on CHD also failing to achieve an LSI greater than  
209 90%. Both of these studies reflect the results found in this study despite differing populations. Overall it would  
210 appear that despite being deemed fit to return to play significant deficits exist in strength and to a lesser extent  
211 hop performance in a variety of populations at the time of return to sport.

212

213 The use of the contralateral (non-injured) leg as a performance comparison has been questioned, because it may  
214 underestimate the true level of deficit. The contralateral leg of the ACLR patient has frequently been found to be  
215 significantly weaker when compared to a control limb in un-injured individuals (4). This is highlighted in the  
216 Wellsandt et al. (22) study, when the ACLR limb was compared to the contralateral leg performance scores  
217 measured pre-operatively 37% failed to have a LSI greater than 90% for quadriceps strength, and when SHD &  
218 CHD were assessed 26% failed to achieve an LSI greater than 90%. The levels of strength and hop performance  
219 of the contralateral limb in this study would appear not to fit this pattern, with performance in line or superior  
220 to previously reported values for non-injured limbs (23). Furthermore, in a group of similar strength levels,  
221 Zult et al. (26) found the uninjured contralateral leg to have had similar levels of strength to those of controls.  
222 Currently, little data is available to determine what might be an acceptable absolute level of strength, both  
223 Gokeler et al (9) and Pietrosimone et al (19) proposed  $>3.0 \text{ Nm.kg}^{-1}$  isometric quadriceps strength. Comparable  
224 data for eccentric and concentric strength would appear not to be available with little normative data present in  
225 the literature (in elite sportsman) to guide the decision making process.

226 This study does call into question only using functional tests such as hop tests and questionnaires such as KOOS  
227 in isolation without also measuring strength. The majority of participants (greater than 2/3) had LSI for hop  
228 tests of greater than 90% and global KOOS score over 90 which have been regarded a sufficient level of  
229 functional performance for return to sport. The findings of this study then support those of Gokeler et al. (9) that  
230 a battery of tests is required including quadriceps strength to define a patient's readiness to return to sport. The  
231 results of this study also call into question the continued reporting of LSI without also presenting absolute  
232 strength scores, both would appear to be required to give a full picture of performance (9).

233

234 The absolute level of quadriceps strength and limb asymmetry, have both been associated with the level of long  
235 term functional performance (8,19,23). Furthermore, deficits in quadriceps strength have been related to the  
236 development of OA in an ACLR population (6). As ongoing knee symptoms and OA occur frequently in this  
237 population (5), it might be that the ongoing deficits in quadriceps performance might be related to this  
238 occurrence (1). A second ACL injury (either contralateral or graft rupture) is another relatively high frequency  
239 occurrence in this population, especially in the under 20 year old's (21). Pietrosimone et al (19) reported  
240 isometric quadriceps strength  $>3.1 \text{ Nm.kg}^{-1}$  increased the chances of achieving acceptable levels of self-reported  
241 outcome by 8.15 times (specificity 0.84, sensitivity 0.61). Whilst having an LSI  $\geq 96.5\%$  for isometric  
242 quadriceps strength increased the likelihood of reporting an acceptable outcome by 2.78 times (specificity 0.70,

243 sensitivity 0.55). Wellsandt et al. (21) reported that failure to achieve a LSI of greater than 90% for quadriceps  
244 strength, gave a specificity of 0.31 and sensitivity of 0.82 for predicting a second ACL injury. Poor quadriceps  
245 performance at return to play could therefore be related to increased risk of further ACL injury, ongoing knee  
246 symptoms and degenerative joint disease. What is unclear from the retrospective studies into ACLR outcome in  
247 football is if players had ongoing issues, as none of these studies (7,20,25) reported levels of symptoms through  
248 tools such as functional questionnaires. They do report around a 1/3 of players are not playing at the same level,  
249 which coincides with the figure reported by Mai et al. (17) for American professional sports, but all of these  
250 studies fail to indicate the reasons for this.

251

252 The levels of quadriceps inhibition in the ACLR leg reported in this paper are similar to those previously  
253 reported by Kuenze et al (13). The level of quadriceps inhibition has been shown to be significantly related to  
254 the level of quadriceps strength (15), so may in part provide an explanation for the differences between the  
255 ACLR and the non ACLR limbs.

256

257 A strength of this paper is that it that it presents data on a unique population, this is obviously also a limitation  
258 as the findings might not be applicable to other sports or non-elite athletes. But because of the full time  
259 professional nature of these athletes it could be expected that other athletes with less support through  
260 rehabilitation, may not do as well as these individuals and have poorer results. Another limitation is that no  
261 detail was presented on the specific elements of the rehabilitation these athletes undertook, future study should  
262 identify if the inclusion (or exclusion) of specific exercises and activities has a significant impact on results. The  
263 study also only included individuals who had had isolated ACL injury, this obviously limits applicability. As  
264 more extensive damage to the knee is likely to create greater levels of inhibition, it is unlikely that these findings  
265 will be reversed in other populations and may even be accentuated. Finally, this study presents no follow up on  
266 these athletes so the impact of these findings on future sporting performance and development of comorbidities  
267 is unknown, future studies should attempt to track these individuals to understand the impact of findings.  
268 Furthermore, it is also not known if these deficits will change over time, some parameters such as rate of force  
269 development appear to normalize after 12 months (3), whilst others such as strength do not (15). Though in  
270 reality in the world of professional sport once findings such as these are identified it is unlikely that there will be  
271 an attempt to address them, so confounding any follow up.

272

273 **Practical application**

274 The retrospective studies into the professional sports, would appear to indicate that a high proportion of players  
275 return to play at the same level following ACLR, but a significant number are not performing at that level within  
276 3 years of surgical repair of their ACL. The findings of this paper demonstrate significant deficits in quadriceps  
277 strength and activation and to a lesser extent performance during hop tests, despite the players being deemed fit  
278 to return to play. It might be hypothesised that there could be a link between the findings of this paper and the  
279 players who fail to maintain their level of performance or develop secondary issues. If this proves to be the case,  
280 then significant attention should be paid to re-establishing full quadriceps activation and strength prior to  
281 returning to unrestricted sporting activity.

282

283

284 Compliance with Ethical Standards: All procedures performed in studies involving human participants were in  
285 accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki  
286 declaration and its later amendments or comparable ethical standards. This study was approved by University  
287 Research Ethics and Governance Committee (ref: HSCR14/68). All participants gave written informed consent.

288

289 Conflict of interest: All authors declare that they have no conflicts of interest.

290

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