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MOTOR CONTROL STRATEGIES TO REDUCE KNEE MOMENTS IN THE INJURED LEG DURING A DOUBLE LEG SQUAT IN ANTERIOR CRUCIATE INJURED PATIENTS

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INTRODUCTION

Individuals with Anterior Cruciate Ligament (ACL) injury are often unable to return to pre-injury activity levels [1] and have an increased predisposition of early-onset osteoarthritis [2]. Double leg squat is used in early rehabilitation to strengthen quadriceps and hamstring muscles and to inform treatment selection [3]. The double leg support allows for compensation strategies to be used [4]. It is unknown what motor control strategies underlie these compensations and these strategies have not been investigated in patients who are treated conservatively. This study therefore investigated motor control strategies during a double leg squat with the aim to investigate if individuals with ACL rupture (ACLD), ACL reconstruction (ACLR) and healthy controls (CONT) used different strategies. We focused on measures of performance using kinematics, kinetics and in particular symmetry between the two legs.

METHODS

17 ACLD (height: 1.79±0.04 m, mass: 81.3±11.6 kg, age: 30±6 years, gender: 3 female, 14 male) and 11 ACLR (height: 1.75±0.06 m, mass: 79.2±8.4 kg, age: 25±8 years, gender: 1 female, 10 male) were compared to 21 CONT (height: 1.75±0.13 m, mass: 77.6±19.6 kg, age: 27±8 years, gender: 9 female, 12 male). Individuals were asked to perform eight consecutive double leg squats to their maximum depth. Ethical approval was obtained from South East Wales Local Research Ethics Committee.

Motion data were collected using a VICON system (Oxford Metrics Group Ltd., UK) at 250 Hz. Reflective markers were placed using the 'Plug-in-Gait' full body marker set. Ground reaction force data were collected using two Kistler force plates (Kistler Instruments Ltd., Switzerland) at 1,000 Hz. Inverse kinematics and dynamics calculations were performed within VICON Nexus software and data were analyzed in Matlab R2010b (The Mathworks Inc., USA). Output parameters were calculated in Matlab and were as follows, with variables with the subscript ending in I relating to the injured leg (or dominant in CONT) and ending in N to the non-injured leg: $\alpha_{kn(mx)}$: peak knee flexion angles; $M_{kn(mx)}$: peak knee extensor moments; M_{sup}: support moment at $M_{kn(mx)}$; $SYM\alpha_{kn(mx)}$: symmetry of the peak knee flexion angles between the injured and non-injured legs; SYM_{Msup}: symmetry of the support moment between the injured and non-injured legs; $SYM\%sup_{kn}$: symmetry of the % support moment of the knee between the injured and non-injured legs. Symmetry was calculated as follows [5]:

$$Symmetry = \frac{2 * Injured}{Injured + Non - injured}$$

A one-way ANOVA was used for the normal distributed kinematic and kinetic output variables and a Kruskal-Wallis test for the not normal distributed symmetry measures to investigate differences between ACLR and CONT and between ACLD and CONT. Linear regression analysis was used to investigate trends between the symmetry measures.

RESULTS AND DISCUSSION

A significant difference ($p<0.01$) in performance was shown by a reduced squat depth in ACLD compared to CONT, but not in ACLR ($\alpha_{kn(mx)I}$; Table 1). Consistent with this, peak knee extensor moments ($M_{kn(mx)I}$) were significantly reduced in ACLD compared to CONT in the injured but not in the non-injured leg ($p<0.01$; Table 1). Interestingly, ACLR also showed a significantly reduced $M_{kn(mx)I}$ even though their squat depth was the same as in CONT ($p<0.01$; Table 1).

Table 1: Mean $\alpha_{kn(mx)I}$, $\alpha_{kn(mx)N}$, $COMzdt_{MAX}$, $M_{kn(mx)I}$, $M_{kn(mx)N}$, $SYM\alpha_{kn(mx)}$, SYM_{Msup}, $SYM\%sup_{kn}$ values with standard deviations for CONT, ACLR and ACLD. A * indicates a significant difference ($p<0.01$) from CONT.

	$\alpha_{kn(mx)I}$ (°)	$\alpha_{kn(mx)N}$ (°)	$M_{kn(mx)I}$ (Nm)	$M_{kn(mx)N}$ (Nm)	$SYM\alpha_{kn(mx)}$ (%)	SYM_{Msup} (%)	$SYM\%sup_{kn}$ (%)
CONT	114±21	112±21	86±45	82±48	101±3	103±9	101±10
ACLR	112±13	112±15	68±15*	75±19	100±3*	99±12*	96±11*
ACLD	107±17*	107±15	66±21*	86±28	100±3*	94±12*	92±13*

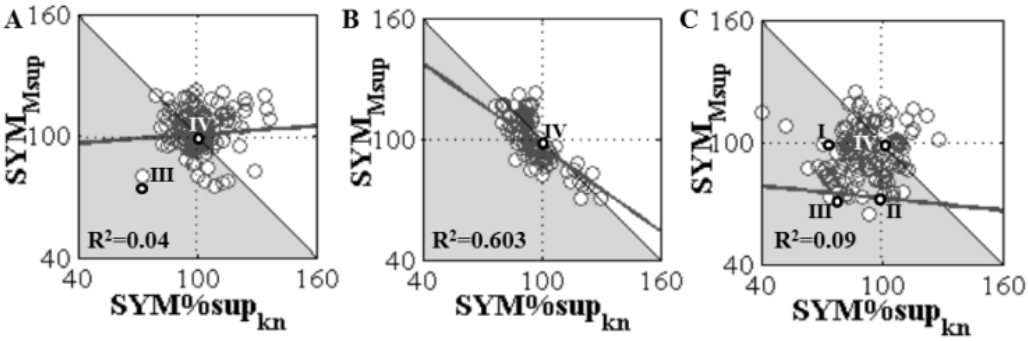

Figure 1: SYM_{Msup} versus $SYM\%sup_{kn}$ for: A) CONT, B) ACLR and C) ACLD. The grey section refers to a reduced knee moment in the injured limb. Points I-IV refer to the strategies identified in Figure 2.

Symmetry of the peak knee flexion angle ($SYM\alpha_{kn(mx)}$) was significantly different in ACLD and ACLR from CONT ($p<0.01$; Table 1). This difference was very small and therefore clinically insignificant. $SYM\alpha_{kn(mx)}$ was close to 100 in all groups indicating near perfect symmetry between the injured and non-injured leg, as expected in this closed chain exercise. Symmetry of the support moment (SYM_{Msup}) was significantly lower in ACLD and ACLR compared to CONT ($p<0.01$; Table 1). It was close to 100 in ACLR (99±12); the support moment was therefore almost identical in both legs. In ACLD SYM_{Msup} was smaller than 100 (94±12); the support moment was therefore reduced in the injured leg. Symmetry of the % support moment by the knee ($SYM\%sup_{kn}$) was significantly reduced in ACLD and ACLR compared to CONT ($p<0.01$; Table 1). It was lower than 100 for both (96±11and 92±13 respectively); therefore the knee contributed less to the support moment in the injured compared to the non-injured leg.

We further investigated motor control strategies by looking at the relationship between SYM_{Msup} and $SYM\%sup_{kn}$ (Figure 1). There was no significant correlation between these variables in CONT (R^2=0.04; Figure 1A). Data were randomly distributed around a point close to IV (100,100; representing perfect symmetry in both legs). This variability would be expected in normal unconstrained performance. ACLR showed a significant correlation between SYM_{Msup} and $SYM\%sup_{kn}$ (R^2=0.603; Figure 1B) and were distributed around a point close to IV (100,100). Whilst performing maximally, ACLR seemed constrained by the knee moment on the injured side. ACLR controlled the knee moment magnitude by using two strategies in combination; 1) transfer of support moment to the non-injured leg; 2) transfer of support moment from the knee to the ankle and hip of the injured leg. Different subjects combined these strategies in different proportions. The effect on the knee moment was however the same, which was demonstrated by the significant correlation along the diagonal. ACLD showed no significant correlation between SYM_{Msup} and $SYM\%sup_{kn}$ (R^2=0.09; Figure 1C). The data were distributed around a point below 100 for both SYM_{Msup} and $SYM\%sup_{kn}$. ACLD therefore used an avoidance strategy where they reduced squat depth and subsequently the support moment in the injured leg and the contribution of the knee to this moment. The lack of correlation could be because some subjects were functioning better than others. The identified motor control strategies are represented in Figure 2: I) similar support moment but reduced contribution of the knee (ACLD and ACLR), II) reduced support moment but similar contribution of the knee (ACLD and ACLR), III) reduced support moment and reduced contribution of the knee (ACLD only), IV) similar support moment and similar contribution of the knee (ACLD, ACLR and CONT).

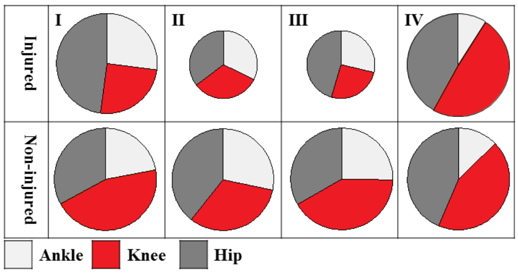

Figure 2: Double leg squat compensation strategies. The slices represent the percentage of support moment produced by the ankle (light grey), knee (red) and hip (dark grey).

CONCLUSIONS

Despite their recovered performance, ACLR demonstrated constrained behavior during a double leg squat to control knee moment magnitude. ACLD used an avoidance strategy with reduced performance, support moment and contribution of the knee to this moment in the injured leg. The double leg squat is often used in rehabilitation. This study demonstrated that ACLD and ACLR used different strategies compared to CONT. Although ACLR could perform the exercise successfully they used compensations. Therefore attention needs to be paid as these patients may not exercise the injured leg as intended and squat depth may not be adequate as a clinical outcome measure. The different strategies also highlight that individualized rehabilitation is essential.

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