Measurement of functional recovery in individuals with acute anterior cruciate ligament rupture

K Button, R van Deursen, P Price

Objectives: To measure functional recovery following acute anterior cruciate ligament (ACL) rupture using a simple and reliable clinical movement analysis system. Clinic based methods that simultaneously quantify different aspects of movement over a range of activities and model functional recovery will help guide rehabilitation.

Methods: A longitudinal study was used to measure gait variables at initial physiotherapy attendance and then at monthly intervals using a digital camcorder and computer for quantitative analysis. Jogging and distance hopping were added during recovery. A sample of 63 ACL deficient subjects entered the study and 48 subjects were measured at least three times. To determine the pattern of recovery, repeated measurements were analysed using a least square fit of the data.

Results: Gait variables took between 95 and 130 days post injury to reach the control mean and stabilise shortly after this. Hopping distance for the injured leg took 62 days to recover to within normal limits and 5 months post injury to reach the control mean. Jogging was already within the control limits at 30 days post injury and demonstrated little change with recovery.

Conclusions: Functional recovery of multiple variables has been modelled. In the early phase of post injury, gait velocity seems to be the most useful variable to measure improvement. Recovery of more challenging activities appears to take an average of 5 months. Therefore, patients may need to be monitored in physiotherapy until this time and advised not to return to sport until sufficient recovery is demonstrated on activities such as distance hopping.

Following anterior cruciate ligament (ACL) rupture, altered levels of physical performance and secondary meniscal damage are commonly cited as complications with non-operative management. Despite this, not all ACL deficient (ACLD) individuals will choose to have a reconstruction. For these patients, physiotherapy rehabilitation is crucial to help them maximise their knee function and return to a level of activity that is safe. In the United Kingdom this is complicated by long surgical waiting lists that can delay surgery receiving a reconstruction and places a greater emphasis on rehabilitation and patient management pre-operatively.

If an individual is receiving rehabilitation, it is important that any change in their functional ability is measured over time. This will help the clinician to make decisions about the appropriateness of treatment, to assess if the patient is achieving functional milestones, and to give advice on what activities/sport are safe for the individual to undertake. Functional outcome measures are recognised as having a role in helping clinicians make decisions because the functional tests reflect the type of activities that patients target as acceptable outcomes. A number of studies have analysed the biomechanics of functional activities such as gait, jogging, hopping, and cutting manoeuvres in ACLD knees. They have analysed compensation strategies that include changes in joint reaction forces, moments, and powers. These studies have not collected data longitudinally, they have been restricted to individuals with chronic ACL tears, and their movement analysis systems do not fulfil the requirements of a clinical gait analysis system.

Some validated measurement tools do exist to predict screening tools, they do not provide information on the pattern of recovery over time. They have also only been designed and tested on athletes who regularly participate in activities requiring a high degree of pivoting and so may not be appropriate for those individuals who participate in leisure activities and sport at a lower level.

This means that there is a lack of information available about the course of recovery following an ACL rupture and its transition from an acute to chronic status. Important rehabilitation questions such as: how long does recovery take, at what stages is it safe to progress to more complex activities, and do functional activities ever fully recover, are left unanswered. Therefore, the aim of this study was to measure functional recovery following ACL rupture in the clinical setting.

METHODS

Subjects

Over the recruitment period from May 2001 to November 2003, 281 individuals attended the Acute Knee Screening Clinic (AKSS) at the University Hospital of Wales (UHW) and were diagnosed with an acute ACL rupture, which was confirmed by MRI. Sixty three of these ACLD individuals lived in the UHW physiotherapy catchment area, and on this basis were invited to enrol in the study. A convenience sample of 61 control subjects without a history of knee damage, were recruited from the same catchment area to match the ACL subjects. Participants were excluded from the study if they were under 18 or over 50 years of age, had other neurological or musculoskeletal pathology that would alter their performance, had received acute arthroscopies, and had had some validated measurement tools do exist to predict functional recovery.
Acute anterior cruciate ligament rupture

Given to the subjects for gait and jogging were to move at a perpendicular to the direction of movement. Instructions were also recorded if subjects had minimal resolving effusion, through rehabilitation, jogging and distance hopping activities. This was staged according to symptoms and time post injury.24 25

Repeated measurements over time

On initial attendance all ACL patients were given a study information sheet. Data collection started on their second visit after they had provided written informed consent. Forty eight participants underwent a minimum of three movement analysis recording sessions and were therefore included in this sample. Recordings for gait analysis were made at approximately monthly intervals. As they progressed through rehabilitation, jogging and distance hopping were also recorded if subjects had minimal resolving effusion, full range of knee motion, and no episodes of full giving way.26 27

Clinical movement analysis

All data collection took place in the gym of the physiotherapy department at UHW. The walkway used was 15 m long. Two sticks with markers at either end were placed midway along the walkway, parallel to each other and 1 m apart for calibration and data processing. A digital camcorder (SONY Digital Handycam DCR-PC110E) was placed 6 m away from the walkway, and calibration sticks could be measured. This spatial information was obtained automatically by the computer after the calibration sticks were used to calibrate the area between them and the injured and non-injured limbs of patients. The reliability of this system for calculating gait velocities has been found to be high, with an inter-tester reliability of ICC = 0.99 and reliability between assessors and an optoelectric timer of ICC = 0.98.28

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Mean and standard deviations of the participant characteristics comparing the ACL and control groups</th>
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<tbody>
<tr>
<td>Characteristic</td>
<td>Mean (SD)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>ACL 171.7 (9.4)</td>
</tr>
<tr>
<td></td>
<td>Control 171.9 (9.4)</td>
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<tr>
<td>Age (years)</td>
<td>ACL 27.5 (7.7)</td>
</tr>
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<td></td>
<td>Control 27.6 (5.6)</td>
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<tr>
<td>Weight (kg)</td>
<td>ACL 72.9 (13.0)</td>
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<td></td>
<td>Control 72.5 (13.8)</td>
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<td>ACL Male/female</td>
</tr>
<tr>
<td></td>
<td>Control Male/female</td>
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The 95% confidence intervals of the difference between groups and the significance level calculated through an independent t test are shown (level = 0.05).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Summary of patient characteristics for the recruited ACLD sample (1) and all ACLD subjects who attended the AKSS (2)</th>
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<tbody>
<tr>
<td>Characteristic</td>
<td>Group</td>
</tr>
<tr>
<td>Age, years</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>

M/F, male/female.

Statistical analysis

Independent t tests and χ² tests were used to compare the ACL and control groups. The same approach was used to check that the ACL subject sample participating in the study was representative of the larger population of all ACL subjects attending the AKSS. As indicated earlier, ACLD subjects needed to have a minimum of three monthly recordings of their gait to be entered for further analysis. Data from the

Figure 1 Recovery over time of gait velocity for each individual ACLD patient. Each data collection visit is represented by an empty circle with a line joining individual visits.
control group were used to calculate means and standard deviations (SD) of the different parameters. Members of the ACL group were classified as having recovered to within a normal range when their values were within $\pm 1$ SD of the control mean.\textsuperscript{29} Changes over time indicative of functional recovery in the ACL group were modelled using a least square fit of the data. Because functional recovery was non-linear, a third order polynomial curve fit was used with “days since injury” as the independent variable to a maximum of 180 days since injury. In addition, 1 SD around this fit line was calculated.

All data from the control and ACL groups were plotted against time (in days) to permit a descriptive exploration of recovery. Two events were noted: the time when the ACL group returned within the range of values found in the control group (average $\pm 1$ SD) and the time when the ACL group returned to the average value of the control group.

**RESULTS**

The control and ACLD groups were matched for age, height, weight, gender, and activity levels (table 1). Patient characteristics of the ACL sample recruited in this investigation compared to all ACLD subjects who attended the AKSS are summarised in table 2.

**Gait**

The raw data for recovery of gait velocity for each individual ACLD subject over time have been plotted in fig 1 for the purpose of illustration. The average recovery for all gait variables have been plotted in figs 2–5. The first gait variable to return to within the control reference value was cadence.

**Figure 2** Recovery over time of gait velocity. The ACLD group is indicated by the solid curved line with 1 SD indicated by the dotted lines. The reference values derived from the control group (average $\pm 1$ SD) are indicated by the horizontal shaded band with straight grey lines.

**Figure 3** Recovery over time of cadence. The ACLD group is indicated by the solid curved line with 1 SD indicated by the dotted lines. The reference values derived from the control group (average $\pm 1$ SD) are indicated by the horizontal shaded band with straight grey lines.

**Figure 4** Recovery over time of step lengths. The ACLD group is indicated by the solid curved line with 1 SD indicated by the dotted lines. The reference values derived from the control group (average $\pm 1$ SD) are indicated by the horizontal shaded band with straight grey lines.

**Figure 5** Recovery over time of step length symmetry. The ACLD group is indicated by the solid curved line with 1 SD indicated by the dotted lines. The reference values derived from the control group (average $\pm 1$ SD) are indicated by the horizontal shaded band with straight grey lines.
Hopping distance

Recovery of hopping distance from the time of injury for the injured and non-injured limbs is plotted in fig 6. At 166 days post injury, the average hopping distance of the injured limb in the ACLD subjects was 1.3 m and starting to stabilise close to the control average of 1.4 m. Initially the hopping distance of the non-injured ACLD limb was shorter than that of the control subjects but by 108 days post injury had reached the control mean. The difference in hopping distance between the injured and non-injured limb decreased with time from injury.

Jogging

Some ACLD subjects start jogging as early as 30 days post injury and jogging velocity, step length, and cadence were all within ±1 SD of the control subjects. Over time there is very little change in these variables. Average jogging velocity for controls was 3 m/s and for ACLD subjects 2.9 m/s. Average step length for both groups was 1.1 m.

DISCUSSION

In this study, a number of functional activities were measured repeatedly during recovery in a group of acutely injured ACLD patients. The results for the gait variables and jogging velocity analysed in this study, are comparable to those found in the literature, but the average hopping distances are slightly shorter than those described elsewhere. This may be due to the subjects in this study participating in all levels and types of sport, not just high level pivoting and cutting activities. The hopping distance of the non-injured limb did recover to the control mean as was expected, but the results of other studies have indicated that this may not always be the case. The initial reduction in hopping distance in the non-injured limb could have been due to over protection in the acute stage post injury. This would indicate that it is not appropriate to use contralateral performance as a reference to evaluate if hopping distance has recovered in the injured limb.

Initially following injury, gait is the only activity that patients can perform, due to an effusion, restricted range of motion, pain, and sensation of knee instability. This study indicated that gait variables took far longer to recover than was anticipated, between 20 and 46 days to be within the control reference values and between 95 and 130 days to reach the control mean and even longer to plateau. Initial quick recovery of cadence to within control limits meant that patients were compensating by walking with more but shorter steps. This strategy may have been adopted during the acute phase to ensure knee stability in the presence of swelling and restricted knee range of motion. Because gait is a basic movement required for many activities of daily living, its lengthy recovery makes it ideally suited to monitoring functional recovery in the early stages post injury, before individuals can perform more challenging activities. The only other study to monitor functional recovery of ACLD subjects over time found using visual analysis that it took between 2.8 and 4 weeks to achieve independent, non-antalgic gait. The speed of this recovery is possibly due to using a different less sensitive method of gait analysis.

Distance hopping had a slower recovery than gait and jogging and was stabilising at 5 months post injury. This would indicate that it is a more difficult activity for ACLD subjects and should be introduced later in rehabilitation. Unlike gait and jogging, it challenges a different aspect of knee stability. In order to successfully land from a hop, individuals need to be able to control large vertical and, in particular, knee joint shear forces, coupled with large extensor moments and rapid deceleration. Although hopping distance is an easy measure, it would not be recommended that a decision about return to sport is made from this variable alone. Several other studies have demonstrated that a battery of outcome measures need to be used to predict if an individual can return to contact sport.

Jogging velocity, cadence, and step lengths demonstrated very little change during recovery. Cadence and step length did recover to the control mean, but the jogging velocity for ACLD subjects consistently performed just below this. There is some disagreement in the literature as to whether jogging velocity and cadence do fully recover following ACL rupture. Overall jogging did not provide any information additional to gait on the recovery of function. Jogging is still an important functional activity because it is essential for the safe return to many sports, but its value as a functional outcome measure was not found to be evident in this study. Instead, it might be advisable to include an analysis of run and rapid direction change in the clinical movement analysis, because it is a lack of rotational stability that often causes individuals’ knees to give way on return to full activity.

Analysis of functional activities in the clinical setting provides clinicians with a greater understanding of what these activities involve. This will allow them to provide more appropriate advice to patients about recovery times and activities they can safely undertake. It will also enable clinicians to set more realistic rehabilitation goals and together this may improve patient compliance, reducing the number of episodes of knees giving way and being further damaged.

Based on our results, it is anticipated that full functional recovery on average could take up to 5 months or longer. It may be even slower if an individual has not attended a full course of rehabilitation or was delayed receiving treatment. There are no clear guidelines in the literature suggesting how
long it could take ACLD individuals to return to sport, but anything between 4 months post injury to never returning have been reported.\textsuperscript{1 14} For the clinician this indicates that individuals could be attending physiotherapy over a prolonged period of time, requiring significant amounts of treatment.

Compared to all patients attending the AKSS, this study sample of ACL subjects contained more female subjects and a greater proportion of individuals participating in sports requiring a high degree of pivoting. This is probably due to the presence of a sports college within the catchment area. This makes it all the more surprising that, despite the higher proportion of high level athletes in this sample, recovery of the functional variables still took a considerable time.

Measuring functional recovery of ACLD patients from initial injury over time in the clinical setting is unique. Analysis of gait provided information on movement compensations and recovery in the early stages following injury, when it would be unsafe to perform sports specific functional activities such as hopping. The jogging variables analysed in this study provided little information on functional recovery. Clinicians can compare this model of functional recovery with individual patient performance to see if patient function is following a typical path of recovery. Overall functional recovery has been found to take a considerable amount of time: 3–4 months for gait and 5 for hopping. This means that patients may need to be treated in physiotherapy until this time and advised not to return to sport until a full recovery is demonstrated on activities such as distance hopping.

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REFERENCES


Objective: To observe the differences in performance variables of the sit to stand transfer (as measured on the NeuroCom Balance Master) in a population of senior athletes.

Method: A convenience sample of 173 subjects aged 50 years and older. Data were obtained from voluntary participation in a health fair offered at the annual Huntsman World Senior Games in St George, Utah, USA. All sit to stand tests were performed on the NeuroCom Balance Master. The measured parameters were weight transfer time (WTT), rising power (force exerted to rise), and centre of gravity sway (COG sway) during the rising phase.

Results: A significant difference was found between stratified age groups (50–64 and 65+ years) on rising power. There was also a sex difference in rising power. No significant differences were found in weight transfer time or COG sway.

Conclusion: While rising power decreases with increasing age in senior athletes, WTT and COG sway remain similar regardless of age or sex. The maintenance of these other two variables (WTT and COG sway) may be attributable to physical activity and/or participation in sport.

This article addresses a clinically relevant topic, that is, functional recovery after anterior cruciate ligament injury. The approach of monitoring the functional restoration of the individual patient or athlete definitely appears worthwhile. It provides the clinician and/or therapist with information that will be useful for recommendations regarding the athlete’s return to sporting activities. It is especially helpful that the authors monitored different activities that provided varying levels of challenge to the knee joint. Therefore, the information presented here should help when devising specific training regimes for individual patients in order to help them regain full functional performance.

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