ORIGINAL ARTICLE

Classification of functional recovery of anterior cruciate ligament copers, non-copers, and adapters

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Br J Sports Med 2006;**40**:853–859. doi: 10.1136/bjsm.2006.028258

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Accepted 5 July 2006
Published Online First 18 August 2006

Objectives: (*a*) To identify whether differences exist in the pattern of recovery with respect to functional outcomes for acutely ruptured anterior cruciate ligament deficient (ACLD) copers, adapters, and non-copers. (*b*) To identify clinically relevant outcomes that could distinguish between three functional subgroups.
Methods: A longitudinal study was used to measure gait variables and distance hop at regular intervals after injury using a digital camcorder and computer for quantitative analysis. A sample of 63 ACLD subjects entered the study; 42 subjects were measured at least three times. At 12–36 months after injury, subjects were classified as functional copers, adapters, or non-copers on the basis of which of their preinjury activities they had resumed. To determine the pattern of recovery, repeated measurements were analysed using a least squares fit of the data.
Results: 17% of ACLD subjects were classified as functional copers, 45% as adapters, and 38% as non-copers. Only 5% of those who participated in high demand activities before injury returned to them. ACLD copers had recovered above the control mean for all gait variables by 40 days after the injury. Hopping distance did not recover to the control mean. Non-copers struggled to recover to control limits and remained borderline for all the gait variables.
Conclusions: Distinctive patterns of functional recovery for three subgroups of ACLD subjects have been identified. Gait variables and activity level before injury were the most useful variables for distinguishing between the subgroups. If potential for recovery is identified early after injury, then appropriate treatment can be given.

Surgical reconstruction is regarded as the optimal treatment for patients with anterior cruciate ligament deficiency (ACLD) who want to return to high demand activities or patients who experience giving way episodes.[1–3] However, some will choose conservative management.[4 5] Most orthopaedic surgeons (80%) agree that physiotherapy is useful in the conservative management of the ACLD knee, and 85% of their patients attend preoperative physiotherapy.[1 2]

Distinct differences in functional outcomes for patients with ACLD can be expected when they are separated into copers, non-copers, and adapters on the basis of which preinjury activities they have returned to.[5–9] Clinically, failure to separate patients into subgroups can result in overestimation or underestimation of a patient's overall performance,[10] and the most appropriate care will not be given.[8] This accounts for the mixed outcomes that have been found in the numerous studies that have evaluated long term function.[11–18]

Several studies have developed evaluation schemes to enable identification of potential ACLD copers.[5 7 19] Although they are valuable screening tools, they do not provide information on the pattern of recovery over time for the individual subgroups. They have only been designed and tested on athletes who regularly participate in high level activities and do not allow early decision making about the long term management. This means that clinicians face a dilemma when evaluating an ACLD patient's potential for recovery. The aim of this study was to identify whether differences are evident in the pattern of recovery with respect to functional outcomes for three subgroups of patients with ACLD: copers, adapters, and non-copers. Clinically relevant outcomes for distinguishing between subgroups were also identified.

METHODS

Subjects

Over the recruitment period from May 2001 to November 2003, 281 patients attended the Acute Knee Screening Service at the University Hospital of Wales with an acute anterior cruciate ligament (ACL) rupture, which was confirmed by magnetic resonance imaging. Potential participants were excluded from the study if they were under 18 or over 50 years of age, had other relevant neurological or musculoskeletal pathology, required an urgent knee arthroscopy, had combined ACL and posterior cruciate ligament injuries, or did not live in the University Hospital of Wales catchment area for physiotherapy. This resulted in 63 patients with ACLD being invited to participate in the study. Only 42 were eligible to be included in the final analysis; 21 were excluded because they did not have a minimum of three movement analyses or were not contactable for the telephone follow up 12–36 months after the injury. A convenience sample of 61 control subjects without a history of knee damage were recruited from the same catchment area to match the patients with ACLD. This study was approved by the South Wales Local Research and Ethics Committee. All patients followed a rehabilitation programme that emphasised full range of motion, muscle strengthening, and neuromuscular control activities. Treatment was staged according to symptoms and time after injury.[20 21]

Repeated measurements over time

A minimum of three movement analysis recordings between zero and five months after injury was required for each subject. Five months was chosen as the cut-off point for data collection on the basis of our earlier findings.[22] This showed no change in the functional outcome measures after five months. The number of days after injury on which individual

Table 1 Characteristics of the anterior cruciate ligament deficient (ACLD) group and control group

Characteristic	ACLD	Control	95% CI	*t* Value	p Value
Height (cm)	171.7 (9.4)	171.9 (9.4)	4.34 to 3.14	−0.111	0.912
Age (years)	27.5 (7.7)	27.6 (5.6)	−2.83 to 1.88	−0.50	0.961
Weight (kg)	72.9 (13.0)	72.5 (13.8)	−4.81 to 6.45	0.128	0.899
Male/female	38/25	35/26		0.775	

Values are mean (SD). The 95% confidence intervals (CIs) of the difference between groups and the significance level calculated through an independent *t* test are shown (α level = 0.05).

data collection sessions took place for each subject was recorded and used in the analysis.

Clinical movement analysis

Gait data collection started once all subjects had provided written informed consent. Distance hopping was recorded if subjects had minimal resolving effusion, full range of knee motion, and no episodes of full giving way.[5 7 23 24] All data collection took place in the gym of the physiotherapy department. The walkway used was 15 m long. Two sticks with markers at either end were placed midway along the walkway, parallel to each other 1 m apart for calibration and data processing. A digital camcorder (SONY Digital Handycam DCR-PC110E) was placed 6 m away from the walkway on a tripod perpendicular to the direction of movement set at 1 m high. Subjects were instructed to move at a comfortable speed along the length of the walkway. Two trials were collected, one in either direction.

For maximal hopping distance, subjects were instructed to start on the limb being tested, hop as far as they could, and land on the same limb, maintaining their balance until instructed to move away.

Follow up

At 12–36 months after injury, subjects were followed up with a telephone questionnaire. They were asked about episodes of knee instability and current work and sport activities. This was compared with their preinjury activity level, and they were then classified as functional copers, adapters, or non-copers. A coper is defined as a patient who has returned to their preinjury level of work and sport with no limitations in their performance. An adapter is someone who has reduced their work or sport level or changed activities to prevent their knee fully giving way.[7] Non-copers are patients who fail to return to their preinjury activities and are experiencing episodes of full giving way with work, activities of daily living, or low demand, non-pivoting sports. Our definition of a non-coper has been adapted from that of Eastlack *et al*[7] to improve its suitability for use with an ACLD population that mainly includes recreational athletes.

Data analysis and processing

All data were processed using a Sony Vaio FX105 laptop with DVGait and MATLAB 12 software. Individual frames corresponding to events of interest were saved from the video and stored as JPEG files. For gait analysis, these frames were three heel strikes of the subject walking in either direction, and, for hopping, two frames corresponding to before take off and landing. Temporal information of these events was obtained in frames from the display in DVGait (resolution 25 frames per second). For stage 2 of the processing, a program was purpose written in MATLAB. The two 1 m sticks were used to calibrate the area between them and create a grid so that the placement of the foot (location of the heel in contact with the floor at heelstrike) relative to the calibration sticks could be measured. This spatial information was obtained automatically by the computer after the operator had indicated the heel location by means of a cross hair displayed on the computer screen. Once this temporal and spatial information had been processed, the following variables could be analysed by the computer: gait velocity, cadence, step length, gait/step length symmetry, and maximal hopping distance.

The reliability of this system for calculating gait velocities has been found to be high, with an intraclass correlation coefficient of 0.99 for inter-tester reliability and 0.98 for reliability between assessors and an optoelectric timer.[25] The intraclass correlation coefficient for intrarater reliability of measuring hopping distance using the method described above was 0.99.

Table 2 Summary of patient characteristics for the anterior cruciate ligament deficient (ACLD) sample recruited (group 1) and all ACLD subjects who attended the Acute Knee Screening Service (group 2)

Characteristic	Group 1	Group 2
Age (years)	27.5 (7.7) (18–53)	29.6 (9.2) (15–58)
Male/female ratio	38/25	170/44

Ages are mean (SD) (range).

Statistical analysis

Independent *t* tests and χ^2 tests were used to compare the ACLD and control groups. The same approach was used to check that the ACLD subject sample participating in the study was representative of the larger population of all ACLD subjects that attended the Acute Knee Screening Service. As indicated above, ACLD subjects needed to have a minimum of three monthly recordings of their gait to be entered for further analysis. Data from the control group were used to calculate means and standard deviations for the different variables.

Changes over time indicative of functional recovery in the ACL groups were modelled using a least squares fit of the pooled data for each subgroup. 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 150 days since injury. One standard deviation around the fit lines was also calculated. Four fit lines were plotted against time (in days) to permit a descriptive exploration of recovery. These fit lines are: the overall mean recovery of all ACLD subjects together with the mean recovery of the subgroups of copers, adapters, and non-copers. Two events were noted: the time when the ACLD groups returned to within the range of values found in the control group (mean (SD)); the time when the ACLD groups returned to the mean value of the control group. The ACLD groups were classified as having recovered to within the normal range when their values were within $\pm$1SD of the control mean.[26]

Table 3 Characteristics of each of the anterior cruciate ligament deficient subgroups

	Copers	Adapters	Non-copers	*F* value (significance)
Age (years)	28.7 (8.0)	29.8 (8.5)	27.31 (6.74)	0.455 (0.638)
Height (cm)	169.17 (12.73)	173.57 (7.2)	170.56 (10.29)	0.327 (0.725)
Weight (kg)	71.33 (14.18)	72 (11.24)	71.78 (10.09)	0.05 (0.995)
Female/male ratio	5/2	6/13	6/10	
Activity level before injury				
Level 1	2	16	12	
Level 2	1	0	2	
Level 3	4	3	2	
Total	7	19	16	

Values are mean (SD) or number of subjects. Activity levels: level 1, contact sports with a high pivoting and jumping demand; level 2, non-contact sport with moderate pivoting and jumping demands; level 3, non-contact sport with low/no pivoting or jumping.

RESULTS

Subjects

Table 1 summarises the characteristics of the control and ACLD groups. All the ACLD subjects who participated in this study were matched to the control subjects for age, height, weight, and activity levels.

Table 2 summarises the patient characteristics of the ACLD sample recruited in this investigation compared with all ACLD subjects who attended the Acute Knee Screening Service. Both ACLD groups had similar mean ages, age ranges and a greater proportion of male than female patients, although the male/female ratio is lower for group 1.

Table 3 summarises the characteristics of each functional subgroup. Of the 42 subjects followed up at 12 months 17% were classified as copers, 45% as adapters, and 38% as non-copers. Overall, only 5% of subjects who participated in high demand activities before injury returned to them.

Gait

Figures 1–3 show the mean recovery for all gait variables for each of the functional subgroups. Table 4 summarises the number of days after injury when the ACLD subgroups and the mean of all ACLD subjects reached ''normal limits'' set by the control subjects.

Initially after injury there is a trend for all gait variables for all ACLD subgroups to be below the normal limits set by control subjects. With time, the recovery plot for each of the subgroups becomes more distinct as they disperse from each other relative to the control mean. If ACLD patients are not subdivided and instead are plotted as one group, then it appears that on average they all recover to the control mean.

For the non-copers, velocity recovered and plateaued at the lower limit of the normal range set by the control subjects. Step length returned to within 1SD of the control mean but then deteriorated and stabilised just within the ''normal'' control range. For cadence, all groups recovered to within 1SD of the control mean; copers were already within this range from the early days after injury. Overall there was a trend for the adapters to recover and plateau close to the control mean, the copers just above this, and the non-copers at the lower limit of the normal range set by the controls. For all gait variables, the copers had the quickest recovery and were within normal limits by 40 days after injury.

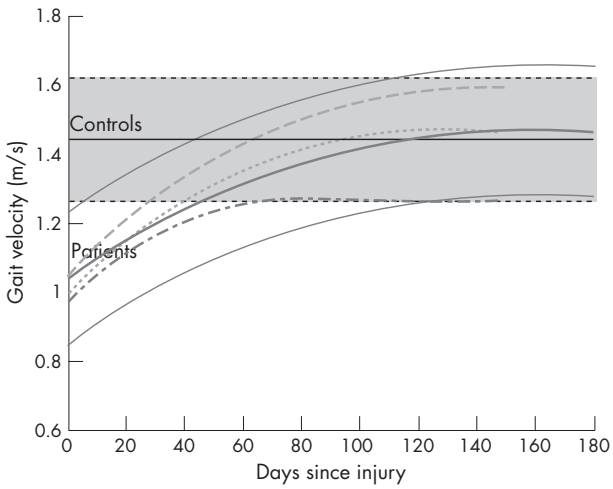

Figure 1 Recovery of gait velocity over time for the three functional subgroups and the mean recovery of all the anterior cruciate ligament deficient subjects. The ACLD group as a whole is indicated by the solid curved line with 1 standard deviation indicated by the thinner solid lines. ACL copers are indicated by the dashed line; adapters by the dotted line and non-copers by the dot dashed line. The reference values derived from the control group (average ± 1 standard deviation) are indicated by the horizontal line with grey band.

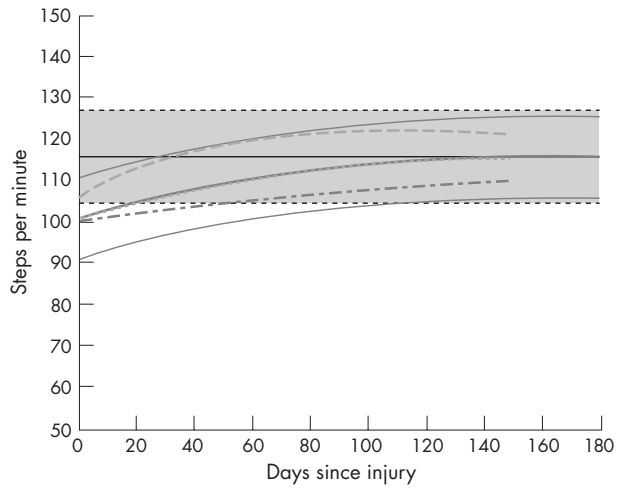

Figure 2 Recovery of gait cadence over time for the three functional subgroups and the mean recovery of all the anterior cruciate ligament deficient subjects. The ACLD group as a whole is indicated by the solid curved line with 1 standard deviation indicated by the thinner solid lines. ACL copers are indicated by the dashed line; adapters by the dotted line and non-copers by the dot dashed line. The reference values derived from the control group (average ± 1 standard deviation) are indicated by the horizontal line with grey band.

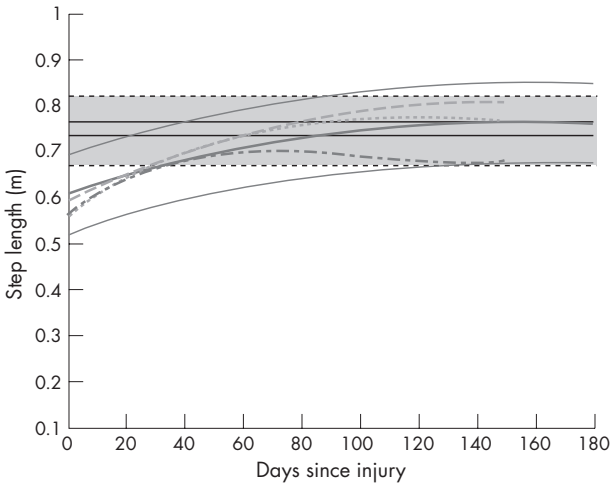

Figure 3 Recovery of gait step length over time for the three functional subgroups and the mean recovery of all the anterior cruciate ligament deficient subjects. The ACLD group as a whole is indicated by the solid curved line with 1 standard deviation indicated by the thinner solid lines. ACL copers are indicated by the dashed line; adapters by the dotted line and non-copers by the dot dashed line. The reference values derived from the control group (average ± 1 standard deviation) are indicated by the horizontal line with grey band.

Hopping distance

Pain, swelling, and instability stopped 10 of the ACLD subjects in the non-coper group from hopping. This means that the results are based on the performance of a small sample, introducing bias into the results. Figure 4 shows the mean recovery for hopping distance for each of the functional subgroups. Table 5 summarises the number of days after injury when the ACLD subgroups and the mean of all ACLD subjects reached ''normal limits'' set by the control subjects.

On average, the whole sample of ACLD patients recovered to the control mean. When they were separated into copers, adapters, and non-copers, it was found that, although non-copers initially hopped the shortest distance, by 150 days after the injury they hopped the furthest. This was greater than the mean hopping distance of the controls and was only just within +1SD of the control mean. Copers were already at the lower limit of being within ±1SD of the control mean 30 days after the injury, but did not reach the control mean.

DISCUSSION

Between 12 and 36 months after injury, ACLD patients were classified as functional copers, non-copers, or adapters on the basis of which of their preinjury activities they had successfully returned to without episodes of giving way. Most were adapters and non-copers, a finding that is well documented in the literature. We also found fewer copers than documented elsewhere; coping was almost non-existent in patients who had high sporting demands.[6 11 14 16–18 27] The recovery for each of our functional subgroups was plotted over time for a range of biomechanical variables during gait and distance hop, with the aim of identifying different patterns of functional recovery for each group. Distinct differences between the copers, adapters, and non-copers were found. Functional copers and adapters did recover to within normal limits, but the non-copers remained borderline. However, our results need to be interpreted with caution, as they have not been tested statistically and no attempt has been made to calculate the sensitivity or positive prediction rates of these variables. All the subgroups were matched for age, height, and weight, eliminating the influence that these characteristics had on the gait recovery plots.[28]

Initially after injury, all ACLD subjects, regardless of subgroup, compensated with a lower gait velocity and shorter step length. For most gait variables, the non-copers struggled to return within normal limits set by the controls. Conversely, all gait variables for the copers returned to well within normal limits by 40 days after injury. This meant that copers were distinguishable from the non-copers at this time on the basis of these simple gait variables. The functional adapters had a recovery similar to the copers, but it was not possible to identify a time after injury when these patients could be distinguished from the copers. In a health service with long surgical waiting lists, it would be beneficial to be able to prioritise cases with the greatest functional loss. If non-copers are identifiable by 40 days after injury, then this fits in well with current practice and guidelines about when ideally to perform an ACL reconstruction.[2 29]

Other studies that have compared similar gait variables between ACLD subgroups or between controls and ACLD subjects have found a full recovery of gait variables or have not shown gait compensation strategies.[8 10 22 30–32] Most of these studies used subjects with chronic ACL tears, or subjects were not subdivided into functional copers, adapters, and non-copers. By grouping all subjects together, differences within the subgroups may have gone unnoticed. Our

Table 4 Summary of number of days to recovery and maximum values for anterior cruciate ligament deficient (ACLD) subgroups during gait

	Copers	Adapters	Non-copers	Mean
Gait				
Days to be within ±1SD of control mean (1.43 m/s)	27	40	70	46
Days to reach control mean	60	93	N/A	118
Mean recovery value (m/s)	1.59	1.47	1.25	1.47
Cadence				
Days to be within ±1SD of control mean (116 steps/min)	Already within	17	52	19
Days to reach control mean	36	N/A	N/A	155
Mean recovery value (steps/min)	116	115	110	116
Step length				
Days to be within ±1SD of control mean (0.73 m)	28	32	39	36
Days to reach control mean	57	60	N/A	85
Mean recovery value (m)	0.81	0.77	0.69	0.77

N/A, did not reach control mean.

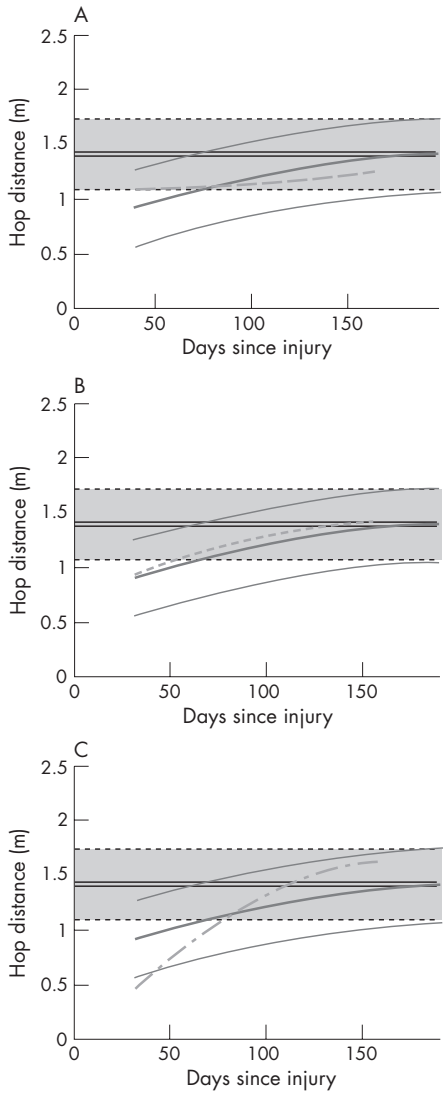

Figure 4 Recovery of hopping distance over time for the three functional subgroups (A, copers; B, adapters; C, non-copers) and the mean recovery of all the anterior cruciate ligament deficient subjects. The ACLD group as a whole is indicated by the solid curved line with 1 standard deviation indicated by the thinner solid lines. The ACL subgroup in each graph is indicated by the dashed line. The reference values derived from the control group (average ± 1 standard deviation) are indicated by the horizontal line with grey band.

non-copers experienced episodes of full giving way with work, activities of daily living, or low demand, non-pivoting sports. Therefore, unlike copers and adapters, they may show compensation strategies during gait to successfully perform activities of daily living. The only other study to monitor recovery of gait over time found that it took 2.8–4 weeks to achieve independent, non-antalgic gait.[33] The speed of this recovery is possibly the result of not separating patients into functional subgroups and using a less sensitive method of qualitative observation.

The second functional activity analysed in this study was hopping distance. This is regarded as a more challenging activity for an ACLD knee because of large shear forces and extensor moments and being representative of sporting manoeuvres.[9 34] Therefore compensation strategies may be expected in all subgroups of ACLD knees. No other studies have compared hopping distance between copers, adapters, and non-copers using an analysis comparable to ours. The mean hopping distance for copers and adapters in this study falls into the range (96–155 cm) found in generalised populations of ACLD subjects.[9 15 17 35 36] The distance hopped by non-copers in the present study is surprisingly high. In part, this may be explained by the fact that not all non-copers were able to hop for fear of the knee giving way, potentially introducing a bias. This problem was also encountered by Rudolph *et al*,[9] and, although it confirms that hopping is a more challenging task when assessing knee stability, it does mean that our results need to be interpreted with caution.

There are two possible explanations that may have contributed to the coper subgroup hopping a shorter distance. The first is that, before injury, most of the coper group did not participate in activities requiring a high degree of jumping and pivoting, so overall may never have had the ability to perform as well at the distance hop. The second explanation may be that a functionally stable knee involves knowledge of the limits of knee stability, achieved at the expense of distance hopped.[37]

Gait is generally not recognised as a functional activity to evaluate performance after acute ACL rupture, but the results of this study indicate that it has greater potential to assist clinical decision making than distance hopping up to five months after injury. All patients were able to walk so were able to participate in this study, and there was no selection bias unlike in the hopping sample. Other studies have highlighted limitations of analysing hopping distance. Patients with poor functional scores still achieve hop distance symmetry and distance within normal limits.[5 7 38 39] The advantage of using video for data collection over other cheaper and simpler methods is that joint angle data were also collected. This allows a more complete movement analysis and provides explanations for compensation strategies.

A further distinguishing feature between our ACLD subgroups was the level of sports participation before injury. The non-copers and adapters played sports requiring a high level of jumping and pivoting before injury, whereas the copers did not. This is supported by previous studies which have found that patients who spent more hours a week participating in jumping and cutting sports before injury have a poorer outcome.[6 19] From our results it would indicate that, in addition to the gait variables, activity level before injury is one factor that should help to distinguish between the functional subgroups.

The overall outcome of ACLD patients with conservative management was poor despite all receiving physiotherapy

Table 5 Recovery of hopping distance for anterior cruciate ligament deficient (ACLD) subjects

	Copers	Adapters	Non-copers	Mean
Days to be within ±1SD of control mean (1.3 m)	Already within	51	72	63
Days to reach control mean	Does not reach	128	105	168
Mean maximal distance at 5 months (m)	1.22	1.41	1.61	1.4

What is already known on this topic

- ACLD copers, adapters, and non-copers are known to perform differently during functional activities and have different outcomes
- Failure to subclassify patients may result in inappropriate care
- Current evaluation schemes are for use only with high level athletes and do not allow early decision making

What this study adds

- ACLD copers, adapters, and non-copers had distinct differences in their pattern of gait recovery by 40 days after injury
- Clinically, gait can be used to distinguish between the subgroups
- Distance hop was not found to be useful in subclassifying ACLD patients up to five months after injury

based on published rehabilitation guidelines.[20 21] Our results indicate that, if gait has not recovered sufficiently by 40 days after injury or if there are high sporting demands, a patient is unlikely to become a coper. So, should the aim of rehabilitation be limited to returning a patient to activities of daily living and straight line sporting activities only and not high levels of pivoting and jumping?

CONCLUSIONS

Uniquely, we have shown that copers, adapters, and non-copers have patterns of recovery that are distinct from each other. Recovery of all gait variables to within ''normal limits'' by 40 days after injury may be valuable clinically to distinguish between subgroups. Hopping distance was not found to be as useful a functional outcome as gait for subclassifying ACLD patients up to five months after injury. We found a very low rate of functional coping in ACLD subjects with high sporting demands.

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Competing interests: none declared

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