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# RETURN TO SPORT AFTER ACL INJURY AND SURGERY: AN EDUCATIONAL MATTER?

# IL RITORNO ALLO SPORT DOPO LESIONE DEL LEGAMENTO CROCIATO ANTERIORE: UN FATTO EDUCATIVO?

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**Abstract**

Return to sport after an anterior cruciate ligament (ACL) injury has always been considered a purely rehabilitative matter. Such approach has been supported by a culture that views the body and the movement from a merely clinical and mechanistic perspective. Scientific evidence suggests that in an ACL injury, in addition to peripheral anatomical damage, a modification in the activation of the cortical areas - in which the injured ACL is represented - is evident. It follows that, to ensure a full movement recovery, the standard surgical and rehabilitation process is not enough, and that there is the need for a sport-specific re-learning intervention. Therefore, the proposed case study monitors, analyzing gait kinematic through a Motion Analysis System, an ACL injured élite volleyball athlete's return to sport (RTS), according to a neurocognitive approach where the sport recovery is also an educational matter. The results show a full restoration of the gait function at the end of the proposed RTS exercise protocol, orienting future perspectives in sport training and sport re-education towards an ecological approach to movement.

Ritornare alla pratica sportiva dopo aver subito una lesione legamento crociato anteriore (LCA) è da sempre considerata una questione puramente riabilitativa. Questo approccio è sostenuto da una cultura che osserva il corpo e il movimento da una prospettiva meramente clinica e meccanicistica. Evidenze scientifiche suggeriscono che in una lesione del LCA, oltre al danno anatomico periferico, è evidente anche una modificazione nell'attivazione delle aree corticali - in cui il LCA è rappresentato. Ne consegue che, per garantire un pieno recupero dell'organizzazione motoria, il normale percorso chirurgico e riabilitativo non è sufficiente ma che è invece necessario un intervento di ri-apprendimento del gesto sport specifico. Pertanto, lo studio che proponiamo monitora, analizzando la cinematica del ciclo del passo attraverso un Sistema di Motion Analysis, il ritorno allo sport di un atleta pallavolista professionista dopo lesione del LCA, che è stata coinvolta in un percorso che segue un approccio neurocognitivo dove il recupero sportivo è considerato anche una questione educativa. Dai risultati è evidente un completo ripristino della funzione del cammino alla fine del nostro protocollo di esercizi, orientando le prospettive future nell'allenamento sportivo e nella rieducazione sportiva verso un approccio ecologico al movimento.

**Keywords**

Sport - Pedagogy – Education - Motion Analysis – Anterior Cruciate Ligament

Sport – Pedagogia – Educazione – Analisi del Movimento – Legamento Crociato Anteriore

## Introduction

In overall incidence of sport injuries, it is well known that ACL (Anterior Cruciate Ligament) injuries frequently occur in active individuals and athletes (Murphy et al., 2003). Epidemiological studies demonstrate that, compared with male, female athletes have a 2- to 8-fold greater ACL injury rate (Quatman et al., 2010). Compared to Contact, Non-contact ACL injuries are more frequent, particularly in athletes participating in landing- and pivoting-type sport (Gokeler et al., 2022). Dauty ad coll. (2022) defined Non-contact ACL injury by a knee twisting mechanism that occurred without collision and without high kinetic reception and underlined the burden of Non-contact ACL injuries in sport (70% to 75% of the overall cases) where the risk factors are classified in extrinsic (or environmental such as playing surface, sport level, etc.) and intrinsic (or individual such as anatomic, neuromuscular, biomechanical, etc.). Some intrinsic risk factors are modifiable i.e., neuromuscular or biomechanical and some not, i.e., female gender and age (>14 or <20 years old) (Beynnon et al., 2014).

Evidence also suggests that some Non-Contact sport-specific movement (jump landing, rapid decelerations, side cutting, e.g.) predispose to the lesions in a kinematic chain that included not only the knee but also the hip, ankle and trunk, which should be taken into account (Griffin et al., 2000).

In order to prevent Non-Contact ACL ruptures, there is a need to better understand the modifiable risk factors, particularly biomechanical, and also to make it measurable in sport practice (Hewett et al., 2015; Dauty ey al., 2022).

In return to sport (RTS) after an ACL injury, and after surgical reconstruction, the restoring of mechanical stability of the joint is a fundamental prerequisite in order to prevent risk of a second ACL injury or other joint alterations, but no guideline or ad hoc protocol are validated (Gokeler et al., 2022).

In recent years the theoretical paradigm of sport and training sciences has developed into educational practices, giving new methodological stimulus not only for the reconceptualization of sport-specific performance models (Chow et al., 2015; Schenk & Miltenberger, 2019; Troisi Lopez et al., 2020) but also for the specific re-education protocols in RTS after injuries (Fort-Vanmeerhaeghe et al., 2022).

RTS has not been accurately described (Doege et al., 2021). There is a variability in definitions that has consequences also in the focus of re-education protocols that, in order to better manage the intervention, should be calibrated on the specific sport and on the specific injury (Fort-Vanmeerhaeghe et al., 2021). In other words, it would be desirable to consider the athlete as such and not as a patient. This would shift the focus from a purely clinical idea of RTS to a re-educational idea where RTS becomes a return to performance (Doege et al., 2021).

It is also recognized that functional instability is often a consequence of an ACL injury and/or reconstruction where, also after rehabilitation program, knee persists in abnormalities of gait kinematic with a considerable risk, in the long period, for additional injuries (Gao & Zheng, 2010; Di Stasi at a., 2013; Slater et al. 2017). Three-dimensional motion analysis (MA) assessment is considered the gold standard to investigate kinematic mechanism that are implied in Non-Contact ACL injury: increasing in knee valgus, increased knee internal rotation and decreased knee flexion (Laughlin et al. 2011; Shabani et al., 2015).

Furthermore, scientific evidence suggests that in an ACL injury, in addition to peripheral anatomical damage, a modification in the activation of the cortical areas - in which the injured ACL is represented - is evident (Valeriani et al., 1996; Kapreli & Athanasopoulos, 2006; Kapreli et al., 2009; Neto et al., 2019; Rucco et al., 2019).

Moreover, a growing amount of literature, since a lot of years, has demonstrated sensory structures in the intact ACL, which could provide force and length sensory-motor information to the central nervous system so as, tension, speed, acceleration, direction of movement and position of the knee joint (Zimny et al, 1986; Valeriani et al, 1999; Adachi et al., 2002; Tashman et al., 2008; Gao et al., 2016; Banios et al., 2022). Thus, altered neuromuscular function secondary to diminished somatosensory information (proprioception and kinesthesia) has been proposed as a key factor in functional instability after ACL injuries (Lui-Ambrose, 2003).

Hence, the role of ACL can no longer be considered merely mechanical (Andersen et al.,1997) and ACL injury cannot simply and solely be considered a biomechanical or peripheral damage. Consequently, the rehabilitation programs should be addressed to the restoration of kinesthetic, sensory-motor (Ageberg et al. 2009, Courtney& Rine 2006) and neuromuscular functions (Ageberg et al.2002) in order to restore the functional knee joint stability. It follows that, to ensure a full movement recovery and a safe RTS, the standard surgical and rehabilitation process is not enough, and that there is the need for a sport-specific re-learning intervention, where sport training and conditioning should be organized as an educational matter (Krakavas et al., 2020; Fort-Vanmeerhaeghe et al., 2022).

In line with this point of view, the aim of the present case study is to evaluate the efficacy of a Neurocognitive Exercise Protocol - NEP, in an ACL injured élite volleyball athlete's RTS; and to analyze qualitatively and quantitatively, by means of three-dimensional MA assessment, the effects of NEP on spatiotemporal and kinematic gait parameters of the athlete.

## 1. Subject and methods

*Athlete description:* in the present study, a 28-year-old female élite volleyball player who sustained a left knee Non-Contact ACL injury (in a jump landing) while playing a volleyball match, is involved. The athlete had no previous injuries in her 10'yrs story of élite sport practice.

*Study design:* the athlete underwent MA assessments before surgery (T0 - 1 week after the injury and T1 - 4 weeks, baseline evaluation); at 4, 12, 36 weeks after surgery (T2, T3 and T4 follow-up evaluation), respectively. After T0 evaluation, the athlete underwent a specific NEP, before and after surgical reconstruction. No other clinical evaluation was conducted.

*Exercise protocol:* according with a neurocognitive approach to movement and re-education (Cappellino et al., 2012; Minino et al., 2020; Piskin et al., 2021), the athlete underwent a specific NEP during a 36-week period (60 minutes individual sessions, 3 time a week), conducted, at different stages, by physiotherapist, conditioner, and coach, since the immediate post-traumatic (see Fig.2A). Each NEP exercise was organized in term of contents (what: intra and extracorporeal relationships; tactile pressure and kinesthetic information from different position), mode (how: organization of movement and/or sport-specific movement in different conditions) and goals (why: intermediate changes in function and performance). All the exercises were linked with verbal feedback of the athlete, that was the trace useful to modify the proposal and to have a first-person response.

*MA Assessment:* motion data were collected using an 8-camera stereophotogrammetric system (Qualisys Inc., SE) at 240 Hz. According to a modified Davies protocol, forty-two sphereshaped reflective markers, 15 mm in diameter, were positioned over the patient's bony landmarks (see Fig.1). After standing calibration and adequate practice, the athlete walked barefoot through the measurement space (10 m) at his/her self-selected comfortable speed. A specific software system (Visual 3D, USA) was used to define the skeletal body segments and for the spatiotemporal and kinematic gait report (Rucco et al., 2020). At least six good trials were recorded. MA assessment was performed at Neuromechanic Laboratory of University Parthenope of Naples (Italy). MA data were collected (1 week after the injury, when the athlete was able to walk - T0), 1 month after the injury and 3 days first to surgical intervention (T1), 1 month after surgical intervention (when the patient was able to walk - T2), after 3 month of rehabilitation (when the patient was able to run - T3), after 9 month to the injury (when the patient was able to play volleyball – T4). MA data were useful for a third-person observation.

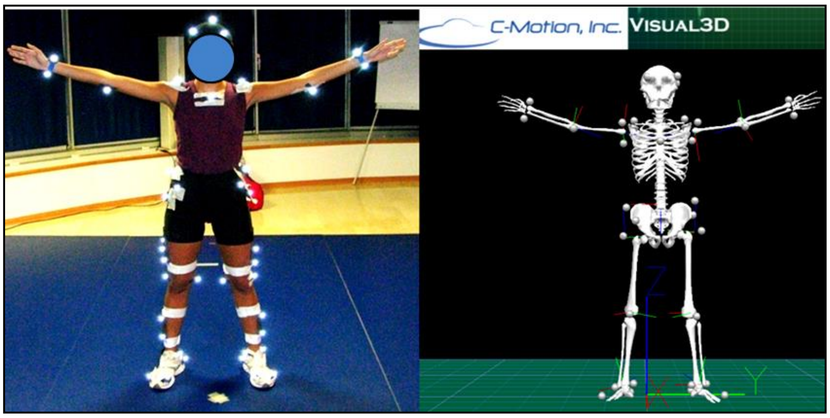


Fig. 1. Markers protocol (on the left) and Skeletal reconstruction by means the Visual 3D software (on the right)

## 2. Results

Descriptive statistics, including means and standard deviations (SD), for knee excursion in the sagittal plane and spatiotemporal gait parameters were examined to compare the data. Specifically, postinjury and postsurgical values were considered if greater than 1 SD which is intended as a measure of variability and not as a statistical indicator. Measures are displayed in table (see Tab. 1) and graphically (see Fig. 2B).

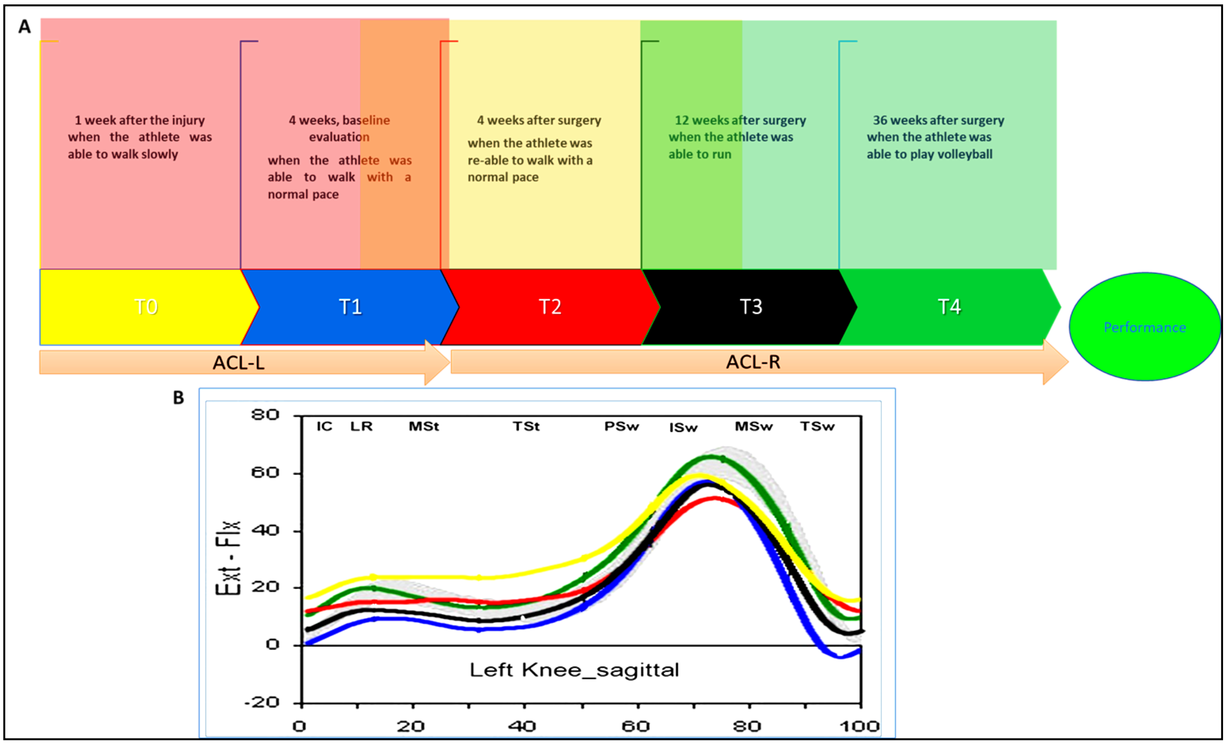


Fig. 2. A) the timeline of the study; B) Left Knee flexion/extension angle during gait. According with the T0, yellow line, 1 week after the injury; T1, blue line, 1 month after the injury; T2, red line, 4 weeks after surgical intervention and NEP; T3, black line, 12 weeks of NEP; T4, green line, 36 weeks of NEP. The color of the curves follows the colors of the timeline.

| | speed (s) (mean±sd) | stride width (m) (mean±sd) | stride length (m) (mean±sd) | step length L (m) (mean±sd) | step time L (s) (mean±sd) | stance time L (s) (mean±sd) | swing time L (s) (mean±sd) | double limb supp time (s) (mean±sd) |
|---|---|---|---|---|---|---|---|---|
| T0 | 1,086±1,520 | 0,133±0,820 | 1,299±2,690 | 0,626±1,930 | 0,59±0,140 | 0,659±0,120 | 0,557±0,160 | 0,114±0,809 |
| T1 | 1,1535±0,08 | 0,087±0,930 | 1,398±2,520 | 0,705±1,870 | 0,610±0,148 | 0,651±0,132 | 0,563±0,102 | 0,0815±0,820 |
| T2 | 0,887±2,180 | 0,102±1,780 | 1,128±1,829 | 0,549±1,003 | 0,618±0,206 | 0,778±0,183 | 0,494±0,182 | 0,276±1,650 |
| T3 | 1,149±0,920 | 0,108±1,120 | 1,312±0,720 | 0,674±0,410 | 0,586±0,033 | 0,645±0,040 | 0,501±0,027 | 0,156±0,040 |
| T4 | 1,172±0,027 | 0,081±0,030 | 1,343±0,134 | 0,671±0,020 | 0,563±0,020 | 0,647±0,020 | 0,51±0,031 | 0,171±0,033 |

Tab. 1. Spatiotemporal parameters. T0, 1 week after the injury; T1, 1 month after the injury; T2, 4 weeks after surgical intervention and NEP; T3, 12 weeks of NEP; T4, 36 weeks of NEP; SD: Standard Deviation; s: seconds; m: meters.

Concerning kinematic curves, the interesting data does not lie in the peaks of the curve but in the shape of the curve. Fig. 2B shows that the trends of curves at t0 (yellow) and t2 (red) have a similar shape, as well as the curves at t1(blue) and t3 (black); in both cases the articular knee kinematics (sagittal) is not completely restored, there is still a gap in the stance phase when the knee must perform the function of cushioning and support. To observe a shape that can be overlapped on the normal curve (gray), it is necessary to reach t4 (green) where, linking the first-person (verbal) feedback, the athlete reported a “full sensations of stability in all sport-specific movements. It is only at this moment that the athlete is able to perform a complete function of the knee and then return to sports.
Concerning spatiotemporal data, it is interesting to highlight that all the indicators of variability remain high at T2 and T3 and drop drastically only at T4, particularly stride width.

## 3. Discussion

A mechanistic theory of movement applied to sport training and conditioning, so as in sport rehabilitation and/or re-education, performance is considered as a "sum" of physical abilities and, consequently, the body as a "sum" of articular segment. Fortunately, in recent years the theoretical paradigm of sport sciences has developed into educational practices giving new methodological stimulus not only for the reconceptualization of sport-specific performance models but also for the specific re-education protocol in RTS after injuries (Cappellino et al., 2012; Agosti, 2019; Krakavas et al., 2020; Agosti & Autuori, 2020). This approach, according to an ecological theoretical paradigm (Woods et al., 2020), requires to think body and movement, so as sport performance, in terms of an educational model which mediate the relationship between pedagogical theory and educational practice (Sorrentino et al., 2019).
The case study evaluates the proposal of a neurocognitive approach in the RTS after an athlete's ACL injury and monitors the outcome by means of a MA system. Scientific evidence describes persisting gait abnormalities also after surgery reconstruction and rehabilitation. This is crucial for athlete RTS where the functional request is more vigorous in activities than walking. Our findings show that a full restoration of the gait function can be obtained only through a re-educational protocol that, in line with a neurocognitive approach, include an educative methodology in proposing exercise: the verbal feedback of the athlete can be followed by the kinematic data and gives a functional sense to what the athlete reports in the first-person and to what the operator observes in the third-person (MA). This means to have both emotional and physiological support in building increasingly targeted exercises. Prior to surgery the athlete was able to walk without aid, but MA data showed a lacking restoration in knee kinematic on sagittal plane so as in spatiotemporal parameters, particularly in SD and for the parameters stride width and double limb support time at T2. This is evident also in the follow-up where the full walking function was restored only after 36 weeks of NEP, when the athlete was able to run and perform volleyball. NEP requires a closed collaboration between physiotherapist, conditioner, and coach necessary to build sport specific training exercises right from the early stages of the re-education process.

## 4. Conclusion

Gait abnormalities as a consequence of ACL rupture and reconstruction are potential causes of re-injury and/or subsequent alterations to the knee joint. The proposed RTS protocols are not yet able to guarantee a full recovery. To our knowledge, this is the first study that quantitatively describes a NEP as an RTS protocol in an ACL injured athlete and proposes, according to an ecological approach to motor learning, RTS in terms of an educational matter. This case study has several limitations. It does not report pre-injury data and analyze gait kinematic only in the sagittal plane but, as preliminary study, our results should be a guidance for further studies, also analyzing both kinematics, in all the three space planes, and kinetics data. Future research should also follow a cohort of healthy athletes at risk for ACL injury to establish pre-injury baseline data that may be helpful in investigating the educational potential of the ecological approach to training and conditioning also in primary prevention.

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