



RESEARCH ARTICLE

# Does the “Rule of Thirds” apply to the management of the injured Anterior Cruciate Ligament

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## ABSTRACT

Noyes et al were among the first to announce a treatment pathway for the management of the cruciate deficient knee over 40 years ago when they postulated “the rule of thirds” which stated that a third will require surgery, a third will require rehabilitation thereby avoiding surgery and a third will be asymptomatic. However, although each category exists it remains uncertain what percentage in terms of management can be assigned to each category. Hence the concept of the “Rule of Thirds” remains unproven. What, therefore, is the optimum management for the cruciate deficient knee.?

Over the past 40 years there has been a plethora of articles in the orthopaedic literature relating to the management of the injured anterior cruciate ligament, some even contributing to the “replication crisis”, and apart from elite sports participants there is no clear consensus on which patients are more likely to benefit from surgery as opposed to rehabilitation alone. It is therefore likely that an unknown number of patients will have undergone surgical reconstruction when rehabilitation alone would have sufficed. This has contributed to a significant “grey area” in the management of the injured ACL. The challenge is, therefore, to detect patients in this “grey area”.

What are required are better designed studies and large multi -centre randomised controlled trials [RCT,s] that have a low risk of bias and that are powered for hard end points and a high level of evidence ,more refined pre-operative assessment in a dedicated knee clinic and the detection of the injury at the earliest possible moment before an undiagnosed injury allows progressive deterioration of knee joint function. Shared data collected from such clinics should aid in the provision of a more accurate consensus on the management of the cruciate deficient knee and each category in Noyes’ “rule of thirds” can be assigned their true value.

## Introduction

It is clear that surgery in some form has been available for the reconstruction of the injured Anterior Cruciate Ligament for nearly 140 years. However, the incidence of the injury itself over the first hundred years is uncertain because of the lack of adequate clinical tests available for its diagnosis.<sup>1</sup>

In the last 40 years, however, reports in the literature on the management of the injured ACL have reached levels where it has become one of the most widely discussed topics in orthopaedic and trauma journals, certainly relating to knee injuries. The injury is now widely recognised due to the development of more refined clinical tests such as the Lachman and the more vigorous Pivot Shift Sign described by Galway and McIntosh.<sup>2</sup>

The incidence in the UK is said to be 30 cases per 100,000 individuals yearly. This means that in an average DGH serving a population of 300,000, 90 new cases will present each year. Rupture of the ACL is therefore a common injury affecting mainly young sporting individuals of both sexes. Female athletes are reported as having a higher incidence of the injury and in mountainous countries where skiing is a common sporting activity, competent middle aged female recreational skiers form the majority with an ACL injury. A study in the USA noted that the peak incidence of the injury in males occurred between the ages of 19 and 25 years, and in females, between the ages of 14 and 18.<sup>3</sup>

Mayo Robson in 1885 at the General Infirmary Leeds, appears to be the first surgeon to report a surgical repair for an injury to the cruciate ligament. He describes the case of a 41-year-old miner who had sustained an injury to his knee joint in a rock fall. At the time of surgery, it was noted that he had torn both cruciate ligaments. These were sutured back to their femoral origins and the patient went on to make a full recovery. In 1917 Hey Groves reported the first ACL reconstruction. His operation employed a proximally based strip of fascia lata brought through the femur across the joint and through the tibia. In 1920 he modified this procedure to a distally based strip of fascia lata with improved results. He also went on to describe the anatomy, physiology and pathomechanics of the injury. He described a diagnostic test as follows “on passive manipulation the head of the tibia can be moved forward on the femur. Sometimes this forward slipping of the tibia occurs abruptly with a jerk”<sup>1</sup>. It therefore seems that he was aware of the pivot shift phenomenon.

From a clinical point of view the pivot shift sign dramatically reproduces the physical symptoms resulting from a torn ACL and no doubt may influence both the patient and the surgeon in their choice of treatment, either surgical or conservative. With practice, the gentler Lachman test is equally effective in uncovering the diagnosis.

Col. John Feagin was the first orthopaedic surgeon to report on the poor results obtained by attempts at direct repair of the torn ligament, when he published his results on a series of West Point cadets who had undergone

surgical repair in the US. The poor results associated with direct repair were explained on the basis of the blood supply to the ligament which is derived from the genicular vessels carried in the synovial covering of the ligament which is torn during injury to the ACL and cannot be restored surgically.<sup>4</sup>

Management of the torn ACL then underwent a rapid evolution of different surgical and conservative measures including extra-articular procedures such as the MacIntosh Tenodesis and external bracing with derotation devices such as the Lenox Hill Brace.

As arthroscopic techniques improved, minimal access surgery led to the development of sophisticated intra articular reconstruction of the ligament using a variety of ligament substitutes. Autografts harvested from the patient's own tissues, donor grafts [allografts] and artificial ligaments have all been used. Currently autografts in the form of Bone-patella-bone [BTB] and hamstring [gracilis and semitendinosus] predominate.

Has surgical management of the torn ACL come full circle as there are reports in the literature that direct repair may have a place in the management of the torn ligament particularly when the precise nature of the tear has been identified by MRI? For instance, avulsion of the ligament from its attachments either proximally or distally when resutured to their origins have a more favourable outcome than an attempted repair of an inter-substance tear. Notwithstanding, the debate on the best graft material for autologous reconstruction remains undecided.

Noyes et al in 1983 were the first to outline a management pathway for the injured ACL when they proclaimed the “rule of thirds” which states that “a third of patients will require surgical reconstruction, a third will require rehabilitation that may avoid ACLR and a third will be asymptomatic not requiring surgery”.<sup>5</sup> There is no question that each of these categories exist. The problem, however is assigning the true percentage of patients to each category. This article sets out to explore this issue.

## Surgical Treatment

There is a broad consensus that surgical reconstruction of the ACL [ACLR] in elite athletes of either sex who play in level 1 sports [hockey, soccer and basketball] may facilitate a return to their chosen sport. Pre-teenage and adolescent knees do not seem to mend well after a torn ACL and therefore they and patients with combined reparable meniscal and ACL tears may benefit from ACLR.<sup>6</sup>

After ACLR, the following ideals should be fulfilled:

- Correction of rotatory and antero-posterior laxity
- Restoration of a full range of motion and restoration of normal knee joint kinematics
- Preservation of the long-term integrity of the articular surface of the joint; and
- Return to pre-injury sporting activities

As noted, a variety of autologous tissue substitutes are used. The most common being either B-T-B and single or

double bundle hamstring tendons [gracilis and semitendinosus] Neither of these substitutes has yet been proven to provide a superior outcome to the other. However, more recent work has shown that a significantly higher incidence of revision surgery is required after using hamstring instead of B-T-B grafts for primary ACLR, particularly in young athletes.<sup>7</sup>

In the UK timing of surgery is sometimes dictated by fiscal rather than clinical considerations and this may be a problem in any publicly funded healthcare system where non-life-threatening conditions may not be prioritised. Whether the delay in performing surgery is a disadvantage is uncertain for recreational sports participants who are diagnosed promptly. There is no clear evidence of whether operative treatment or rehabilitation has a better outcome in this group. A recent RCT from Oxford reported in the *Lancet* by Beard et al indicated in a multicentre trial of surgical intervention v a period of rehabilitation followed by surgery, that if symptoms persisted, early surgical intervention had a better outcome at a 2-yearly review.<sup>8</sup> However the trial was conducted on “non-acute injuries”. It is not known what the outcomes are of individuals with an ACL injury, who have been diagnosed and treated conservatively at an early stage. But, as postulated by Noyes, it is likely that there are significant numbers of active individuals in this category, managing quite well without a functioning ACL. Elite athletes are likely to have privately funded healthcare and therefore they have the option of prompt operative management when this is indicated.

Function follows form and it is axiomatic that restoring normal function after tearing an ACL demands surgery that provides accurate replication of the natural ligament if surgery is required. Can this be achieved?

A number of myths have arisen over the last few decades relating to ACLR surgery.<sup>9,10</sup>

In the past, one of the drivers towards prompt surgical reconstruction was based on the premise that the “ACL acts in synergy with all the other stabilising elements in the knee joint including menisci and ligaments. Once the ACL is ruptured, this can lead to an uncoupling of its five modes of function which are, in conjunction with other knee ligaments: -

1. The ACL resists anterior tibial translation on the femur in flexion [assessed by the anterior drawer sign]
2. The ACL together with the PCL resists hyperextension
3. The ACL provides a check to internal axial rotation, thereby affording rotatory control of the knee
4. The ACL acts as a secondary restraint resisting both valgus and varus forces throughout the range of knee joint motion
5. Tension in the ACL and PCL fine tunes the screw home mechanism of the joint as it approaches terminal extension].

Repetitive cyclical loading of the cruciate deficient knee will result in the development of joint disorganisation and arthritis”. Whilst this may be the result in some neglected cases, in others this may not occur, especially if the injury has been detected at an early stage. Prompt detection enables the patient to undertake a period of

rehabilitation and activity modification. Whilst they may have joint laxity, they will not necessarily experience instability since the ACL is loaded to only about 20% of its maximum during activities of daily living.

Another common myth is the concept of isometricity in the reconstruction of the ligament. The idea arose following the elegant demonstration of the rolling and gliding movement of the femur on the tibia during flexion and extension in a two-dimensional sagittal plane. The interaction of the ACL and PCL during knee movement has been likened to a rigid, four-bar linkage system, in which the ACL and PCL act as isometric structures.<sup>11</sup> This led to the introduction of isotometers designed to aid isometric placement of an implant during surgery. However, dynamic MRI studies clearly show that the ACL and PCL wind around each other particularly during terminal extension when the “screw home” mechanism is active. This has been likened to the action of a ‘Spanish windless’ causing minimal shortening of the two structures in terminal extension. Hence Isometric reconstruction has been replaced by the concept of anatomical siting.

A further myth relates to the process of ligamentisation which was thought to convert the implanted graft into a facsimile of the ACL. It is known that the implant undergoes an initial period of vascularisation accompanied by rapid weakening, followed by a period of cellular ingrowth and maturation which is partly complete by six months after implantation. Proof of this process has been derived mainly from animal studies and human biopsy specimens [which of necessity must be relatively superficial]. Studies reporting on animal models also note that there is a significant difference between animal models and humans in the timescale taken for the process of ligamentation to be complete, with a much longer time required for human grafts. Most studies on the process of ligamentisation in human implants indicate that full restoration to either the biological or the mechanical properties of the natural ACL does not seem to be achieved.<sup>12,13</sup> Indeed one significant study, which employed gadolinium enhanced MRI after ACLR in military personnel, indicated that the graft remained avascular for up to 2 years after implantation.<sup>14</sup> Electron microscopy has also confirmed that the ultrastructure of the implant after maturation is not the same as the natural ligament.<sup>15</sup>

A further myth states that an ACL implant can be placed anatomically. The term “anatomical placement” implies that the tunnels are sited somewhere within the anatomical origins of the ACL on the tibia and femur. For a single bundle reconstruction, the recommended site is the centre of the tibial or femoral origins. With the natural ligament the tibial origin is larger than the femoral origin and extends anteriorly on the tibial plateau. Therefore, particular care is required during the drilling of a tibial tunnel to avoid placement that is too far anteriorly as this may lead to impingement of the implant by the apex of the intercondylar notch when the knee joint is fully extended.<sup>16,17,18</sup> It has led some surgeons to perform a notchplasty of the intercondylar region to accommodate the implant and avoid impingement.

It has also been reported that tunnels and, therefore implants that are placed in the centre of the anatomical origin of the femoral insertion are more likely to fail than those that are placed off centre. What is clear is that after ACLR using current techniques, normal knee joint kinematics are not restored. Point to point fixation of individual fibre bundles which extend from their true anatomical origins on their tibial and femoral attachments and enable sequential tensioning throughout the ACL during flexion and extension, is not achieved. Indeed, given the highly complex nature of the anatomy of the natural ligament, it is improbable that current methods of ACLR, be they isometric or anatomical, can truly replicate its form, and, therefore, its true function.

Finally, it is a myth that in their current form some ACLR techniques are always reproducible. Even in experienced hands, workshop studies and post-operative radiographs of tunnel positions have shown a wide variation in tunnel placement, particularly on the femoral side.<sup>19,20</sup>

It is recognised that an ACLR can stabilise a knee that has sustained an acute ACL injury in elite athletes allowing them to return to their pre-injury status in their chosen sport. Return to pre-injury sporting levels is clearly a gold standard for surgical success in ACLR. The major advantage that elite sportsmen are likely to have is access to high quality treatment in the private sector which leads to a diagnosis at the earliest possible stage allowing a precise treatment pathway without the possibility of sustaining further damage to the knee which may occur if the diagnosis is delayed or missed. It is not known what the proportion of ACLRs are in elite athletes in Noyes's first category but it is likely to be small.

In reports on the results of ACLR it is therefore unknown what percentage of these were elite athletes. However, medium term results [5 years or more] discussing knee joint function after ACLR in general, confirm that moderate functional stability had been restored, but often with some degree of laxity, particularly rotatory laxity, which is often termed a tibial slip. Research at Mayday University Hospital, where post-operative follow up included serial side to side difference measurement [SSD] with an arthrometer, suggested that provided the SSD was less than 4mm and there was a stiff end point then the knee remained stable. John Ireland et al, however, regarded a post-operative tibial slip as heralding the return of instability.<sup>1, 21</sup>

A satisfactory range of motion and restoration of function is also reported. However, a report on rates of return to sports among individuals who had undergone ACLR indicated that only 50% were able to achieve their pre-injury status. Re-injury rates among patients who had undergone revision ACLR were up to six times more likely than following primary ACLR.<sup>22</sup> There is also a higher reinjury rate in female athletes who have previously sustained an ACL rupture when compared with primary injury rates and a greater risk that a second injury will occur in the contralateral knee.<sup>23,24</sup> There is also the question as to whether or not a torn ACL is ever truly an isolated injury. “Bone Bruising” is often noted on MRI after so-called isolated ACL ruptures. Do these lesions

contribute to the later development of traumatic osteoarthritis?

Following ACLR, it is apparent that the main beneficiaries are elite athletes who are, presumably, willing to accept the possible consequences of long-term deterioration of knee joint function after ACLR [as described above], for the short-term gain of being able to return to their chosen sport.

In terms of Noyes' “rule of thirds” in the first category, ACLR in its current form is likely to be significantly greater than the one third that he postulated.

## Conservative Management

ACL rupture in level 1 sports usually results from a cutting movement at speed where a rotational force, either internal or external is applied to the flexed knee. Characteristically the rupture is accompanied by a “popping sensation” both felt and heard with immediate pain and loss of function. Within 2 hours the knee becomes swollen due to a haemarthrosis.

Ideally, thereafter, if the individual is reviewed in a Casualty setting a treatment pathway can be set in motion leading either to surgery or conservative management. What is not known is how many individuals following an ACLR injury fail to gain an early diagnosis. Consequently, without it, within 6 weeks or so the knee swelling may subside and the symptoms resolve. During activities of daily living the knee is likely to be asymptomatic and the individual may return to cutting sports with or without symptoms. If symptoms return the individual has the opportunity to seek further advice leading to an appropriate management pathway, Others may avoid cutting sports and remain symptomless.

In the 1980s and onwards at Mayday University Hospital a large number of patients with undiagnosed significant chronic antero-lateral instability leading to instability with activities of daily living were seen in a clinical setting having been referred by Primary Care. The average time from injury to clinical review was three and a half years and the treatment provided at that time was a MacIntosh Tenodesis with mixed results.<sup>1</sup> It became apparent that there was an urgent need for earlier recognition of the injury to prevent the consequences of long-term neglect.

Chronic instability is a problem that was commonly noted in the past in individuals with neglected knee injuries. There are, however, many individuals with an injured ACL who are little troubled by instability although the knee may demonstrate laxity occasionally. These people have been termed copers while those who suffer chronic symptoms are termed non-copers or non-adapters. However, there are no clearly defined means of regularly distinguishing between the two categories. Non-copers have been identified as having deficits in muscular and neurological function and other specific anatomical features, such as narrowing of the intercondylar notch [ notch stenosis], an excessive posterior sloping tibial surface or an increased Q angle in females. Gender is also a risk factor; reports indicate



a 2 to 10-fold increase in rates of ACL rupture in female athletes when compared to males “At present no single test or measurement can determine the functional status of a knee with ACL deficiency. Current passive instability test are poor predictors of outcome following detailed rehabilitation”.<sup>25,26.</sup>

It would seem that, apart from acute injuries in elite athletes, there is a large grey area in the management of individuals with a cruciate deficient knee for whom the benefits of surgical reconstruction are unclear when compared with a focused rehabilitation programme. This means that there are an unknown number of individuals who have undergone ACLR who may well have benefited from rehabilitation alone. This will produce a confounding effect in papers that report the results of ACLR in non-elite athletes.

Noyes’ three treatment pathway, mentioned in this article, remains valid for the second two categories. However, the challenge still remains to determine the percentage of patients in each of these two remaining categories.

After injury, initial treatment in the form of RICE [rest, ice, compression and elevation] is required at the earliest possible moment for both those individuals undergoing either elective surgery or conservative management. Subsequently, precise details of the type of rehabilitation vary, but the general principles remain the same. In the coper category, where focused rehabilitation may obviate the need for surgery, issues may arise with the required intensity and duration of the rehabilitation and the patients’ commitment to the programme. Failure to comply with such a programme should not be an indication that a surgical solution is required. The patients’ expectations and psychosocial status require careful consideration. Also, the sports physiotherapists role in managing cruciate deficient knees requires greater emphasis.

## Summary

It is clear that the management of the injured ACL is a deeply nuanced issue. ACLR certainly has a role to play, but an increasing number of orthopaedic surgeons believe that too many ACLRs are being performed unnecessarily. An RCT undertaken in young active sporting individuals with acute ACL injuries at Lund University in Sweden indicated that as many as 60% of ACLRs were probably not needed.<sup>27</sup> A recent umbrella review on the efficacy of commonly performed orthopaedic procedures has also questioned whether ACLR rather than rehabilitation has a better outcome.<sup>28</sup>

Reaching a consensus on the optimum management of the injured ACL is confounded by a large volume of sometimes contradictory studies reported in the literature. For example, favourable results on ACLR in elite athletes that were reported in a systematic review and meta-analysis were contradicted by further studies that showed poorer outcomes in this group.<sup>29,30.</sup> This has led to a phenomenon termed the “replication crisis” where a body of work remains unconfirmed by repeated studies.<sup>31</sup>

Other studies may have suffered bias due to poor study design. Observer bias may arise when the study is reported by the authors rather than independent reviewers accounting for up to 15% of favourable results. Detection bias occurs when success is defined according to variable knee scoring systems. There is now, however, some agreement on the use of standardised post-operative scoring systems such as the Lysholm and Tegner [devised by the IKDC] and the more recently introduced knee injury outcome score [KOOS].

Susceptibility bias occurs when there is pooling of results from patients with fundamentally different prognoses, such as the young athletic individual versus the occasional middle-aged skier. Stratification based on their prognoses is required. Performance bias can arise when researchers pool results for cases in which different surgical techniques and rehabilitation programmes are employed. Transfer bias occurs when unknown subsets of patients are lost to follow-up, which creates a false impression of either success or failure in those available for review. Finally, confirmation bias is enabled by the plethora of studies available for review allowing the researcher to select reports that support preconceived notions.

There can also be a confusing disconnection in terms of results, between surgeon-based clinical tests and scores and patient-based assessments. For example, paradoxically, a return of some degree of laxity is not necessarily matched by a decline in post-operative patient satisfaction. However, some surgeons may not regard a return of any degree of laxity as a satisfactory outcome. As discussed, J Ireland et al noted a close correlation between even a modest degree of laxity and the patient’s inability to return to sports. Several researchers have emphasised the need to consider what determines patient satisfaction and its correlation with knee laxity.<sup>32</sup>

## Conclusion

Noyes’ “Rule of Thirds” describes three separate treatment pathways or categories each containing a third of individuals with an ACL injury. It is clear that each category exists but currently it remains unclear whether each category represents a third of the total.

At present, there is a concern that perhaps too many ACLRs are being performed where conservative management would have sufficed.

It has been emphasised throughout this account that there is a requirement to detect a torn ACL at the earliest possible moment. This will allow a treatment pathway that avoids the consequences of neglected injuries leading to deteriorating knee joint function.

It seems that there is a need for a specialised referral system, in which acute knee injuries, seen in a casualty setting, are referred to a dedicated-outpatient facility where an accurate diagnosis can be made and a specialised care pathway implemented<sup>33.</sup>

If an ACLR is being considered a rigorous and targeted preoperative assessment of the knee is required. It should include imaging [X-ray and MRI], measurement of laxity by arthrometer, examination of neurological and muscular function and the general anatomy of the joint to exclude the bony risk factors outlined previously. Gender may also be a factor. Paradoxically, the musculoskeletal features of the knees that are at risk in non-copers are likely to contribute to the risk of further injury. Therefore, is ACLR indicated for patients in this category?

To provide the above specialised care pathway a Knee Clinic is required. It has been pointed out that setting up such a clinic is unlikely to be a priority in publicly funded healthcare systems. However, in the UK, orthopaedic training has shifted away from the provision of surgeons with a broad training. Currently specialist training in a specific anatomical region or sub specialisation has been implemented. Hence, the provision of knee clinics could become a reality.

The large number of articles in the orthopaedic literature relating to all aspects of the injured ACL is indicative of the fact that a consensus on the management of such

injuries has yet to be reached. The setting up of specialised knee clinics will allow the collection of information from many centres along the lines of the Swedish ACLR review, contributing to a strong evidence base. Better constructed RCTs that have a low risk of bias and that are powered for hard end points and a high level of evidence are required. Currently the evidence base for performance of orthopaedic procedures compares unfavourably with that of other specialities, as only 20% of procedures have been supported in at least one low-bias randomised trial that found surgery was favoured over non-operative measures.<sup>34</sup>

All interested parties must also accept that ACLR alone does not protect against possible future development of traumatic degenerative changes in the operated joint and that there is a significant risk of re-injury.

With time early detection of the injured ACL, referral to specialised Knee Clinics with the widespread sharing of data and better constructed studies should lead to a consensus on the general management of the cruciate deficient knee and the true assignment of treatment to each of the three categories of Noyes triad.

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