The story of anterior cruciate ligament reconstruction - part 1

by Oliver S. Schindler

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Once upon a time the anterior cruciate ligament (ACL) enjoyed a relatively unchartered existence, when only a fall from a jousting horse or chariot might have sent a knight or gladiator into early retirement due to an unstable knee. In today’s world of high speed travel and an ever increasing number of sports enthusiasts, injuries of the ACL are almost common place with a yearly incidence of about 35 per 100,000 of the population. Although we have known about the existence of the cruciate ligaments since they were first described by Galen over 2000 years ago, awareness of their function and the consequences of their loss were not appreciated until much later. Robert Adams observed the first clinical case of an ACL tear in 1837 but treatment in those days was largely conservative and surgery was reserved for life threatening conditions as mortality was high. The first ACL repair was performed in 1895 by Mayo-Robson of Leeds and was followed by Grekow and Hey Groves who initiated ACL reconstruction with autologous tissue between 1914 and 1920, almost as we know it today.

The knowledge and achievement of these early pioneers however was not uniformly appreciated at the time. Over the following 50 years surgeons experimented with a variety of different tissue grafts including synthetic materials. During this period surgical ingenuity and dissatisfaction with available techniques created a barrage of intra- and extra-articular procedures, some of which disappeared even before clinical results were published. Improved understanding of kinematics and biomechanics combined with a better appreciation of spatial arrangement and functional behaviour of the various ACL bundles created the platform for modern ACL surgery in the latter part of the 20th century. The concept of anatomic graft placement and double-bundle reconstruction are two of the most promising developments which aim to improve knee kinematics and to reduce the prevalence of post-surgical arthritis. Advancements in arthroscopy and instrumentation have allowed for greater surgical reliability and reproducibility and firmly established ACL reconstruction as one of the most successful procedures in orthopaedic surgery.

Introduction

This is the first part of a two part article on The story of anterior cruciate ligament reconstruction. It is concerned with the historical developments surrounding the ligament’s discovery, the acknowledgement of its function and the appreciation of the detrimental effects once it becomes damaged. It also describes the efforts of the early pioneers who recognised the need to re-establish ligament function by ways of ligament repair or reconstruction with autologous tissue. The second part will be presented in the next issue of the journal and will explore the surgeons’ quest to find the ideal graft material by experimenting with various synthetic materials, as well as those derived from animals (xenografts) and other human beings (allografts). It will look at attempts to stabilise an unstable knee by means of extra-articular reinforcements which were popular until not too long ago and review the developments of the various graft fixation methods available today. Furthermore it will evaluate the influence of arthroscopy which revolutionised not just the procedure of ACL reconstruction, and place particular focus on new developments including double bundle techniques and mapping the ligaments anatomic footprint.

From Galen to the 19th century

Although the cruciate ligaments owe their name to the Greek physician Galen of Pergamon (131-201 BC), they received little attention in the scientific world until the 19th century (Galen 1968) (Figure 1). In 1836 the German scientist Wilhelm (1806-1871) and Eduard Weber (1804-1891) not only described the exact anatomical location of the cruciate ligaments but also discovered that the anterior cruciate (ACL) was made-up of two distinct fibre bundles (Weber & Weber 1836) (Figures 2 & 3). Through experiments they further discovered that cutting of the ACL would lead to abnormal knee movement, allowing...
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the tibia to move forward on the femur, a phenomenon which became known as anterior draw.

The first clinical presentation of an ACL injury in the English literature was provided by the Irish physician Robert Adams (1791-1875) (Adams 1847) (Figure 4). In 1837 he observed the case of a 25 year old male who injured his knee when he got into a brawl after leaving a pub. For some reason the knee became septic and the patient died. Out of curiosity Adams opened the knee and discovered that the ACL attachment had torn off the tibia.

The French surgeon Arnaud de Bonnet (1809-1858) first described the three clinical signs of acute ACL rupture in 1845: ‘In patients who have not suffered a fracture, a snapping noise, haemarthrosis, and loss of function are characteristic of ligamentous injury in the knee’ (Bonnet 1845) (Figure 5). Bonnet preferred conservative management for those injuries and advocated the application of cold packs in the acute stage. Through his own experiments he was aware of the detrimental effects of prolonged immobilisation on articular cartilage and hence encouraged early motion exercises using a sliding frame and an exercise apparatus (Bonnet 1853) (Figure 5). For patients who continued to suffer from instability he suggested wearing of a long-leg hinged brace not dissimilar in principle to modern stabilising braces. Although Bonnet’s ideas and suggestions on the treatment of acute ACL injuries were ahead of their time they received little recognition outside his home country.

In 1850 the Scottish GP James Stark (1811-1890) published two cases of cruciate tears, describing the problem of knee instability patients commonly affected by: ‘... and felt something gave way with a snap in the left knee: when raised, she found she had lost all command over the leg’ (Stark 1885). He was followed by the Greek physician Georgios Nousis (1849-1915) who in 1875 realised that the excessive mobility

Figure 1 Galen of Pergamum (131-201BC) was one of the most prominent and accomplished physicians of antiquity. At first he devoted himself to the study of the anatomy and performed extensive dissections on dead bodies and animals which gained him immeasurable insight into the human body and the discovery of the cruciate ligaments. Although Greek by birth he travelled extensively and settled in Rome where he became physician to the emperor. Amongst Galen’s discoveries is that arteries are filled with oxygenated blood and that the brain controls all the motions of the muscles by means of the cranial and peripheral nervous systems.

Figure 2 Wilhelm Eduard Weber (1800-1871), pictured on the left, was Professor of Physiols in Göttingen whilst his brother Eduard Friedrich (1804-1891), was a Professor of Anatomy in Leipzig. Both brothers collaborated on many projects but their treatise on the mechanics of the human walking apparatus, which represented the first description of human biomechanics, remains their most famous work. They recognised the complex anatomical nature of the cruciates and their importance in providing joint stability (Images courtesy of Universitätsbibliothek Leipzig).

Figure 3 Cross sectional drawing by the Weber brothers of the internal knee ligaments showing intricate detail of the anterior cruciate ligament and its attachment sites (Weber & Weber 1836)

Figure 4 Illustration from Adams’s chapter on ‘Abnormal conditions of the knee joint’ showing the first confirmed case of ACL rupture. Robert Adams (1791-1875) was born in Ireland in 1791 and studied at Trinity College in Dublin from which he received a BA in 1814. He was founder of the Cork Michael School of Medicine and became Surgeon Ordinary to Her Majesty Queen Victoria in Ireland, a post to which considerable prestige was attached. Adams had an enquiring mind and was fascinated by performing post mortem examination in order to define the cause of death. He published a wide range of topics but most famously on heart disease and gout, the latter of which he was affected by himself. In 1839 he observed the first documented case of a cruciate ligament rupture. His name is given to Stoke-Adams Disease, a transient episode of syncope often caused by ventricular fibrillations.
Experimenting on human cadavers in the late 19th century helped clinicians to understand the impact that extremes of movement might exert on the ACL.

of the tibia following ACL rupture was most noticeable when the leg was near full extension (Noulis 1875). Almost 100 years later this phenomenon and its association with ACL deficiency was rediscovered by the US surgeons Ritchie and Torg and utilised in the creation of the Lachman test. The test, which was dedicated to John Lachman of Philadelphia, has since become one of the most popular clinical manoeuvres in the assessment of ACL integrity (Ritchie 1960, Torg et al 1976).

Experimenting on human cadavers in the late 19th century helped clinicians to understand the impact that extremes of movement might exert on the ACL. The Viennese Leopold Dittel (1815-1896) observed that the ACL either tore close to its femoral insertion, or avulsed with a fragment of bone of the tibia (Dittel 1876). Dittel also noted the common association between tearing of the ACL, medial collateral ligament (MCL) and meniscal, a pattern of injury, which in the 1950s became known as the ‘Unhappy Triad of O’Donoghue’ (O’Donoghue 1950) (Figure 6).

The French surgeon Paul Segond (1851-1912) summed-up the key physical signs associated with ACL injuries in 1876 as ‘strong articular pain, frequent accompanying pop, rapid joint effusion and abnormal anterior-posterior movement of the knee on clinical examinations’ (Segond 1879). Segond also described the so-called ‘Segond Fracture’, a small bony avulsion on the lateral tibial plateau, commonly associated with an ACL tear.

In the intervening years before the First World War, a number of famous anatomists and physiologist further advanced our knowledge on the importance of the functional unit of ACL and PCL in providing normal rolling, gliding and sliding motion of femur on tibia. Clinicians gradually became aware that any disturbance of this unit would disrupt this mechanism, and create un-physiological movement patterns likely to lead to joint degeneration (Meyer 1853, Zuppinger 1904, Fick 1911, Strasser 1917).

Direct ligament repair

In the 19th and early 20th century clinicians showed general reluctance to consider surgery for cruciate ligament injuries as both morbidity and mortality associated with surgery was high and in the absence of anti microbial agents, joint sepsis was commonly encountered. Sir Arthur Mayo-Robson of Leeds (1853-1933) was bold enough to become the first surgeon to repair a torn ACL.

Figure 5 Amedee Bonnet (1809-1858) was born in France in 1809. He attended medical school in Paris and went on to become Professor of surgery at the University of Lyon, a position he held until his death. In 1845 he published the first part of his Traité de thérapeutique des maladies articulaires. This seminal work on the treatment of joint disorders anticipated many aspects of modern conservative management including the need for joint aspiration in cases of purulence to release pus as well as the benefits of elevation and cold application following sprains. Bonnet was aware that articular cartilage degrades when the joint is immobilised for too long and advocated the early use of a motion apparatus. He showed an amazing understanding of the consequences of cruciate ligament injuries, their assessment and clinical signs. Although ahead of his time with many of his ideas, Bonnet failed to achieve wider appreciation as most of his work was only translated into some Continental languages. The right image shows apparatus used by Amedee Bonnet in 1853 to encourage early mobilisation following ACL injury.

Figure 6 Drawing of a knee specimen used in Dittel’s experiments showing a tear to the ACL and MCL and damage to the medial meniscus (Dittel 1876).

Figure 7 Sir Arthur Mayo-Robson (1853-1933) a Yorkshire man who worked for 10 years as demonstrator in anatomy following his qualifying from Leeds medical school in 1870. He soon obtained a professorship and in 1892 decided to leave Leeds for London, Lord Moynihan called him ‘indisputably one of the greatest surgeons in Europe’ and it was hence not surprising that he received a knighthood in 1908. For Mayo-Robson there was hardly a field that he did not adorn. Most of his scientific contributions focussed on abdominal surgery, nerve grafting and surgery of the extremities and he became the first surgeon to attempt the repair of a torn cruciate by direct suture.
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ACL in a 41 year old miner in 1897 (Mayo-Robson 1903) (Figure 7). He was followed by William Battle who performed a similar procedure in 1899 although his publication predates that of Mayo-Robson's (Battle 1900). Following surgery, knees were commonly immobilised in a Plaster of Paris for up to 12 weeks and it was hence not surprising that they often failed to regain a full range of motion. Critics like MacGuire of New York believed that surgical repair could not give any benefit other than that derived from the period of immobilisation following operation' (MacGuire 1926).

By 1913 Hubert Goetjes of Cologne was able to trace a total of 30 cases of ACL rupture in the available scientific literature most of which were still treated conservatively (Goetjes 1913). He recognised the problems of chronic instability associated with conservative management and hence recommended suture repair of the torn ligament. He was also the first surgeon to suggest examination under anaesthesia when the clinical diagnosis was uncertain.

Repairing a torn ligament in the centre of the knee posed difficulties to most surgeons and results were often unpredictable. In 1926 Georg Perthes of Tübingen (1869-1927), better known for his description of femoral head necrosis in children, suggested a new repair method which became the standard technique worldwide (Perthes 1926) (Figure 8). Perthes attached a wire suture to the ligament which he pulled through drill holes in the femur and secured by twisting the wire across a bony bridge. Perthes believed in early intervention and was critical of his colleagues who only considered ACL repair once conservative management had failed.

Figure 8 Georg Clemens Perthes (1869-1927) studied in Bonn under Trendelenburg. He spent one year as a military surgeon on an expedition to China and after his return took up position of Professor of Orthopaedics first at Leipzig and later at Tübingen University. Perthes was a well educated man with many interests but is probably best remembered for his description of femoral head necrosis in children, a disease which carries his name. He also introduced radiotherapy for the treatment of skin and breast cancer. In recognition of the difficulties to reconnect stumps of the torn cruciate he introduced trans-cortical wire sutures. This technique provided for a more reliable ligament repair and remained in use for over 60 years (With kind permission of Wolther de Gryster, Berlin).

Figure 9 Don O'Donoghue (1901-1992) who was Professor of Orthopaedics at the University of Oklahoma, lent legitimacy to the early efforts of Sports Medicine. His book ‘Treatment of Injuries in Athletes’ published in 1942 was the first text book on sports medicine for the orthopaedic practitioner and became a worldwide success. He pioneered acute ligament repair but was equally enthusiastic about rehabilitation of the injured knee.

Figure 10 Ernest William Hey Groves (1874-1944) the son of a civil engineer was born in India but moved to Bristol at the age of 3. He obtained a BSc in engineering in 1890 planning to follow in his father’s footsteps, but changed his mind when he was granted a scholarship to St Bartholomew’s Hospital. To advance his knowledge he spent one year in Tübingen with Perthes and others before taking up the position of GP in Somerset. Finding no scope for his talents he turned his attention to orthopaedic surgery. Hey Groves had an enquiring personality and ingenious mind which made him one of the foremost surgeon inventors of his time, designing various surgical instruments, external fixators, a surgeon friendly operating table, and the first functional hip arthroplasty. Hey-Groves recognised that a cruciate ligament once torn had little or no ability to heal and most repairs were futile. His contributions to cruciate ligament surgery, bone healing and fracture care have since become legendary. Even after retiring from active surgery he continued his involvement in editing the British Journal of Surgery which he had founded together with Lord Moynihan in 1913. Image on the left is showing Hey-Groves’ original ACL reconstruction technique first published in 1917 (With kind permission of The Lancet, London).
ACL repair received a massive boost in the US in the 1950s through Don O’Donoghue of Oklahoma (1901-1992)

Figure 11. Hey Groves’ own drawing of his revised reconstruction technique, utilizing only a section of fascia which he left attached distally to increase its length and to ease its introduction into the joint.

Erwin Payr of Leipzig (1861-1946) offered a variation to transtricular suture fixation by using a fascia strip looped through a small hole in the intercondyloid notch and tied to the ACL remnant (Payr 1927).

ACL repair received a massive boost in the US in the 1950s through Don O’Donoghue of Oklahoma (1901-1992) who published his experience in the treatment of athletes (O’Donoghue 1955) (Figure 9). Long-term results of ACL repair however did not become available until the 1970s and were generally disappointing and overshadowed by good results achieved with emerging techniques of ligament reconstruction (Feagin & Cull 1976, Engbretsen et al 1990). Subsequently intra-articular ligament repair was abandoned by most clinicians by the end of the 1980s.

ACL reconstruction with autologous tissue

Although it is not entirely clear who performed the first ACL reconstruction, the first publication on the subject appeared in 1914. Ivan Grekov (1867-1934) a surgeon from St Petersburg encountered a 40 year old man who had dislocated his knee and torn his ACL. Grekov used a free strip of iliotibial band (ITB) which he placed through a drill hole in the femur and connected to the ACL remnant with apparently good results. Around the same time Max zur Verth of Hamburg also experimented with ITB for replacing the torn ACL, but no formal report of his technique exists (Hölzeit 1917).

The first properly documented reconstruction is credited to Ernest Hey Groves of Bristol (1872-1944), who in 1917 used the entire ITB, which he detached from Gerdy’s tubercle, passed through tunnels in femur and tibia and sowed to the periosteum of the tibia (Hey Groves 1917) (Figure 10). Hey Groves believed that by leaving the tendon attached to the muscle belly, blood supply and nutrition to the tendon would be maintained. Hey Groves was already aware that proper knee joint function could only be re-established if the reconstructed ligament graft was placed in the exact anatomic position of the original.

Figure 12. Kaspar Niederecker of Würzburg was a passionate supporter of using menisci for the reconstruction of ACLs during the 1950s. In his technique the medial meniscus was fashioned into a loop and connected to the lateral condyle with trans-femoral sutures. With kind permission of Hans Marseille Verlag, Munich (Niederecker 1957).
ACL 'in contradistinction to a mere passage of new ligaments across the joint' (Hey Groves 1920). He also anticipated the importance of oblique graft placement to improve rotational stability, a fact which took over 80 years to be widely recognised (Loh et al 2003). Hey-Groves made a particular point of describing the anterior-lateral subluxation of the tibia, a phenomenon which was later used by MacIntosh & Galway to devise the pivot-shift test, a sensitive diagnostic assessment tool to identify ACL incompetence (Galway et al 1972).

In 1918 the Welsh surgeon Alwyn Smith (1884-1931) proposed a modification to the Hey Groves technique, using only a section of the ITB which he detached from its muscle belly, pulled through femoral and tibial tunnels and placed over the medial joint space to reinforce the MCL (Smith 1918). Hey Groves later adopted Smith's variation on his earlier technique but dropped the medial re-enforcement, thereby creating an operation very similar to modern ACL reconstruction (Hey Groves 1920) (Figure 11). ACL surgeries in first half of the 20th century were challenging procedures which, in the words of Sir Robert Jones 'are usually grave and require the highest craftsmanship, and should never be undertaken without a sense of grave responsibility' (Jones & Lovett 1923).

Although ITB remained a popular choice as ACL graft until the end of the 20th century (Insall 1981), surgeons started to experiment with many other autologous tissues, namely patellar, quadriceps and hamstring tendons as well as meniscus and cuts (Hölzel 1917, Wittke 1927, Anderson 1956, Blauth 1984). In 1917 Max zur Veth replaced the ACL of a soldier with the torn lateral meniscus (Hölzel 1917). Meniscus was often seen as a disposable structure which if torn was commonly removed. It hence appeared logical to utilise it as suitable graft material (Wittke 1927, Niederecker 1957, Tillberg 1977) (Figure 12). Knowledge of the importance of the meniscus and the consequences of its removal eventually prompted a shift in opinion and meniscus was virtually abandoned as graft material by the end of the 1970s (Fairbank 1948, Walsh 1972, Maletius & Messner 1996).

Figure 14 ACL reconstruction with extensor fascia and patellar tendon according to Campbell. With kind permission of Elsevier, Philadelphia (Campbell 1936).
The idea to replace the torn ACL with hamstring tendons was created in 1926 through the work of the Scottish surgeon Alexander Edwards.

The use of patellar tendon to replace the ACL was first entertained by the American Mitchell Langworthy (1891-1929), who unfortunately never published on his method and sadly suffered an untimely death when he became the victim of a bullet from an unhappy patient in his private practice in 1929 (Eikenberg 1927). Four years later zur Verth reported on the successful treatment of chronic ACL-deficient knees with a strip of the patellar tendon he had left attached to the tibial tubercle (zur Verth 1933). Wittke of Graz used the ‘Zur Verth Technique’ in the following years and expressed satisfaction with the patients’ clinical performance (Wittek 1935). In 1936 Willis Campbell of Memphis (1880-1941) published his operative guide to ACL surgery and coined the term ‘giving way’, in describing the distressing sign of knee instability (Campbell 1936) (Figure 13). As ACL graft he utilised a combination of extensor retinaculum and patellar tendon (Figure 14). Like Smith, Campbell also recommended simultaneous reinforcement of the medial collateral ligament if it appeared damaged.

Kenneth Jones became, together with William Clancy, the major proponent of patellar tendon in the US (Jones 1963, Clancy 1985). In the early 1960s Jones started using the central third of the tendon, which he passed "beneath the fat pad" into the femoral tunnel. As the graft was generally shorter than a normal ACL, the tunnel had to be brought forward, away from the anatomical foot-print of the ligament. This created an extremely non-physiological graft placement and was responsible for the relatively disappointing long-term results (Jones 1980). His technique nevertheless gained widespread popularity, and patellar tendon ACL reconstruction became known as the ‘Jones Procedure’ (Lam 1968).

Helmut Brückner of Germany recognised the shortcomings of Jones’s technique (Brückner 1966). To overcome problems of insufficient graft length, he routed the patellar tendon through a tibial tunnel, thereby gaining enough distance to position the femoral tunnel at the anatomic footprint. In Sweden the group of Broström and Gillquist introduced a similar technique, but instead using a femoral tunnel, the tendon graft was secured against the femoral footprint with trans-osseous sutures (Broström et al 1968) (Figure 15). As an alternative to a pedicled graft, Brückner also introduced free bone-patellar-tendon-bone, which was to become one of the most popular graft choices in ACL surgery (Brückner 1966, Pietruch et al 1969, Franke 1976, Clancy 1985).

Harvesting of the patellar tendon graft however was not without morbidity (e.g. patellar tendinopathy, anterior knee pain), prompting some surgeons to consider quadriiceps tendon as alternative graft material (Sachs et al 1989, O’Brien et al 1991, Aglietti et al 1993). It was first used by Walter Blauth in Germany in 1984, but it was not until John Fulkerson of Connecticut started promoting quadriiceps ACL reconstruction in the mid 1980s, that it became recognised as a suitable alternative by a wider audience (Blauth 1984, Fulkerson & Langeland 1995). Although quadriiceps never achieved the popularity of patellar or hamstring grafts it continues to occupy a fringe position and is often considered in revision situations or when other graft sources are unavailable (DeAngelis & Fulkerson 2007, Garofalo et al 2006).

The idea to replace the torn ACL with hamstring tendons was created in 1926 through the work of the Scottish surgeon Alexander Edwards who published an operation he had performed on a cadaver (Edwards 1926). His idea was picked up by the Italian Riccardo Galeazzi (1866-1952), who in 1934 pioneered anatomic ACL reconstruction with pedicled semitendinosus tendon based on Hey-Groves original technique (Galeazzi 1934) (Figure 16). He was followed in 1939 by Harry Macey (1905-1981) staff surgeon at the Mayo Clinic, who introduced the procedure in the US (Macey 1939). The 1950s saw a variety of different techniques emerge, most notably the ‘Lindemann Procedure’. By using proximally based gracilis tendon, Lindemann (1901-1966) preserved the tendon and muscle unit, which he believed would work as a dynamic stabiliser, preventing anterior subluxation of the tibia (Lindemann 1950). He reported on 14 of his patients, 11 of which achieved a good result. Robert Augustine, unaware of Lindemann’s publication, developed almost identical procedure but proposed to use the stronger semitendinosus tendon instead (Augustine 1956) (Figure 17).

It was however not until 1975, when Kenneth Cho rediscovered the use of distally based semitendinosus routed through tibial and femoral tunnels, that...
hamstrings became recognised as suitable ACL reconstruction grafts particularly in the US (Cho 1975). The real breakthrough for hamstrings as ACL graft came in 1982 with Brant Limpscomb, who started using both semitendinosus and gracilis tendon as a double strand (Limpscomb 1982). Marc Friedman followed in 1988, pioneering arthroscopically assisted four-stranded hamstring, a technique which continues to be used today (Friedman 1988). Recent clinical studies comparing hamstrings with patellar tendon revealed little difference with regard to knee function and the prevalence of osteoarthritis (Holm et al. 2010). Because of their excellent safety profile and low level of harvesting morbidity, hamstring tendons have become one of the most popular graft sources in the reconstruction of the ACL of all times.

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