Information about authors:

Liabakh Andrii Petrovych – D.Med.Sc., professor, head of the Department of Foot Pathology and Complex Prosthetics, SI "Institute of Traumatology and Orthopedics of NAMS of Ukraine", 27 Bulvarno-Kudriavska St., Kyiv, 01601, Ukraine. ORCID: 0000 0001 5734 2392.

Lazarenko Halyna Mykolaivna – Ph.D. in Medicine, the Department of Foot Pathology and Complex Prosthetics, SI "Institute of Traumatology and Orthopedics of NAMS of Ukraine", 27 Bulvarno-Kudriavska St., Kyiv, 01601, Ukraine.

Piatkovskyi Volodymyr Mykhailovych – Ph.D. in Medicine, the Department of Foot Pathology and Complex Prosthetics, SI "Institute of Traumatology and Orthopedics of NAMS of Ukraine", 27 Bulvarno-Kudriavska St., Kyiv, 01601, Ukraine.

Сведения об авторах:

Лябах Андрей Петрович – доктор медицинских наук, профессор, заведующий отделом патологии стопы и сложного протезирования ГУ "Институт травматологии и ортопедии НАМН Украины", ул. Бульварно-Кудрявская, 27, Киев, 01601, Украина. ORCID: 0000 0001 5734 2392.

Лазаренко Галина Николаевна – кандидат медицинских наук, сотрудник отдела патологии стопы и сложного протезирования ГУ "Институт травматологии и ортопедии НАМН Украины", ул. Бульварно-Кудрявская, 27, Киев, 01601, Украина.

Пятковский Владимир Михайлович – кандидат медицинских наук, сотрудник отдела патологии стопы и сложного протезирования ГУ "Институт травматологии и ортопедии НАМН Украины", ул. Бульварно-Кудрявская, 27, Киев, 01601, Украина.

Для кореспонденції: Лябах Андрій Петрович, доктор медичних наук, професор, завідувач відділу патології стопи та складного протезування ДУ "Інститут травматології та ортопедії НАМН України", вул. Бульварно-Кудрявська, 27, Київ, 01601, Україна. Тел. +38(097)9010364. E-mail: **anliabakh@gmail.com.**

For correspondency: Liabakh Andrii P., D.Med.Sc., professor, head of the Department of Foot Pathology and Complex Prosthetics, SI "Institute of Traumatology and Orthopedics of NAMS of Ukraine", 27 Bulvarno-Kudriavska St., Kyiv, 01601, Ukraine. Tel. +38(097)9010364. E-mail: **anliabakh@gmail.com.**

Для корреспонденции: Лябах Андрей Петрович, доктор медицинских наук, профессор, заведующий отделом патологии стопы и сложного протезирования ГУ "Институт травматологии и ортопедии НАМН Украины", ул. Бульварно-Кудрявская, 27, Киев, 01601, Украина. Тел. +38(097)9010364. E-mail: **anliabakh@gmail.com.**

УДК: 616.728.3-018.38-001.5-089.844(048.83)(091)
DOI: 10.37647/0132-2486-2020-105-2-17-25

ACL Reconstruction: Problems, History and Future.
Part 1

Zazirnyi I.M.[1], Kostrub O.O.[2]

[1]Clinical Hospital "Feofaniya" of the Agency of State Affairs, Kyiv
[2]SI "Institute of Traumatology and Orthopedics of NAMS of Ukraine", Kyiv

Summary. *Damage to the anterior cruciate ligament (ACL) of the knee joint is a common injury in sports medicine. Before advances in arthroscopy and surgical techniques, an ACL damage was considered a career ending injury for many athletes. Since the 1990s, there has been a rapid* *development of arthroscopic surgery for ACL and continuous improvement of these techniques. Today's athletes can expect a pre-injury level of stability and function after an ACL reconstruction. Modern surgical interventions have come a long way, having studied both the successes and failures of previous surgical techniques. In the United States, an ACL damage is diagnosed annually from 100,000 to 200,000 cases, making this the most common ligament injury [9, 10]. This number continues to increase in both the general population and in individuals who play sports. Football players sustain the greatest number of ACL injuries (53% of the total), with skiers and gymnasts also at high risk. The history of ACL reconstruction can be traced as far back as the Egyptians times. Research and innovation are constantly evolving, and this leads to improved clinical results. The knowledge of the evolution of ACL reconstruction is invaluable to those who continue to try to improve the outcomes of the procedure and reduce the risks of repeating mistakes of the past.*

***Key words**: ACL; reconstruction; anatomy; biomechanics; arthroscopy.*

Introduction

Damage to the ACL of the knee joint is a common injury in sports medicine. Before advances in arthroscopy and surgical techniques, an ACL damage was considered a career ending injury for many athletes. Since the 1990s, there has been a rapid development of arthroscopic surgery for ACL and continuous improvement of these techniques. Today's athletes can expect a pre-injury level of stability and function after an ACL reconstruction. Modern surgical interventions have come a long way, having studied both the successes and failures of previous surgical techniques. An ACL injury is one of the most commonly seen injuries in sport and has a devastating influence on activity levels of patients and quality of life.

ACL injuries account for anywhere between 25 and 50% of ligamentous knee injuries [1] and pose unique clinic problems because of their poor capacity to undergo biological healing due to the local intra-articular conditions.

Gottlob et al. [2] estimated that approximately 175,000 primary ACL reconstruction surgeries were performed annually in the USA with an estimated cost of over US $2 billion. Complete ACL rupture can induce other pathological knee conditions including knee instability, damage to menisci and the chondral surface, and osteoarthritis. Studies have repeatedly shown that patients with complete ACL rupture have chronic knee instability and secondary damage to menisci and chondral surfaces [3].

Approximately 70% of ACL injuries are noncontact injuries, and the remaining 30% are contact injuries [4]. A deceleration event and a sudden change in direction with a planted foot (i.e. cutting maneuver) is the most common mechanism of non-contact ACL injury [5].

ACL injuries that occur without physical contact between athletes, are referred to as non-contact ACL injuries, and occur through a non-contact mechanism of injury in sports in which sudden deceleration, landing and pivoting maneuvers are repeatedly performed [6].

Female athletes had a higher incidence of ACL injuries compared with their male counterparts. Studies have shown that the incidence in female athletes is two to eight times higher than in males in soccer, basketball, and volleyball [7, 8].

In the United States, an ACL damage is diagnosed annually from 100,000 to 200,000 cases, making this the most common ligament injury [9, 10]. This number continues to increase in both the general population and in individuals who play sports. Football players receive the greatest number of ACL injuries (53% of the total); skiers and gymnasts are also at high risk [11].

Anatomy

The ACL is attached medially to the anterior intercondylar area of the tibia, partially connecting to the anterior horn of the lateral meniscus; it ascends posterolaterally, twisting on itself and fanning out to attach to the posteromedial surface of the lateral femoral condyle. It is anterolateral to the posterior cruciate ligament [12].

It is suggested that the ACL can be divided into two functional and anatomic separate bundles: the anteromedial (AM) and the posterolateral (PL) bundles. This classification is based on their tibial insertion sites, and this division can be achieved by the varying orientation and tensioning patterns of the fibers during knee range of motion [13, 14].

Cruciate ligaments consist of a highly organized collagen matrix, which accounts for approximately three fourths of their dry weight. Collagen type I (90%), type III (10%). In the ACL, the collagen is organized into multiple fiber bundles 20 μm that are grouped into groups 20–400 μm in diameter. Occasional fibroblasts and other substances, such as elastin (5%) and proteoglycans (1%), compose dry weight. Water makes 60% of the net weight under physiologic conditions. At the microscopic level, ligament and tendon insertions into bone have a distinct structure consisting of collagen fibrils directly continuous with fibrils within the bone. A calcified facade, similar to that seen between osteoid and mineralized bone, can be distinguished.

The cruciate ligaments are named for their attachments on the tibia and are important to the function of the knee joint. The cruciate ligaments stabilize the knee joint and prevent anteroposterior displacement of the tibia on the femur. The existence of many sensory endings also implies a proprioceptive function. These ligaments are intraarticular; however, because they are covered by synovium, they are considered extrasynovial. They receive their blood supply from branches of the middle genicular and both inferior genicular arteries [15].

The ACL originates from the medial surface of the lateral femoral condyle posteriorly in the intercondylar notch in the form of the segment of a circle. The anterior side of the attachment is nearly straight, and the posterior side is convex. The ligament courses anteriorly, distally, and medially toward the tibia. Over the length of its course, the fibers of the ligament undergo slight external rotation. The average length of the ligament is 38 mm and the average width 11 mm. About 10 mm beneath the femoral attachment, the ligament stands out, as it proceeds distally to the tibial attachment, which is a wide, depressed area localized anterior and lateral to the medial tibial tubercle in the intercondylar fossa. The tibial attachment is oriented in an oblique direction and is wider than the femoral attachment. There is a well-marked slip to the anterior horn of the lateral meniscus [15]. In summary, proximal to distal, the anatomic centrum of the ACL femoral footprint, as a whole, is 43% of the distance from the proximal articular cartilage margin to the distal articular margin. Such a line can be identified and quantitated arthroscopically [16].

On MRI, the ACL is best visualized on sagittal images. Because of its oblique course, the ACL should routinely be imaged on two or three sagittal sections. A normal ACL has a relatively low signal, but toward the distal insertion, the ACL may appear linear. The specificity of the examination is higher in the sagittal level compared to that in the coronal level, and it is better imaged in the T2 sequence. A rupture in the fibers or a soft tissue mass in the notch with high-signal characteristics resulting from edema and hemorrhage indicates an ACL tear. Partial ACL tears may be imaged by increased signal, thickening or redundancy in the ligament. However, accurate diagnosis of partial injuries remains challenging. Arthroscopic evaluation of the ACL remains the gold standard for assessing suspected partial and complete tears [14, 15].

Biomechanics

The ACL is the main static stabilizer against anterior translation of the tibia on the femur and accounts for up to 86% of the total force resisting anterior draw. At different stages of knee motion, distinct parts of the ACL appear to differently stabilize the knee joint. Clinical studies have not revealed distinct bundles, so that the bundles seem to be more functional, rather than anatomical structures. The anteromedial bundle becomes strained at 90 degrees of flection, and the posterolateral bundle becomes strained as full extension of the knee joint is approached. The ACL also plays a lesser role in resisting internal and external rotation. The maximum tensile strength of the ACL is approximately 1.725±270 N, which is less than the maximum force that occurs in vigorous athletic activities. Stability is enhanced by dynamic stabilizers, such as the muscles that apply a force across the knee joint. For the muscles to aid in protective stabilization of the knee, effective proprioceptive feedback regarding joint position is crucial. It appears that the ACL plays an important proprioceptive function because a variety of mechanoreceptors and free nerve endings have been identified. In humans with ACL-deficient knees, a significantly higher threshold for detecting passive motion of the involved knee has been suggested. The afferent and efferent signals concerning the ACL are carried by branches of the posterior tibial nerve [14].

These complex anatomies make the ACL particularly efficient for limiting excessive anterior tibial translation as well as axial tibial and valgus knee rotations. Laboratory studies have determined load-elongation curve of a bone-ligament-bone complex by a uniaxial tensile test. The stiffness and ultimate loads are appropriate to represent the structural properties. In the same test, a stress–strain relationship can also be obtained, from which the modulus, tensile strength, ultimate strain, and strain energy density can be measured to represent the mechanical properties [15].

The ultimate aim of an ACL reconstruction is to restore the function of the intact ACL. Laboratory studies on human cadaveric knee designed to test the effectiveness of an ACL reconstruction under clinical maneuvers, that is, anterior drawer and Lachman test, reveal that most of the current reconstruction procedures are satisfactory during anterior tibial loads. However, they fail to restore both the kinematics and the *in situ* forces in the ACL under rotatory loads and muscle loads [14, 15, 17, 19].

The Early Years History

The cruciate ligaments have been known about since old Egyptian times, and their anatomy was described in the famous Smith Papyrus (3000 BC). Hippocrates (460–370 BC) also mentioned the subluxation of the knee joint with ligament pathology, but Claudius Galen, a Greek physician in the Roman Empire, was the first to describe the true nature of the ACL.

Prior to Galen's description, it was believed that the cruciate ligaments were part of the nervous system, but Galen was the first to describe the ACL as being a structure that supports the joint and prevents abnormal knee motion. He called the cruciate ligaments *genu cruciata*, but he did not describe in detail their function [19].

In 1836, the Weber brothers from Goettingen in Germany noted an abnormal anterior-posterior movement of the tibia after transection of the ACL. They also described the roll and glide mechanism of the knee and the tension pattern of the different bundles of the cruciate ligaments and, to our knowledge, were the first to describe that each bundle of the ACL was tensioned in different degrees of flexion of the knee joint [19].

In 1845, Amade Bonnet (1809–1858) of Lyon, France, published his first cadaveric studies for the mechanism of knee ligament injuries in his treatise on the treatment of joint diseases. The first recorded description of rupture of the ACL, however, was done by Stark in 1850 [19].

In 1875, the Greek Georgios C. Noulis [6] described the technique of the Lachman test for the first time. He wrote: “Fix the thigh with one hand, while with the other hand hold the lower leg just below the knee with the thumb in front and the fingers behind. Then, try to shift the tibia forward and backward. When only the anterior cruciate ligament is transected, this forward movement is seen when the knee is barely flexed, whereas a backward movement is noted in 110 degrees of flexion when the posterior cruciate ligament is transected.” His 110 degrees of flexion would translate into 70 degrees of flexion today, since at that time they used 180 degrees as full extension.

In 1879, Paul Segond described an avulsion fracture of the anterolateral margin of the *tibial plateau*. This is routinely associated with an ACL disruption. This fracture is now known universally as the Segond fracture and is considered pathognomonic for an ACL tears.

In 1900, Battle first reported an ACL repair. It was done two years earlier during treatment for dislocation of the knee. The results were satisfactory. No further description was made [19]. Battle published the first report and Mayo-Robson performed the first repair.

In 1903, he reported the repair of both cruciate ligaments of the knee in a 41-year-old miner. A diagnosis of rupture of the anterior and posterior cruciate ligaments was made. Further arthrotomy revealed that the ligaments had been avulsed from their femoral attachments, and they were duly repaired with catgut sutures. After some weeks of cast immobilisation, the knee was allowed to move; six years postoperatively, the patient reported the knee to be “perfectly strong” [9].

Mayo-Robson felt that this case should be published and that surgical repair was both “feasible and hopeful.” Yet later in 1903, Fritz Lange of Munich attempted to replace an ACL using braided silk attached to the semitendinosus as a ligament substitute. This ultimately failed. The importance of the ACL was recognized by Fick as early as 1911 [20].

In 1913, Goetjes produced a detailed study of ruptures of the cruciate ligaments. He discussed ligament function and mechanisms of rupture, as determined by cadaver studies. He advocated repair for the acute injury and conservative treatment for chronic ruptures. By 1916, Jones had remarked that stitching the ligaments is absolutely futile: “Natural cicatricial tissue is the only reliable means of repair.” Jones’ early observation was confirmed 60 years later by Feagin and Curl [21] when they published their long-term follow-up of West Point cadets who had had ACL repair during their college years.

They concluded: “Long-term follow-up evaluations do not justify the hope that anatomic repositioning of the residual ligament would result in healing”. Such views led to a trend away from primary ACL repair (without augmentation) and instead towards the concept of immediate reconstruction of the ACL.

Autologous Fascia Lata and Meniscal Grafts

In 1912, K. H. Giertz operated on a 13-year-old girl with a totally unstable knee. She had septic arthritis of her knee when she was one year old. First, he corrected the fixed flexion deformity of 45 degrees by an osteotomy. Two weeks later, he stabilised the knee with free transplanted strips of *fascia lata*, sutured on the medial side to the medial femoral epicondyle and to the tibial tubercle, and on the lateral side from the lateral epicondyle to the fibular head. Postoperatively, the girl was asymptomatic and did not attend for follow-up for 6 months. For all practical purposes the knee was stable [13].

In 1917, Hey Groves published a short case report on reconstruction of the ACL [22]. He detached a strip of *fascia lata* from its insertion and directed it through a tunnel in the tibia. In the following year (1918), Smith published a paper reporting on nine cases he had treated with Hey Groves’ technique. Smith was critical of the incomplete nature of the construct, which failed to strengthen the medial collateral ligament. One year later, Hey Groves presented fourteen further cases in which he modified his technique by leaving the graft attached to the tibia and detaching it superiorly, following the same route as in the previous cases. In 1920, Hey Groves was the first to state clearly that flexion and extension of the knee affect tension within the ACL [22].

The Hamstring Graft

In 1934, the Italian orthopedic surgeon Riccardo Galeazzi described a technique for the ACL reconstruction using the semitendinosus tendon. The tendon was released from its musculotendinous junction and placed intraarticularly through a 5 mm diameter bone tunnel drilled in the tibial epiphysis and a tunnel drilled through the lateral femoral condyle, where it was fixed to the periosteum. Galeazzi used three incisions: one for harvesting of the semitendinosus tendon, another for arthrotomy, and a third laterally for fixation. He used a cast for 4 weeks and partially weight bearing for 6 weeks. He reported on three cases. One patient, operated on in 1932, had a follow-up of 18 months, and the final outcome was a stable knee with full extension and only a mild reduction of flexion. Galeazzi was the first that ever published the usage of hamstrings tendon autograft in an ACL reconstruction.

In 1939 Macey reported on using the semitendinosus tendon for the reconstruction of the ACL. Only the tendinous portion of the semitendinosus muscle was harvested. During harvesting, Macey stopped short of the musculotendinous junction and attached the graft with the knee held in full extension. For many years it was believed that Macey was the first one to ever use hamstrings in an ACL reconstruction. The Orthopedic community had failed to take into consideration Galeazzi's publication 5 years earlier [19].

In 1950, Lindemann used the semitendinosus tendon as dynamic stabilizer of ACL deficient knees. Augustine reported a similar procedure [23]. In 1974, McMaster et al. used the gracilis tendon alone [24]. It was left attached distally, pulled through the tibial and femoral tunnels, and fixed to the lateral condyle using a staple.

Patellar Tendon Grafts

In 1935, Campbell reported the first use of a tibia-based graft of the medial one third of the patellar tendon, the prepatellar retinaculum, and a portion of the quadriceps tendon [25].

Campbell's technique involved the drilling of two tunnels, one in the tibia and one in the femur. The graft was sutured to the periosteum at the proximal end of the femoral tunnel. The procedure did not achieve widespread approval immediately. It was reintroduced by MacIntosh a few years later.

In 1944, Abbott noted that, in the absence of a fracture, examination of the knee joint was all too often superficial and cursory, with many ligamentous injury patterns grouped together as "internal derangements of the knee" and treated inadequately [26]. He advised that to avoid the later development of a painful, unstable joint with recurrent effusions, subsequent arthritic changes, and the attendant permanent disability, "a far greater precision in diagnosis and therapy is a necessity in a joint of such manifold complexity".

Bone-Patellar Tendon-Bone Grafts

In 1963, Jones published a new surgical technique for the reconstruction of an irreparably damaged ACL [27]. Jones commented that while the need for surgical reconstruction of an irreparably torn ACL had long been appreciated, there was a need for a satisfactory technique to address the problem. The technique described was considered simpler and more "nearly physiological" than previous techniques. Jones described his technique as having the greatest application to old injuries, whilst suggesting that surgical repair was still the procedure of choice for acute injuries. The Jones' procedure uses a medial parapatellar incision extending from one inch distal to

the patella to just distal to the tibial tubercle. After drilling of a femoral tunnel, the middle third of the patellar tendon is incised throughout its length, with the incisions continuing proximally across the patella and into the quadriceps tendon. A saw is then used to cut a triangular block of bone from the superficial cortex of the patella in line with the longitudinal incisions. The articular surface of the patella is not breached. In this manner, a graft consisting of a bone block from the patella and the central one third of the patellar tendon is created, which is still in continuity with the tibia through the tibial insertion of the patellar tendon. This graft is then passed through the femoral tunnel, embedding the patellar component of the graft within the femoral tunnel, when pulled taut patellar tendon and the skin incision are then closed. Jones reported on 11 patients who underwent this procedure with excellent clinical outcomes.

Criticism of the technique centered around the fact that because the graft was so short, the femoral tunnel had to be drilled at the anterior margin of the notch and not at the insertion of the native ACL. However, the technique was simple and caused minimal surgical trauma, and so gained widespread acceptance.

Bruckner described a similar technique in 1966, using the medial one third of the patellar tendon [28]. The graft, harvested with a patellar bone block, was left attached to the tibia and then passed through a tibial tunnel, giving the graft more working length than in Jones' technique. After being passed through the joint, the graft was then placed in a socket in the femur and secured to the lateral aspect of the lateral femoral condyle of the femur with sutures passing through a button.

By 1969, Franke had further developed the techniques described by Jones and Bruckner. Franke pioneered the use of free bone-patellar tendon-bone graft consisting of one quarter of the patellar tendon with blocks of bone derived from the patella and proximal tibia at opposite ends of the graft [29]. His graft was fixed with a wedge-like piece of bone anchored in the tibial plateau and a shell-like piece of bone implanted into the femoral condyle. Although very similar to the Jones and Bruckner techniques, this was the first description of a free graft used in this manner.

In 1979, Marshall et al. also used the central third of the patellar tendon but left it distally attached, and they added for length a strip of the quadriceps tendon, which was secured in the over-the-top position to the lateral condyle [30].

By the 1990s, the technique of using a free bone-patellar tendon-bone graft harvested from the central one third of the patella became the "Gold Standard" of treatment. This technique was broadly termed the Jones Procedure in reference to the pioneering work done by Kenneth Jones in the 1960s [27]. It was popular because it was relatively simple and because it yielded consistently good results. During this period, researchers devised the metal interference screw as a form of tibial and femoral graft fixation. Bioabsorbable interference screws soon followed.

Synthetic Grafts

Benson suggested the potential biological and biomechanical significance of pure carbon in 1971 [31]. During the 1970s and early 1980s, a group from Cardiff experimented extensively with the use of carbon implants as an agent for the induction of new tendon synthesis in animal models [32]. Jenkins argued that ”since a high proportion of the tissues of living organisms is composed of carbon compounds, it would not perhaps be surprising that implants of the pure element should be well tolerated by these tissues” [32]. Initial results were promising with new tendon being formed around the carbon grafts at three months after implantation and no obvious clinical dysfunction in an ovine model [32]. Jenkins et al. concluded that filamentous carbon is accepted in living tissues with virtually no adverse reaction and that it can be used to induce the formation of new tendon or ligament with a physical strength equal to that of the normal structure [32]. The implants were extremely well tolerated in the ovine model with regard to foreign body response, and this encouraged the Cardiff group to progress to clinical trials in the human lower limb [33]. This study included two ACL reconstructions in isolation and thirty-one combined knee ligament procedures. The two ACL reconstructions were reviewed yearly postoperatively (maximum three years), and both reported a significant improvement in the function of their knees. The only complication documented in this preliminary report was of sinus formation overlying graft material in two ankles where the graft was considered too superficial. No complications were reported in the knee group.

In 1983, Rushton et al. reported the clinical, arthroscopic, and histological findings in ten knees that had undergone an ACL reconstruction using a carbon-fibre graft [34]. Carbon-fibre ACL grafts had been implanted into thirty-nine patients; ten patients had experienced pain and discomfort postoperatively. All ten patients had synovitis with evidence of carbon fibre in the joint. Occasionally, the fibre stained the articular surface and menisci. The femoral notch of some patients contained inflamed synovium. Such synovium was stained black. In some patients a “new ligament” appeared to have formed, but gentle probing with a blunt hook revealed this to be a thin, fibrous sheath covering unchanged carbon-fibre graft. Histologically two patients demonstrated a fibroblastic response to the carbon fibre. Five patients showed evidence of chronic synovial inflammation, and papillary proliferation of the synovium was present in all ten knees. A mild foreign-body giant-cell reaction to the carbon-fibre filaments and hemosiderin was seen in surface cells of the synovium, in macrophages, and around some fragments of carbon fibre. Other complications included ulceration of the skin over subcutaneous carbon-fibre knots used to secure the graft, similar to the findings of the Jenkins study three years earlier [33].

The Use of an Allograft

During the 1980s, a remarkable interest developed in the use of allograft tissue for an ACL reconstruction. The first experimental published studies concerning the mechanical, biological, and functional properties [35–37] were compensatory, and this led sports medicine surgeons to adopt allografts in an ACL reconstruction in humans.

In 1983, Webster and Werner conducted a study on dogs where they harvested flexor tendons from the forepaws and hind-paws of mongrel dogs [35]. These tendons were freeze-dried and then thawed, rehydrated, and implanted in recipient dogs as an ACL substitute graft. The purpose of the study was to ascertain whether or not freeze-dried grafts functioned as well as autografts over time. The use of allografts in theory would decrease the surgical morbidity associated with autograft harvest and would also allow for more precise graft size, shape, and quantity to be implanted than would an autograft. Webster and Werner reported preliminary results similar to those for patellar tendon graft for graft strength and similar to normal the ACL for mode of failure.

In 1985, Curtis et al. reported on a similar study, where freeze-dried fascia lata grafts were implanted in dogs as an ACL substitute graft [36]. All grafts were found to be intact at sacrifice with no overt evidence of biological incompatibility. The knees displayed only mild instability to clinical testing without evidence of arthrosis. Histologically, the grafts appeared to function as collagenous scaffolding for revascularization and fibrovascular creeping substitution. Shino et al. echoed these findings. They found no significant differences between the mechanical properties of allografts and autografts and also reported no evidence of implant rejection.

In 1986, Nikolaou et al. seemed so sure of the future of freeze-dried allografts that they attempted to design and implement an experimental model for testing the feasibility of cryopreserved an ACL allotransplantation. Groups of dogs were used to evaluate the effect of cryopreservation on ligament strength and to compare the relative performance of both autograft and allograft ACL transplants up to 18 months after implantation. The ligaments were examined mechanically, histologically, and microangiographically. They reported that the cryopreservation process and duration of storage had no effect on the biomechanical or structural properties of the ligament. The mechanical integrity of the allografts was similar to that of the autografts, with both achieving nearly 90% of control ligament strength by 36 weeks.

Revascularization approached normal by 24 weeks in both autograft and allograft. No evidence of structural degradation or immunological reaction was seen. Based on these results, Nikolaou et al. believed that a cryopreserved ACL allograft could provide the ideal material for an ACL reconstruction and so outlined a surgical technique for harvesting and implanting this graft clinically.

In 1987, Jackson et al. reported disappointing results of implanted freeze-dried bone-ACL-bone graft in goats [37].

By 1991, however, the same group reported much better results in a similar trial whereby the graft material was frozen *in situ* and then subjected to a freeze-thaw process whereby the graft material was devitalized and devascularized prior to harvesting [38]. This resulted in a significant increase in graft strength and a decrease in knee laxity at six weeks and six months. The authors deduced that the loss of strength seen in allografts postoperatively was not a result of the freezing and revascularization process, but rather the consequence of improper orientation and tensioning of the graft. They concluded that techniques of implantation that precisely provide proper orientation and tensioning of the graft might minimize the loss of strength.

During the 1980s, techniques for arthroscopic ACL reconstruction were becoming increasingly popular. There were two distinct schools of thought with regard to this. Some surgeons preferred the outside-in method, where the ligament is routed into the joint through a femoral tunnel [39, 39]. Yet other surgeons preferred the inside-out technique, where the ligament is routed from inside the joint into a femoral socket [41]. Despite the differing techniques, the 1980s were a time when arthroscopic ACL reconstruction became popularized, leading to a much better understanding of the ligament and its sites of attachment.

Conflict of interest. The authors declare no conflict of interest. This publication has not been, is not and will not be the subject of commercial interest in any form.

References

1. Risberg MA, Lewek M, Snyder-Mackler L (2004) A systematic review of evidence for anterior cruciate ligament rehabilitation: how much and what type? Phys Ther Sport 5:125–145. https://doi.org/10.1016/j.ptsp.2004.02.003.
2. Gottlob CA, Baker CL Jr, Pellissier JM, et al. Cost effectiveness of anterior cruciate ligament reconstruction in young adults. Clin Orthop Relat Res 1999;(367):272–82.
3. Irvine GB, Glasgow MM. The natural history of the meniscus in anterior cruciate insufficiency. Arthroscopic analysis. J Bone Joint Surg Br 1992;74(3):403–5.
4. Hewett TE, Myer GD, Ford KR: Anterior cruciate ligament injuries in female athletes: Part 1. Mechanisms and risk factors. Am J Sports Med 2006; 34(2): 299-311.
5. Renstrom P, Ljungqvist A, Arendt E, et al: Non-contact ACL injuries in female athletes: An International Olympic Committee current concepts statement. Br J Sports Med 2008;42(6):394-412.
6. Boden BP, Dean GS, Feagin JA, et al. Mechanisms of anterior cruciate ligament injury. Orthopedics 2000;23:573–8.
7. Harmon KG, Ireland ML. Gender differences in noncontact anterior cruciate ligament injuries. Clin Sports Med 2000;19(2):287–302.
8. Huston LJ, Greenfield ML, Wojtys EM. Anterior cruciate ligament injuries in the female athlete. Potential risk factors. Clin Orthop Relat Res 2000;(372):50–63.
9. Buoncristiani AM, Tjoumakaris FP, Starman JS, et al. Anatomic double- bundl anterior cruciate ligament reconstruction. Arthroscopy. 2006;22: 1000–1006.
10. Freedman KB, D'Amato MJ, Nedeff DD, et al. Arthroscopic anterior cruciate Ligament reconstruction: a meta-analysis comparing patellar ten- don and hamstring autografts. Am J Sports Med. 2003; 31:2–11.
11. Pujol N, Bianchi MP, Chambat P. The incidence of anterior cruciate ligament injuries among competitive alpine skiers: a 25-year investigation. Am J Sports Med. 2007;35:1070–1074.
12. Arnoczky SP (1983) Anatomy of the anterior cruciate ligament. Clin Orthop Relat Res 172:19–25.
13. Buoncristiani AM, Tjoumakaris FP, Starman JS, Ferretti M, Fu FH (2006) Anatomic ouble-bundle anterior cruciate ligament reconstruction. Arthroscopy 22(9):1000–1006.
14. d Reider B, Marshall JL, Koslin B et al (1981) The anterior aspect of the knee joint: an anatomical study. J Bone Joint Surg Am 63:351
15. Woo SL, Wu C, Dede O, Vercillo F, Noorani S (2006) Biomechanics and anterior cruciate ligament reconstruction. J Orthop Surg Res 1:2.
16. Piefer JW, Pflugner TR, Michael D. Hwang MD, Lubowitz JH (2012) Anterior Cruciate ligament femoral footprint anatomy: systematic review of the 21st century literature. J Arthrosc Relat Surg (article in press).
17. Woo SL, Gomez MA, Seguchi Y, Endo CM, Akeson WH (1983) Measurement of mechanical properties of ligament substance from a bone-ligament-bone preparation. J Orthop Res 1:22–29.
18. Tallay A, Lim MH, Bartlett J (2008) Anatomical study of the human anterior cruciate ligament stump's tibial insertion foot- print. Knee Surg Sports Traumatol Arthrosc 16:741–746.
19. G. A. Snook, "A short history of the anterior cruciate ligament and the treatment of tears," Clinical Orthopaedics and Related Research, vol. 172, pp. 11–13, 1983.
20. H. E. Cabaud, "Biomechanics of the anterior cruciate ligament," Clinical Orthopaedics and Related Research, vol. 172, pp. 26–31, 1983.
21. J. A. Feagin Jr. , W. W. Curl "Isolated tear of the anterior cruciate ligament: 5 year follow up study," American Journal of Sports Medicine, vol. 4, no. 3, pp. 95–100, 1976.
22. "The classic. Operation for repair of the crucial ligaments Ernest W. Hey Groves, MD., F.R.C.S.," Clinical Orthopaedics and Related Research, vol. 147, pp. 4–6, 1980.
23. R. W. Augustine, "The unstable knee," The American Journal of Surgery, vol. 92, no.3, pp. 380–388, 1956.
24. J. H. McMaster, C. R. WeinertJr., P. Scranton Jr.,"Diagnosis and management of isolated anterior cruciate ligament tears: a preliminary report on reconstruction with the gracilis tendon," Journal of Trauma, vol. 14, no. 3, pp. 230–235, 1974.
25. W. Campbell, "Repair of the ligaments of the knee: report of a new operation for the repair of the anterior cruciate ligament," Surgery, Gynecology & Obstetrics, vol. 62, pp. 964–968, 1936.
26. L. C. Abbott, J. B. M. Saunders, F. C. Bost, and C. E. Anderson, "Injuries to the ligaments of the knee joints," The Journal of Bone and Joint Surgery. American, vol. 26, pp. 503–521, 1944.
27. K. G. Jones, "Reconstruction of the anterior cruciate ligament using the central one-third of the patellar ligament," Journal of Bone and Joint Surgery. American, vol. 52, no. 4, pp. 838–839, 1970.
28. H. Bruckner, "A new method for plastic surgery of cruciate ligaments," Chirurg, vol. 37, no. 9, pp. 413–414, 1966.
29. K. Franke, "Clinical experience in 130 cruciate ligament reconstructions," Orthopedic Clinics of North America, vol. 7, no. 1, pp. 191–193, 1976.
30. J. L. Marshall, R. F. Warren, T. L. Wickiewicz, and B. Reider, "The anterior cruciate ligament: a technique of repair andreconstruction,"Clinical Orthopaedics and Related Research", vol. 143, pp. 97–106, 1979.

31. B. J. Benson, “Elemental carbon as a biomaterial,” Journal of Biomedical Materials Research, vol. 5, no. 6, pp. 41–47, 1972.
32. D. H. R. Jenkins, I. W. Forster, B. McKibbin, and Z. A. Ralis, “Induction of tendon and ligament formation by carbon implants,” Journal of Bone and Joint Surgery. British, vol. 59, no. 1, pp. 53–57, 1977.
33. D. H. R. Jenkins and B. McKibbin, “The role of flexible carbon-fibre implants as tendon and ligament substitutes in clinical practice. A preliminary report,” Journal of Bone and Joint Surgery. British, vol. 62, no. 4, pp. 497–499, 1980.
34. N. Rushton, D. J. Dandy, and C. P. E. Naylor, “The clinical, arthroscopic and histological findings after replacement of the anterior cruciate ligament with carbon-fibre,” Journal of Bone and Joint Surgery. British, vol. 65, no. 3, pp. 308–309, 1983.
35. D. A. Webster and F. W. Werner, “Freeze-dried flexor tendons in anterior cruciate ligament reconstruction,” Clinical Orthopaedics and Related Research, vol. 181, pp. 238–243, 1983.
36. R. J. Curtis, J. C. Delee, and D. J. Drez Jr., “Reconstruction of the anterior cruciate ligament with freeze dried fascia lata allografts in dogs. A preliminary report,” American Journal of Sports Medicine, vol. 13, no. 6, pp. 408–414, 1985.
37. D. W. Jackson, E. S. Grood, B. T. Cohn, S. P. Arnoczky, T. M. Simon, and J. F. Cummings, “The effects of in situ freezing on the anterior cruciate ligament: an experimental study in goats,” Journal of Bone and Joint Surgery. American, vol. 73, no. 2, pp. 201–213, 1991.
38. S. M. Howell, M. P. Wallace, M. L. Hull, and M. L. Deutsch, “Evaluation of the single-incision arthroscopic technique for anterior cruciate ligament replacement: a study of tibial tunnel placement, intraoperative graft tension, and stability,” American Journal of Sports Medicine, vol. 27, no. 3, pp. 284–293, 1999.
39. F. R. Noyes, D. S. Matthews, P. A. Mooar, and E. S. Grood, “The symptomatic anterior cruciate-deficient knee. Part II. The results of rehabilitation, activity modification, and counseling on functional disability,” Journal of Bone and Joint Surgery. American, 1983, vol. 65, no. 2, pp. 163–174.

Відновлення передньої хрестоподібної зв’язки: проблеми, історія та майбутнє. Частина І

Зазірний І.М.[1], Коструб О.О.[2]
[1]Клінічна лікарня “Феофанія” Державного управління справами, м. Київ
[2]ДУ “Інститут травматології та ортопедії НАМН України”, м. Київ

Резюме. *Пошкодження передньої хрестоподібної зв’язки (ПХЗ) колінного суглоба – поширена травма в спортивній медицині. До появи артроскопії та ендоскопічних хірургічних методик пошкодження ПХЗ вважалися травмою, яка спричиняла закінчення кар’єри для багатьох спортсменів. З 1990-х років спостерігається бурхливий розвиток артроскопічної хірургії ПХЗ та постійне вдосконалення цих методик. Сьогоднішні ж спортсмени можуть очікувати відновлення стійкості та функціонування після реконструкції ПХЗ до того рівня, який вони мали до травми. Теперішні хірургічні втручання пройшли довгий шлях, вивчивши як успіхи, так і невдачі попередніх хірургічних методів. У США травми ПХЗ щорічно становлять від 100 000 до 200 000 випадків, що робить їх найпоширенішою травмою зв’язок. Ця кількість продовжує зростати як в цілому, так і серед осіб, які займаються спортом. Футболісти зазнають найбільшої кількості травм ПХЗ (53% від загальної кількості), лижники та гімнасти також мають високий ризик отримати її пошкодження. Історія реконструкції ПХЗ простежується ще з часів давніх єгиптян. Дослідження та інновації в цій галузі розвиваються безперервно, тому клінічні результати постійно покращуються. Знання еволюції реконструкції ПХЗ безцінні для тих, хто намагається поліпшити результати процедури і зменшити ризик повторення помилок минулого.*

Ключові слова*: ПХЗ; реконструкція; анатомія; біомеханіка; артроскопія.*

Восстановление передней крестообразной связки: проблемы, история и будущее. Часть I

Зазирный И.М.[1], Коструб А.А.[2]
[1]Клиническая больница “Феофания” Государственного управления делами, г. Киев
[2]ГУ “Институт травматологии и ортопедии НАМН Украины”, г. Киев

Резюме. *Повреждения передней крестообразной связки (ПКС) коленного сустава – распространенная травма в спортивной медицине. До появления артроскопии и эндоскопических хирургических методик повреждения ПКС считались травмой, которая приводит к окончанию карьеры для многих спортсменов. С 1990-х годов наблюдается бурное развитие артроскопической хирургии ПКС и постоянное усовершенствование этих методик. Современные спортсмены могут ожидать вос-*

становления стабильности и функции после реконструкции ПКС до того уровня, который они имели до травмы. Современные оперативные вмешательства прошли длительный путь, изучив как успехи, так и неудачи предыдущих хирургических методов. В США повреждения ПКС ежегодно диагностируются от 100 000 до 200 000 случаев, что делает их самой распространенной травмой связок. Это количество продолжает увеличиваться как в целом, так и среди лиц, которые занимаются спортом. Футболисты получают наибольшее количество травм ПКС (53% от общего числа), лыжники и гимнасты также имеют большой риск получить ее повреждение. История реконструкции ПКС прослеживается еще со времен древних египтян. Исследования и инновации в этой области развиваются непрерывно, поэтому клинические результаты постоянно улучшаются. Знания эволюции реконструкции ПКС бесценны для тех, кто стремится улучшить результаты процедуры и уменьшить риск повторения ошибок прошлого.

Ключевые слова: *ПКС; реконструкция; анатомия; биомеханика; артроскопия.*

Відомості про авторів:

Зазірний Ігор Михайлович – доктор медичних наук, керівник Центру ортопедії, травматології і спортивної медицини клінічної лікарні "Феофанія" Державного управління правами, вул. акад. Заболотного, 21, Київ, 03143, Україна. E-mail: zazirny@ukr.net. ORCID: hppt://orcid.org/0000-0001-7890-1499.

Коструб Олександр Олексійович – доктор медичних наук, професор, завідувач відділом спортивної та балетної травми ДУ "Інститут травматології та ортопедії НАМН України", вул. Бульварно-Кудрявська, 27, Київ, 01601, Україна. E-mail: akostrub@ukr.net. ORCID: https://orcid.org/0000-0001-7925-9362.

Information about authors:

Zazirnyi Ihor Mykhailovych – D.Med.Sc., head of the Center of Orthopedics, Traumatology and Sports Medicine of Clinical Hospital "Feofaniya" of the Agency of State Affairs, 21 Zabolotnoho akademika St., Kyiv, 03143, Ukraine. E-mail: zazirny@ukr.net. ORCID: http://orcid.org/ 0000-0001-7890-1499.

Kostrub Olexandr Oleksiiovych – D.Med.Sc., professor, head of the Department of Sports and Ballet Injuries, SI "Institute of Traumatology and Orthopedics of NAMS of Ukraine", 27 Bulvarno-Kudriavska St., Kyiv, 01601, Ukraine. E-mail: akostrub@ukr.net. ORCID: https://orcid.org/0000-0001-7925-9362.

Сведения об авторах:

Зазирный Игорь Михайлович – доктор медицинских наук, руководитель Центра ортопедии, травматологии и спортивной медицины клинической больницы "Феофания" Государственного управления делами, ул. акад. Заболотного, 21, Киев, 03143, Украина. E-mail: zazirny@ukr.net. ORCID: hppt://orcid.org/0000-0001-7890-1499.

Коструб Александр Алексеевич – доктор медицинских наук, профессор, заведующий отделом спортивной и балетной травмы ГУ "Институт травматологии и ортопедии НАМН Украины", ул. Бульварно-Кудрявская, 27, Киев, 01601, Украина. E-mail: akostrub@ukr.net. ORCID: https://orcid.org/0000-0001-7925-9362.

Для кореспонденції: Зазірний Ігор Михайлович, вул. Дашавська, 25, кв. 14, 03056, Київ, Україна. Тел. +38(067)7563247. Факс: +38(044)2596768. E-mail: **zazirny@ukr.net**.

For correspondence: Zazirnyi Ihor M., Apt. 14, 25 Dashavska St., 03056, Kyiv, Ukraine. Tel. +38(067)7563247. Fax. +38(044)2596768. E-mail: **zazirny@ukr.net.**

Для корреспонденции: **Зазирный Игорь Михайлович**, ул. Дашавская, 25, кв. 14, 03056, Киев, Украина. Тел. +38(067)7563247. Факс: +38(044)2596768. E-mail: **zazirny@ukr.net**.