

Review Article

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Various Prosthetic ACL Grafts: A Review of Literature

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ABSTRACT

Satisfactory prosthetic replacement of the ACL has been a focus of orthopaedic research endeavours for the past thirty years. Desires to provide immediate mobility and strength to the ACL-deficient knee while avoiding the donor site morbidity caused by the commonly used autograft surgical techniques continually drive new research initiatives. Most of the grafts that have been developed to date have failed due to unsatisfactory long-term physiologic and functional performance. Most permanent ACL prostheses are prone to creep, fatigue, and mechanical failure within several years after implantation. Tissue ingrowth scaffolds and ligament augmentation devices require further refinement to provide effective mechanical support while avoiding stress shielding of the host tissue. In view of these factors, prosthetics are not widely used today in ACL reconstruction, and autogenous tissue grafts remain the gold standard used by the majority of surgeons. Perhaps development of resorbable, tissue-inducing and cell-seeded biomaterials will improve the long-term biomechanical performance of the reconstructed anterior cruciate ligament. Advances in tissue engineering combined with developments in molecular biology and gene therapy may couple with the rapid gains in computer-assisted surgery to provide improved options for the ACL-deficient knee, with a greater potential to restore its pre-injury state.

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Introduction

The anterior cruciate ligament (ACL) is the most frequently injured ligament in the knee and consequently, the majority of research into knee ligament injuries has been directed towards the ACL. Approximately 100 000 anterior cruciate ligaments (ACLs) are injured every year in the United States [1,2]. The cost of surgical repair and rehabilitation has been estimated at approximately \$17 000 per case (2), which does not include the medical costs associated with future complications, such as osteoarthritis or total knee arthroplasty, thought to occur more often in ACL-deficient or ACL-reconstructed knees [3-5].

Surgical reconstruction is therefore the most frequent mode of treatment pursued when the ACL is torn. The patients who experience ACL injuries are significantly younger and more active than those who experience many other orthopaedic injuries. The need for reconstruction options that exhibit longevity in the face of great stresses is therefore imperative [6].

Historically, options for surgical treatment have included primary repair with or without synthetic augmentation and reconstruction using either biological tissue grafts or prosthetic ligaments. Likewise, prosthetic replacements have traditionally tended to be inadequate due to post-surgical complications arising from wear and degeneration. Hence, biological tissue autograft reconstruction using the patellar tendon or quadrupled semitendinosus/gracilis tendons has become the most popular procedure in surgical

treatment of an ACL rupture. However, the frequency of significant anterior knee pain post-surgically and high occurrence of flexion contracture and crepitation in tendon autografts have kept research interests focused on the further development of prosthetic ligament implants. A significant number of early research endeavours into prosthetic ACL replacements failed due to a poor understanding of the biomechanical and physiological properties of the ACL. Tremendous gains in understanding have been made in these areas, with significant progress being made in understanding the inter-dependence between ACL anatomy, tissue composition, biomechanics, and the healing processes.

Unfortunately, to date, no prosthesis has proven itself as a viable alternative to the patellar or hamstring tendon autografts, currently used in over 90% of ACL reconstructions. This article reviews some of the major historical milestones in ACL reconstruction technology and looks forward to the continuing evolution of this technology. The literature used for this review was obtained using the PubMed database with keywords “anterior cruciate ligament” searched in tandem separately with “prosthetics” and “tissue engineering”.

It should be noted that many of the studies cited in this review obtained funding from orthopaedic and biomaterial companies that sponsored the implant.

Surgical Repair: Advantages and Disadvantages of Biological Tissue Grafts

Bone-patellar tendon-bone (BPTB) and semitendinosus/gracilis

tendon autografts are currently the most common grafts used in ACL reconstruction. Advances in hamstring graft fixation have led to similar strengths of fixation between BPTB and semitendinosus/gracilis grafts [7].

The bone-patellar tendon-bone graft is often selected for young, high-demand athletes because of this graft's load to failure, stiffness, quality of fixation, durability and success at long-term follow-up. This graft allows for the earliest return to high-demand activities. The advantages of the hamstring tendon graft include a smaller incision, theoretically less anterior knee pain, and a thicker tendinous portion within the knee joint and the bone tunnels. Fixation site healing of the hamstring tendon graft within the osseous tunnel is still under investigation. Also, recent studies have reported tunnel widening with the use of the hamstring tendon graft. The advantages of the quadriceps tendon autograft include a potentially wide tendinous portion along with a bone plug fixation at one end. Potential disadvantages include the size and location of the donor-site scar [8].

Recent literature supports the use of allograft tissue as an alternative for ACL reconstruction, 25 provided that the graft material is carefully screened for viral disease and that appropriate harvesting, sterilization, and preservation techniques that do not weaken the graft are used. Both animal and clinical data suggest that, as with autograft tissue, allograft tissue revascularizes and becomes viable after implantation. There are a few studies demonstrating that the rate of graft incorporation and remodeling are slower for allograft than for autograft reconstructions.

Clinical studies with 5-year and 7-year follow-up demonstrate that the outcomes of early ACL allograft reconstructions are similar to those of autograft reconstructions. The incidence of chronic knee effusion after allograft reconstruction appears to be diminishing, perhaps because of improved allograft procurement and avoidance of ethylene oxide sterilization [8]. The techniques now offer a high degree of strength and stiffness in the reconstructed ligament. Additionally, use of the patient's own tissue eliminates the risk of rejection and good to excellent results are reported in 85-90% of patients receiving either of these grafts for ACL reconstructions. Nonetheless, with patellar tendon autografts, many patients experience impaired function and significant morbidity at the donor site including secondary anterior knee pain, patellar tendonitis, infrapatellar contracture, and patellar fracture.

To avoid complications resulting from donor site morbidity in autograft reconstructions, allograft reconstruction has also been examined. While eliminating the donor site morbidity, the use of allografts is not currently considered advantageous due to a limited donor tissue supply, delayed biological incorporation, risks of disease transmission and tissue rejection. In an attempt to overcome these concerns, research into the use of synthetic prosthetic ligaments began over 30 years ago and continues today in hopes of eliminating donor site morbidity and reducing the risk of disease transmission and supply shortages. One of the main obstacles in finding an adequate prosthetic replacement for the ACL is the longevity of the graft, with autogenous tissue consistently proving to be a more durable and long-lasting replacement than the many biomaterials that have been applied to ACL replacement [9].

Prosthetic Beginnings and Past Use

The first attempts at a synthetic ACL reconstruction were conducted by Alwyn-Smith in 1918 using silk sutures; they however failed within 3 months [10]. Reconstruction with a prosthetic ligament

made of polytetrafluoroethylene (PTFE) with embedded carbon or aluminum oxide fibers (Proplast) was first reported in 1973 [11]. Results with this system yielded an average time to breakage of just over 1 year. A report by James et al. suggests that only 52% of reconstructions utilizing this graft yielded satisfactory results [12]. Satisfactory results include all grafts that patients were content with and had not ruptured at time of latest follow-up. Current classification systems for synthetic replacements of the ACL include grafts, ligament augmentation devices, or total prosthetics. Grafts (polyethylene, PTFE), typically fixed at both ends, were the initial focus of synthetic ACL replacement and were meant to provide stability to the ACL-deficient-knee until secondary reconstruction procedures gained popularity [13]. Similarly, ligament augmentation devices (polypropylene, polyester) were intended to provide immediate protection for autogenous tissue grafts until revascularization was complete and the ingrown tissue was capable of withstanding local tensile and compressive forces. Unfortunately, these devices may in fact accomplish the opposite of their intended purpose by stress-shielding autogenous tissue, preventing it from developing adequate mechanical strength. Fixed at both ends like a graft, the total prosthesis was intended as a permanent ACL replacement without any soft-tissue ingrowth that would allow the patient to begin aggressive rehabilitation immediately as no tissue maturation or revascularization was required. While the implantation of a full-strength ACL replacement generally led to excellent short-term results, long-term efficacy results were poor due to wear and ensuing rupture of the prosthesis [13].

Combining the mechanical focus provided by these prior prosthetic approaches with tissue engineering principles has led to the development of a scaffold design intended to serve as a foundation for soft tissue in-growth. Scaffolds may be permanent or may be intended to gradually degenerate as the host tissue replaces them. Problems associated with the biological incorporation of scaffolds include variability of tissue in-growth, immature degeneration of the implant and insufficient maturation of the host tissue resulting in an inability of the scaffold to withstand inherent mechanical stresses placed on the ACL. Current directions in this area involve the use of tissue engineering focusing on developing a mechanically and biologically functional matrix for the scaffold and the use of in vitro mechanical signals to guide new tissue development [13].

Carbon Fibre Prosthetics

Some of the earliest attempts to discover an appropriate alternative to the biological graft resulted in a variety of carbon fibre prostheses that varied greatly with respect to material and implantation technique. In 1977, Jenkins et al. were the first to use a flexible carbon fibre implant, and suggested that the carbon fibre induced the formation of tendon in animals and humans. However, subsequent studies reported the generation and migration of carbon wear particles into the joint space and regional lymph nodes following implantation of the prosthesis. To combat this problem, attempts were made to coat the carbon fibre with collagen and absorbable polymers. Of particular interest was a carbon fibre implant proposed by Alexander et al. coated with a co-polymer of polylactic acid (PLA) and polycaprolactone [14,15]. The carbon filaments were thought to act as a scaffold for tissue ingrowth by evenly distributing and reducing the interfacial stress between the implant and soft tissue attachment, while the PLA/polycaprolactone would protect the fibre during implantation. Over time, the PLA was meant to resorb and the carbon fibres degrade as new tissue developed, thereby encouraging normal tissue regeneration without permanently replacing it [15]. A 24-month

study involving 82 patients was conducted by Weiss et al. to further examine the PLA coated prosthesis using a variety of subjective and objective measures (pain, stability, function, and isokinetic strength testing), which revealed significant improvements over the duration of the study [16].

Arthroscopic evaluation demonstrated collagenous tissue ingrowth, confirmed by histological studies, to be composed of Type I and III collagen in similar proportions to that found in normal healing ligamentous tissue [16]. A similar design was used in the Surgicraft ABC prosthetic ACL (Surgicraft Ltd., Redditch UK) composed of carbon and polyester fibres oriented in a partial braid by a zig-zag pattern. However, a study by O'Brien et al. with an average follow-up of 34 months showed only 11 of 31 knees (41%) had good results defined as a Lysholm score greater than 76. The Lysholm knee score is an outcome measure that assesses knee function on a 100 point scale. The authors also noted unacceptable stretching and complete rupture as major complications and concluded that the implant is unsuitable for clinical use [17].

Gore-Tex Permanent Prosthesis

The Gore-Tex ligament prosthesis is composed of a single long fiber of expanded polytetrafluoroethylene (PTFE) arranged into loops. Extensive mechanical testing has shown that the resulting ultimate tensile strength is about 3 times that of the human ACL and the results from cyclical creep tests and bending fatigue testing seem to identify Gore-Tex as the strongest synthetic ACL replacement in terms of pure material stability [16]. 18 Bolton and Bruchman reported that 129 out of 130 patients receiving a high strength PTFE ligament showed improved knee stability at 15 months or less [18]. Glousman et al. reported an initial improvement upon physical examination and subjective scores. However, at mean follow-up of 18 months, they reported a progressive loosening of the prosthesis [19].

Similarly, Woods et al. presented 2- and 3-year followup of Gore-Tex ACL reconstructions and showed a similar pattern of early improvement post-operatively, but deterioration over time. They reported an overall failure rate of 33% at 3-year follow-up [20]. Indelicato et al.'s follow-up of Gore-Tex implant ACL reconstructions showed a 90% success rate at 2 years versus only a 76% success rate at 3 years or more [21]. Despite similar reports describing complications with the Gore-Tex ACL prosthesis, subjective results in several studies remain acceptable at 60-80 % [19,21]. The Gore-Tex ACL prosthesis is currently FDA approved for use in patients who have had a failed autogenous intra-articular graft procedure.

Dacron

With its success as a vascular surgery implant, various forms of Dacron grafts have been developed as a scaffold for ACL replacements [22]. The implant is a composite of four tightly woven polyester strips wrapped in a sheath of loosely woven velour, designed to minimize abrasion of the graft and act as a scaffold for fibrous tissue ingrowth. Seventy-five percent of the patients were found to have a negative Lachman, anterior drawer, and pivot shift at their most recent follow-up. However, Richmond et al. Reported failure rates of 37.1% in a study of Dacron reconstruction with mean long-term follow-up of 50 months [23]. Likewise, Barrett et al. reported higher failure rates of 47.5% after a four-year follow-up period [24]. A clinical study by Lopez-Vazquez et al. examining ACL reconstruction with a Dacron prosthesis showed a similar deterioration of results after the first post-operative year [25]. With the initial short-term strength shown by these grafts offset by their poor longterm stability,

Dacron grafts should not be considered a viable alternative for ACL reconstruction.

Leeds-Keio Artificial Ligament

With the desire to design a graft that combined the properties of a permanent prosthesis and a tissuepromoting scaffold, Fujikawa and Seedhom developed the Leeds-Keio artificial ligament: a polyester meshlike structure anchored to the femur and tibia with bone plugs [26]. This mesh was intended as a scaffold for soft tissue ingrowth through the intra-articular and extra-articular sections of the ligament, eventually uniting the bone plugs. The implant was considered sufficiently flexible to be effective with a maximal tensile strength of approximately 2100 Newtons (N), which significantly exceeds that of the average young adults' natural ACL (about 1730 N) [26]. Initial descriptions from the inventors also described minimal articular wear with the ligament [26]. The inventors of this graft have reported successful clinical results with arthroscopic observations documenting neoligamentous tissue within the implanted Dacron scaffold. Other investigators, however, have reported the ingrowth of non-aligned fibrous tissue (i.e. non-neoligamentous tissue) within the device after implantation and suggested that the Leeds-Keio ligament did not serve as a true scaffolding graft, but instead behaved as a permanent load-bearing prosthesis, subject to long-term failure in the joint [27].

McLoughlin and Smith presented a 3.8 year follow-up study of 25 patients implanted with the Leeds-Keio ligament for chronic ACL instability. They reported a low complication rate and considerable success in the elimination of instability after finding good postoperative results with the anterior drawer test using an arthrometer at 90° of flexion [28]. Nevertheless, ensuing long-term follow-up studies showed a deterioration of results after the first post-operative year and a large number of long-term graft ruptures despite excellent early results in stability testing and on the Lysholm scale [29]. These findings were similar to earlier results reported by Schindhelm, who found that good early results in a sheep model were not maintained [30]. Due to the number of long-term graft ruptures and the lack of long-term stability provided, the Leeds-Keio ligament is no longer suitable for reconstruction of the human ACL [29,30].

Kennedy Ligament Augmentation Device (LAD)

Kennedy et al. introduced the concept of the Ligament Augmentation Device (LAD) in 1980 [31]. The graft, composed of a band-like braid of polypropylene, was originally developed to reinforce the area of pre-patellar tissue considered to be a weak area of autogenous patellar tendon grafts. Use of this prosthesis employed the MacIntosh/Marshall transfer of a portion of the rectus femoris tendon, pre-patellar tissue, and central third of the patellar tendon in an over-the-top fashion [32]. Originally, the graft was developed to protect the autogenous tissue graft from excessive stresses during the initial remodelling phase (characterized by degeneration and revascularization), allowing for earlier resumption of pre-operative activity levels [31].

Research has shown that the percentage of load accepted by the LAD varies according to the type of graft employed and method of reconstruction. Comparisons of the patellar tendon and semitendinosus/gracilis LAD composite grafts revealed that the LAD will accept approximately 28% and 45% of the applied load, respectively [33]. To prevent excessive stress shielding that would otherwise prevent the autogenous tissue from developing a normal functional tensile strength, the LAD was attached to the bone at only one end. Despite a promising beginning, the suture interface

between the LAD and the graft was identified as the weak link of the composite. Whether collagen fibres become truly incorporated into the LAD remains a controversial issue. Most histological evidence has been derived from animal studies and thus may not be fully indicative of results in humans. Nevertheless, this evidence seems to point to adequate longitudinal collagenization of the graft with inconclusive results on whether or not collagen ingrowth within the LAD has occurred [34].

Furthermore, as an intra-articular foreign body, the LAD has been reported to induce an inflammatory response characterized by foreign body giant cells and macrophages in the surrounding tissue. A review by Kumar et al. reported that the majority of complications seen following use of the LAD were characterized as effusions and reactive synovitis, likely a result of LAD induced inflammatory response [35]. The decline in use of the aforementioned MacIntosh/Marshall transfer, combined with the weak graft-prosthetic suture interface and propensity of the LAD to cause high rates of post-operative synovitis have resulted in a lack of widespread use of the device.

The Future: Ligament Advanced Reinforcement System (LARS) Artificial Ligament

The Ligament Advanced Reinforcement System (LARS) (Arc-sur-Tille, France) artificial ligament consists of fibres made of polyethylene terephthalate (PET). An intra-osseous segment is composed of longitudinal fibres bound together by a transverse knitted structure while an intra-articular segment is composed of parallel longitudinal fibres twisted at 90°. The main innovation of this artificial ligament lies in its ability to mimic the natural ligamentous structure and reduce shearing forces by orientating the free fibers of the intra-articular portion of the graft clockwise or counter-clockwise for use in right and left knees, respectively. Furthermore, the PET fibres of the intraarticular segment are designed to encourage tissue ingrowth due to the porosity of the material, allowing ingrowth from the surrounding osseous tunnels. Ideally, such tissue ingrowth between the ligament fibres would contribute to the viscoelasticity of the graft and protect against friction at the opening of the bony canal and between the fibres themselves [1].

A study by Lavoie et al. examined ACL reconstruction with the use of the LARS artificial ligament [36]. Thirtyeight of forty-seven patients suffered from chronic ruptures of the ACL, while nine others presented with acute or subacute ruptures at a mean follow-up of 21.9 months. Six patients had previously had an unsuccessful ACL reconstruction. The Knee Osteoarthritis Outcome Score (KOOS) was administered to assess patients' opinions regarding their knee, while a modified International Knee Documentation Committee (IKDC) scoring system was used to examine knee stability. The IKDC form initially consisted of seven knee-related parameters that were each rated as either normal, nearly normal, abnormal, and severely abnormal. The worst score amongst the seven categories determined the final score. The form was later modified in 2001 to include subjective factors such as symptoms, sports activities, and ability to function. The Tegner activity scale, a subjective ten point activity scale, was obtained to assess patient activity levels. A Telos radiographic stress system was used to examine anterior knee displacement, which involves obtaining radiographs with the knee in ninety degrees of flexion and a posterior force applied to the knee. When results are compared to the normal knee, this test helps in the assessment of post-operative laxity in the reconstructed knee which may indicate that the graft is failing. None of the patients presented symptoms of synovitis, but longer follow-up time is required to properly draw conclusions

with respect to patient outcome. Although Tegner scores improved significantly following surgery, no patients returned to pre-injury activity levels. Data obtained by the KOOS demonstrated patient satisfaction ranged from 73.5 to 93.0 %. In comparison to the uninjured knee, postoperative Telos stress radiography and the Lachman test indicated an average posterior-anterior displacement of 7.3 mm for the involved knee [30].

A more complete examination of the LARS artificial ligament was provided in a subsequent study by the same authors. Like the preceding study, assessments included clinical examination, anterior laxity testing, as well as the KOOS, IKDC, and Tegner scores. In particular, IKDC evaluation revealed little significant difference between the two methods. Follow-up values for instrumented laxity testing were greater in the LARS group. Another recent study by Talbot et al. examined the use of the LARS artificial ligament for ligament reconstruction in knee dislocations [6]. Twenty patients were included with a mean follow-up of 27.4 months. Each patient was evaluated using the Lysholm score, underwent clinical examination to identify ligamentous laxity and range of motion, and completed the ACL quality of life (ACL-QoL) questionnaire. The mean Lysholm score was 71.7, which is lower than scores reported by several other studies (range of 74.7 to 91.3) investigating the outcomes of knee dislocations treated with surgery as reported by Fanelli [37]. Following the same trend, Telos radiometry revealed a mean residual laxity of 5 mm in patients post-surgery, which is also greater than these previously reported results. The average range of motion post-surgery was 118° with a mean fixed flexion contracture of 2° [6]. Although preliminary investigations into the use of the LARS artificial ligament have been encouraging, concerns regarding the risk of rupture remain and must be addressed through long-term follow-up studies.

Tissue Engineering Advances

Permanent synthetic prostheses are capable of duplicating the mechanical and structural properties of the ACL. However, they generally tend to lose strength with time. Tissue-based or tissue-aided implants offer the additional possibility of the restoration of normal joint kinematics while the mechanical behaviour of these implants is expected to improve over time as tissues are remodelled within the knee [38]. An ideal ACL scaffold must meet the immediate functional mechanical demands within the reconstructed knee, however, they must also degrade at a rate similar to that of tissue ingrowth. Accordingly, the ACL scaffold should lose its mechanical integrity while allowing the remodelled tissues to gain strength and accept an increasing amount of the mechanical demands placed on the ACL.

Current research into this novel tissue engineering approach has focused on seeding either collagen-based scaffolds or synthetic biodegradable polymers with a variety of different cell types. In hopes of stimulating early healing, reducing biomaterial related inflammatory response and improving neoligament formation, several researchers have sought to adopt a cell sheeting technique to improve the performance of the synthetic ACL scaffold. Several groups have conducted experiments on this tissue-engineered approach to ACL ligament reconstruction using both fibroblast-seeded synthetic scaffolds and collagen-based prosthetics [39,40].

Bellincampi et al. measured the ingrowth characteristics of rabbit fibroblasts on skin and ACL scaffolds [41]. Subsequent in vivo studies suggested that fibroblastseeded collagen scaffolds were viable after reimplantation into the donor rabbit. The major limitations of these approaches are the allogenicity of the collagen

scaffolds, often leading to further complications. Collagen-based constructs also suffer from batch-to-batch variability, making consistent reproduction of these prostheses difficult. As an alternative to the scaffolds made of nondegradable polymers, investigators have begun to examine biodegradable materials that would provide immediate stabilization to the repaired ligament but would also act as a scaffold for the ingrowth and/or replacement by host cells. Cao et al. described the generation of neo-tendons in a nude mice model by implanting polyglycolic acid (PGA) scaffolds seeded with bovine tendon fibroblasts in the subcutaneous space of athymic mice [42]. In both studies, the tissue developed histological characteristics similar to normal tendon and ligament over time. Ouyang et al. reported that bone marrow stromal cells (bMSCs) seeded onto poly-lactic and -glycolic acid (PLGA) scaffolds grew as a multi-layer of cells intertwined in a collagen matrix synthesized by the cells themselves. They also noted that the cell sheet formed faster than scaffolds seeded with terminally differentiated cells, such as fibroblasts and smooth muscle cells [43]. They reported that degradation of the scaffolds occurred over time, as indicated by a decrease in failure load. Altman et al. seeded 6-cord silk scaffolds with human bone marrow stromal cells and cultured them for 14-21 days. Their results similarly suggested a slow degradation of the scaffolds. However, fatigue analysis and subsequent regression analysis revealed an expected matrix lifetime equivalent to 1 year in vivo. While these reports are an estimate, the authors suggest that this is a marked improvement compared to similar studies using collagen scaffolds [38].

The future of tissue engineering may also require a significant contribution from cell-specific growth factors influencing the maturation and homeostasis of the healing response of ligament tissue. Studies have suggested that individual growth factors may have an important effect on cell division and enhance ligament healing, while others have pointed to the synergistic effect of a combination of growth factors as important to cell outgrowth in ACL explants [44,45]. In a study observing the effects of several growth factors on the cell migration, proliferation and collagen production in human ACL cells, Murray et al. suggested that specific dose-response relationships may exist for the optimal activity of each growth factor [46].

These authors observed that the addition of transforming growth factor (TGF) β -1 led to an increased cell population, as well as increased collagen and smooth muscle actin production in human ACL cells cultured on top of a collagenglycosaminoglycan scaffold. Despite the complex nature of the inter-dependent factors at play during the recovery and rehabilitative period following an ACL reconstruction, much of the literature today suggests that tissue engineering techniques will lead to a new generation of ACL replacements, capable of regenerating a mechanically robust and natural ACL.

Conclusion

Biological tissue autograft reconstruction using the patellar tendon or quadrupled semitendinosus/gracilis tendons has become the most popular procedure in surgical treatment of a ruptured ACL. This article provides a review of the history of the use of prosthetics with respect to ACL reconstruction grafts including Carbon Fibre, Gore-Tex and Dacron prosthetics as well as the Leeds-Keio Artificial Ligament and the Kennedy Ligament Augmentation Device (LAD). Emphasis is placed on the Ligament Advanced Reinforcement System (LARS) as preliminary investigations of its use have been encouraging. Significant progress has been made recently with respect to the understanding of ACL anatomy, composition, biomechanics, and healing processes, leading to

innovative techniques using approaches based in tissue engineering principles and computer – assisted surgery. While research into improved ACL treatment options continues, the synthesis of recent advancements provides a new optimism towards the regeneration of an ACL mirroring its original stability, function, and longevity.

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