

ANTERIOR CRUCIATE LIGAMENT: HISTORY, ANATOMY, AND RECONSTRUCTION

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The purpose of this article is to provide surgical technologists with a better understanding of anterior cruciate ligament (ACL) reconstruction. It will cover a brief history of the ACL and its anatomy, diagnosis, and treatment.

Acquiring a better understanding of any surgical procedure can only enhance performance level and broaden the professional knowledge base.

Historical Background

One of the characteristics of modern surgical practice is the delusion that we are the first to present new concepts and treatments to our profession, only to discover upon closer examination that we have "reinvented the wheel." We sometimes forget that all our accomplishments are only a few stones added to the massive wall of medical knowledge already built by our medical ancestors.

Snook accurately accounts the history of the ACL in *The Crucial Ligaments*. He records that Claudius Galen of Pergamum and Rome must be given the credit for first describing the anatomy and nature of the ACL. Before his writing, ligaments were thought to be part nerve and to have some sort of contractile power. Galen wrote that ligaments were the supporting structures of diarthrodial joints, serving as stabilizers of these joints and limiting abnormal motion.

Interest in the structure lapsed for the next 1,600 years as medical attention was drawn to infectious disease and major trauma. The injured ligament was mentioned only in connection with dislocations and severe sprains. A knee with an injured ligament could always be braced.

In 1850, Stark treated patients with casts. In recovery, he found they had slight residual disability.

By 1917, Grone used different procedures such as replacements of the bony fragment by detaching a strip of fascia lata from its insertions and routing it through a tibial tunnel. Two years later, this procedure was modified by detaching a graft from its origin rather than from the insertion. This operation is the basis of the intraarticular reconstruction we use today.

In 1918, Alwyn Smith presented an overall review of the anatomy, biomechanics, mechanism of injury, diagnosis, and treatment of injuries to the ACL. He recommended reconstruction of the neglected tears by bringing the end of the graft up to the medial femoral condyle to reinforce the medial collateral ligament. He advanced the sartorius inser-

tion to provide extraarticular reinforcement and was the first to attempt prosthetic reconstruction using a silk substitute. Many theses have been published on the injuries to the ligaments of the knee joints.

By 1941, study of the ACL was still limited to case reports or descriptions of new procedures. A thorough study of sections of different ligaments and an analysis of the abnormal movement that resulted in the interactions between the several ligaments and menisci were discussed in a paper published by Brantigan and Voshell entitled "The Mechanics of the Ligaments and Menisci of the Knee Joint." This paper is usually quoted in any discussions of the biomechanics of the knee joint.

At the end of World War II, there was a rise in the popularity of athletics and the development of antibiotics. Infectious diseases ceased to be the major preoccupation of the medical profession. At the same time, surgery became safer because of antibiotics and the improvements in anesthesia techniques.

Shortly after this period, the concept began of dynamic reconstruction of ACL by transplanting semitendinosus tendon through the back of the knee forward into the tibia.

More progress was made in the diagnosis and treatment of injuries of the ACL. Simultaneous advances were made in other fields of medicine that had a direct effect upon the study of the ligament. The first of these was the improvement of radiologic diagnosis, especially arthrography.

In 1905, 10 years after Roentgen announced his discovery, Wendorff and Robinson performed the first arthrogram, a gas arthrogram of the knee. Lindblom in the late 1930s became the major proponent of arthrograms, but the popularity of the technique did not surge until the development of water-soluble media and the many technical developments in radiography in the late 1950s.

Advances in the treatment of ACL injuries occurred when a few orthopedic surgeons started working as physicians for American football teams. Coaches had been using films for scouting and teaching purposes since the early 1930s, and in this high-risk sport, the orthopedic surgeon could also use them to analyze the mechanics of injury to the intact knee. With the development of fiberoptic transmission of light, the use of arthroscopic surgical techniques increased rapidly through the work of several pioneers: Ward Casscells, Richard O'Connor, Robert Jackson, Lanny Johnson, Robert Metcalf, and many others.

Early diagnosis is important in the treatment of ACL injuries. DeHaven recommended the early use of the arthroscope in acutely injured knees in the presence of hemarthrosis. This procedure has lead to early diagnosis

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and repair of injuries, sparing the patient the more difficult reconstruction with its prolonged recovery. Today, arthroscopy is performed on an outpatient basis.

ACL Anatomy

The cruciate ligaments are bands of oriented, dense connective tissue that connect the femur and tibia. They are surrounded by a mesentery-like fold of synovial membrane that originates from the posterior intercondylar area of the knee and completely envelopes the ligaments. The cruciate ligaments are intraarticular and also extrasynovial.

The ACL is an intraarticular structure inserted between the anterior horns of the medial and lateral menisci, originating on the lateral femoral condyle posteriorly and inserting on the anterior tibia. It measures approximately 4 by 1.1 cm. It is responsible for guiding the tibia during flexion and extension and assists in the proper rollback of the femoral condyle. If the ACL is not properly functioning, the tibia is able to sublux anteriorly. This translation during knee motion may cause meniscal damage and increased articular cartilage destruction.

Femoral and Tibial Attachment

The ACL is attached to a fossa on the posterior aspect of the medial surface of the lateral femoral condyle. The femoral attachment is in the form of a segment of a circle with the anterior border straight and the posterior border convex. The long axis of the femoral attachment is tilted slightly forward from the vertical, and posterior convexity is parallel to the posterior articular margin of the lateral femoral condyle.

The ACL is attached to a fossa in front of and lateral to the anterior tibial spine. At this attachment, the ACL passes beneath the transverse meniscal ligament. A fascicle of the anterior of the ACL may blend with the anterior attachment of the lateral meniscus. The tibial attachment of the ACL is wider and stronger than the femoral attachment.

Ligament Bone Attachment

The cruciate ligaments attach to the femur and tibia via the interdigititation of collagen fibers of the ligament with that of adjacent bone. The abrupt change from flexible ligamentous tissue to rigid bone is mediated by a transitional zone of fibrocartilage and mineralized fibrocartilage. The structure from ligament to bone allows for a graduated change in stiffness and prevents stress concentration at the attachment site.

Vascular Anatomy

The major blood supply to the anterior and posterior cruciate ligaments arises from the ligamentous branches of the middle genicular artery as well as some terminal branches of the medial and lateral inferior genicular arteries. The synovial membrane, which forms an envelope about the ligament, is richly endowed with vessels that originate predominately from the ligamentous branches of the middle genicular artery. A few smaller terminal branches of the lateral and medial inferior genicular arteries also contribute some vessels to this synovial plexus through its connection with the infrapatellar fat pad. The synovial vessels arborize to form a weblike network of periligamentous vessels that insheath the entire ligament. These periligamentous vessels then give rise to smaller connecting branches that penetrate the ligament transversely and anastomose with a network of endoligamentous vessels. These vessels, along with their

supporting connective tissues, are oriented in a longitudinal direction and lie parallel to the collagen bundles within the ligament.

The anterior and posterior cruciate ligaments are supplied with blood from soft tissue origins. While the middle genicular artery gives off additional branches to the distal femoral epiphysis and proximal tibial epiphysis, the ligamentous-osseous junctions of the cruciate ligaments do not contribute to the vascular scheme of the ligaments themselves.

Nerve Supply

The cruciate ligaments receive nerve fibers from branches of the tibial nerve (posterior articular branch of the posterior tibial nerve). These fibers penetrate the joint capsule posteriorly and along with the synovial and periligamentous vessels surrounding the ligaments to reach as far anteriorly as the infrapatellar fat pad. Smaller nerve fibers have been observed throughout the substance of the ligaments. While most fibers are associated with endoligamentous vasculature and appear to have a vasomotor function, some fibers have been observed to lie alone among the fascicles of the ligament. These latter neural elements are located within multiple clefts in the tibial origin of the ACL and in its richly vascularized synovial coverings.

Diagnosis

By virtue of its shape, the knee possesses very little inherent stability. It depends on its ligaments, menisci, and the dynamic action of its surrounding muscles working together, in concert, to provide stability. John A. Feagin, editor of *The Crucial Ligaments*, poetically wrote that "the knee is a harmonious symphony of ligaments in which no ligament stands alone." The ACL has been termed by some as the "watchdog" of the knee. It is generally felt that when this ligament is disrupted, other problems will inevitably occur.

Rupture of the ACL usually occurs when forces generated by an individual in either changing direction or decelerating exceed the tensile strength of the ligament. An example of this would be that of a running athlete stopping suddenly or changing directions. Simply landing from a jump, as in skiing or basketball, is also a common mechanism by which the cruciate is ruptured. When an ACL rupture occurs, the individual usually experiences a popping sensation, severe pain, a giving-way movement of the knee, and an inability to continue present activity; rapid swelling of the knee within 3 hours occurs in 75% of the cases. The popping sensation occurs because the structural arrangement of the ACL allows it to store considerable energy before its elastic limit is reached. As a result, when this limit is reached, the ligament tears and the patient defines the sensation as a "pop." This pop is a classic sign of a tear or severe injury to the ACL and is noted in 40% of patients. A rapid tense hemarthrosis occurs in 75% of patients.

Treatment Options

The decision to reconstruct the ACL should be made with the understanding that the condition may alter the patient's life style, but will not shorten his or her life span. The ability to ambulate may be somewhat impaired and the activity level may need to be altered, but ACL insufficiency is not a life-threatening condition. A study was conducted involving Naval recruits with torn anterior cruciates. Surgical

reconstruction was not employed and good results were obtained in 30% of the cases (good results being defined as the ability to resume normal activity). According to a study conducted by Noyes, a basic rule of thirds generally applies to patients suffering from a torn ACL. He concluded that without surgical intervention, one-third of the individuals with ACL-insufficient knees will return to normal activity, one-third will have to adapt their activity by wearing a brace or giving up certain sports activities, and one-third will have chronic instability despite brace wear. There is no current literature that can indicate scientifically how to differentiate which patients will have a potentially quiescent ACL-deficient knee from those who will develop functional instability, meniscal tears, and posttraumatic arthritis.

If, however, the decision to reconstruct is made, a graft medium must be selected. There are several types of graft options available used in the substitution for the ACL. The most commonly used is the central third of the patellar tendon. This tendon is 168% stronger than the original cruciate. This percentage decreases, however, during the devascularization period experienced by the graft. Once revascularization and biological remodeling occur, the original biomechanical strength is regained and the graft is a stronger structure than its predecessor. Other grafts used are the semitendinous tendon, the gracilis tendon, the iliotibial band, or a synthetic ligament augmentation device commonly referred to as an LAD. The selected tendon can be an autograft, which is harvested from the patient; an allograft, which is harvested from a cadaver; or a xenograft, which is harvested from a different species. The most commonly used graft is the autogenous central third of the patellar tendon.

ACL Reconstruction

No matter which graft is selected, the goals of surgery include normal stability, preservation of motion, muscular rehabilitation, and a return to sports unbraced. The steps performed in an ACL reconstruction are reasonably standard but the order in which they are performed may vary from surgeon to surgeon. The following procedure is an outline of the steps performed by Bernard R. Bach Jr, MD, director of sports medicine at Rush-Presbyterian-St Luke's Medical Center.

Preoperative Testing

A thorough exam is performed while the patient is in a supine position and under anesthesia. This allows the physician to examine the knee freely without interruption from the patient due to discomfort. The Lachman, pivot-shift, and KT-1000 tests are routinely performed. The results of these tests help to reaffirm the original diagnosis and provide a presurgical reference base to compare with postsurgical results.

Diagnostic Arthroscopy

The first operative step performed is a diagnostic arthroscopy. During this stage, a general overview of the knee joint is performed. The knee joint is examined and evaluated for the presence of any degenerative joint disease, torn menisci, an existing ACL, and the status of residual ACL tissue. Any additional meniscal debridement or meniscal repair that needs to be performed is diagnosed and performed at this time. Prior to the scope insertion, a solution of epinephrine 1:300,000 is injected intraarticularly at the supermedial



Figure 1. Arthroscopy inflow setup, showing Argyle 'Y' connector.

fluid inflow site and the inferolateral and inferomedial portal sites. The hemostatic property of this solution can generally allow the diagnostic arthroscopy to be performed without inflating the tourniquet. ACL reconstruction and possible meniscal repair usually require tourniquet inflation; however, minimizing total tourniquet time is always a goal.

Fluid infusion is obtained by gravity using four 3,000-cc bags of 0.9 normal saline connected to two TUR tubings and to an inflow cannula by means of an Argyle 'Y' connector (Figure 1). However, inflow pumps are now being used by some physicians for this purpose.

Intercondylar Preparation

After the diagnostic arthroscopy has been completed, intercondylar preparation is performed. During this process any residual tissue is debrided using a motorized arthroscopic shaver (Figure 2). If an ACL remnant is noted it is also debrided. It is important to debride residual tissue aggressively to visualize the intercondylar wall of the lateral femoral condyle and the ligament insertion site on the tibial eminence. If the tibial eminence region is not debrided, soft



Figure 2. Motorized arthroscopic shaver debriding residual tissue.

tissue incarceration may occur as the graft is passed intraarticularly.

Notchplasty

Following the ACL tissue debridement, a notchplasty is performed. A notchplasty is the act of expanding the intercondylar notch of the femur. The purpose of the notchplasty is twofold. The primary purpose is to protect the graft from abrasion in the area that the graft must lie and pass through. Its secondary purpose is to assist in visualization during graft placement and femoral drill hole placement.

Procurement of the Graft

Once the notchplasty and all intercondylar preparation have been completed, the autograft is procured. A longitudinal skin incision is made, using a no. 15 blade, medial to the region of the patella tendon. The tendon is marked and outlined with a no. 10 scalpel incision. An oscillating saw is used to deepen the outline and obtain bone blocks on each end of the graft, one from the tibial tubercle and the other from the patella. The graft is then lifted from its bed with a curved 1/2-to 5/8-inch osteotome. The fat pad is dissected from the patellar tendon with Metzenbaum scissors. Leaving the fat pad intact at the patellar tendon site should help prevent any extravasation of irrigation fluid as a result of harvesting the patellar tendon segment. All sharp bone edges of the graft are contoured to facilitate passage through femoral and tibial holes. Three holes are placed at each end of the graft using a .062 K-wire. One no. 5 braided polyester nonabsorbable suture is passed through each drill hole. The graft is then wrapped in an antibiotic-soaked lap sponge and placed in a safe place on the back table.

Supracondylar Femur Preparation

The preparation of the supracondylar femur follows the graft procurement. This involves making an incision in the midline of the lateral supracondylar area of the femur. The iliotibial band is noted and divided parallel to its fibers for a similar length to the incision. The vastus lateralis is identified and retracted with a Chandler elevator. The knee is then placed in about 45-degree flexion and the lateral supracondylar geniculate vessels are located and cauter-



Figure 4. Attachment of rear entry guide to J-shaped guide passer.

ized. Dissection is continued with a Cobb elevator until the surgeon is able to place a finger over the lateral femoral condyle and palpate the "over the top" extracapsularly.

Femoral and Tibial Drill Holes

The next step, and probably one of the most crucial, is the placement of the drill holes. Inadequate placement of these drill holes can cause improper graft placement. The entire success of the operation depends on where the drill holes are placed. If the holes are off by just a couple of millimeters, it can significantly affect the strain on the graft, causing it to either stretch or elongate. An Acufex system (Acufex, Inc., Mansfield, Massachusetts) is what is presently employed at the authors' institution for drill-hole placement. For the placement of the femoral drill hole, a J-shaped guide is passed through the midpatellar rent intraarticularly and under arthroscopic visualization passed over the top, entering the lateral supracondylar area to the lateral incision previously made (Figure 3). The rear-entry guide, right or left according to the operative leg, is then attached to the J-shaped guide passer, introduced and positioned (Figure 4). Position is checked arthroscopically, and if correct, a Richards F 3/32 guide pin is then drilled. Placement is then verified by using an arthroscopic probe with reference to the "over the top" position. The next hole to be drilled is in the tibia. A 1.5- to 2.0-cm osteoperiosteal flap is created on the tibia with electrocautery and a Cobb elevator. The tibial eminence is visualized arthroscopically and an intraarticular guide wire is then drilled at an angle that when overdrilled will be in the center of the original insertion site of the ACL. If the placement is satisfactory, with a guide wire in place, a cannulated disposable drill is used for overreaming (Figure 5). If any further debridement is needed, it is performed at this time using a synovial resector. An arthroscopic rasp is now used to smooth the intraarticular openings and eliminate potential points of high stress on the graft. In order to decrease fluid extravasation, the holes are temporarily occluded using a Concept carrot (Concept, Inc., Largo, Florida) (Figure 6).



Figure 3. Intraarticular passage of J-shaped guide.

Isometry Testing

Now the moment of truth arrives, isometry testing. This is the means by which accuracy of drill hole placement is

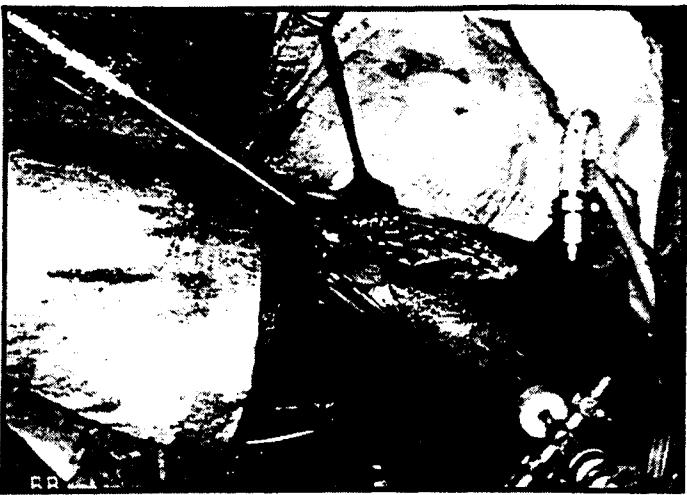


Figure 5. Tibial site overreaming.

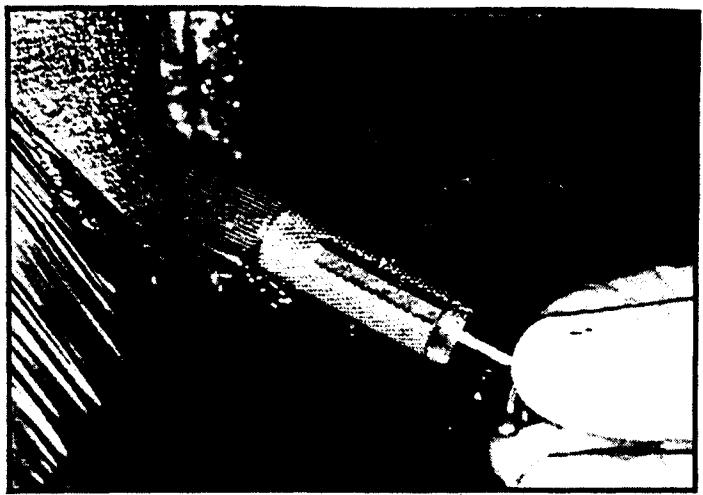


Figure 7. Isometry testing with strain gauge.

tested. This test can indicate the amount of strain that a graft placed through these drill holes and anchored in this position would experience. The isometry testing is done by first replacing the guide wire in the lateral femoral condyle with a monofilament suture that is secured with a hemostat. A strain gauge suture is attached and drawn back through the tibia, the joint, and out of the lateral femur and secured with a hemostat. The knee is then extended from 90 to 0 degrees noting the strain gauge reading (Figure 7). If the reading is greater than 2.5 mm, the drill-hole placement is not acceptable. The joint must be inspected with the arthroscope and the problem located and corrected, which may include redrilling. When the strain gauge excursion is less than 2.5 mm, the suture attached to it may be replaced by a .062 K-wire, which is eventually overreamed by a previously determined size disposable cannulated reamer. The posterior cruciate ligament is protected during femoral overreaming.

Graft Placement

Graft placement is the final step taken. The graft is taken from its secure place on the back table and admitted into the femoral side, through the joint, and into the tibial

tunnel where it is secured. Ligament passage is facilitated by use of a Yankaur suction tube passed retrograde or by use of a commercially available ligament passer. Manual external tension is placed on the sutures and the new ligament is visualized and probed arthroscopically for any laxity. An assessment of the new ligament is made by taking the knee through full extension and checking for any impingement. If everything tests well, the graft is secured using Kurosaka interference screws. The primary advantage of using interference screw fixation is that it allows for a rigid fixation that permits a more aggressive early rehabilitation program. Care, however, must be taken to avoid screw divergence, convergence, graft or suture laceration, graft advancement, or intraarticular placement of the screw. Once secured, the graft is once again examined arthroscopically and palpated with a probe to assess tension and orientation. The knee is again placed through a full range of motion testing to assess the need for further notchplasty. The pivot-shift and Lachman tests are now repeated and the results are compared with the preoperative findings. The pivot-shift should be normal and the Lachman should have a firm end point and a 2- to 3-mm translation.

Conclusion

Scrubbing for an ACL reconstruction is both a challenging and professionally rewarding experience. The array of equipment utilized can be overwhelming. However, once a structured system is contrived and made familiar, the anxiety level diminishes substantially and is replaced with an air of confidence and accomplishment.

Learning this or any ACL reconstruction procedure in detail through outside reading and discussion with surgeons cannot be overemphasized. Being able to follow the steps of the procedure and anticipate the needs of the surgeon becomes a monumental asset to the entire team, an asset from which everyone, including the patient, eventually benefits. □

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(continued on p 29)



Figure 6. Concept carrot.

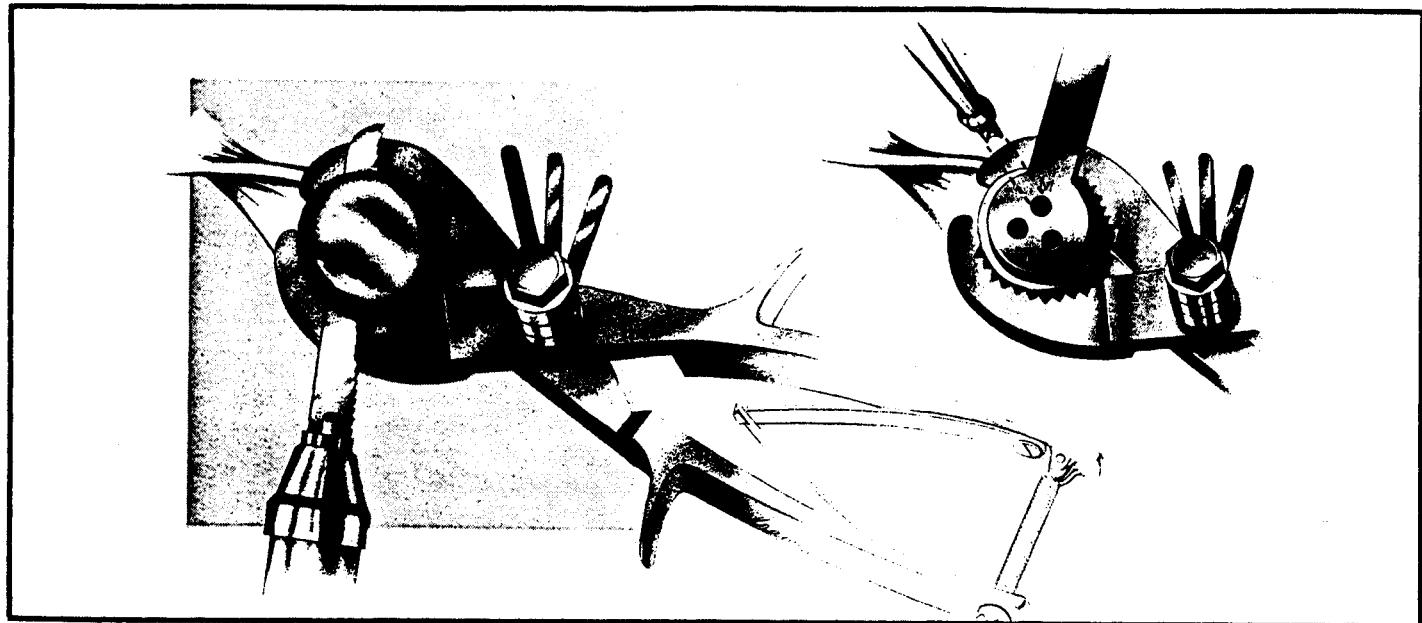


Figure 6. The patella is prepared.

screws, or press fitted. The patella is always cemented in by using Insall-Burstein patellar buttons. Tibial base plates can be held in with screws or cement. Femoral components are either cemented in, or depending on fit, held in by press fit.

When cementing, it is important to get rid of all excess cement that is extruded from around the prosthesis by use of a knife or periosteal elevator.

Caution should be taken when using methylmethacrylate. It can produce irritation of the respiratory tract, eyes, and possibly the liver. Methylmethacrylate is highly volatile. It has also been known to cause hypersensitivity and contact dermatitis. Soft contact manufacturers advise against wearing contact lenses while mixing the cement due to their high permeability. It may cause contacts to adhere to the eyes.

Complications

Patients may experience adverse reactions to the cement including cardiac arrest, pulmonary embolism, and cerebrovascular accident. The most common problems experienced are loosening or displacement of the prosthesis, surgical wound infection, deep wound infection, trochanteric bursitis, and heterotopic new bone.

After the components are in place and the excess cement is removed, the knee is irrigated with copious amounts of sterile water or sterile saline.

Closure

The knee is closed in three layers: (1) fascia, which is closed with a heavy polyglactin 910 suture no. 1, (2) subcutaneous, which is closed with a 3-0 polyglactin 910 suture, and (3) skin, which is closed with skin staples.

Before closing subcutaneously, a drain is inserted, usually with a medium or small closed suction drainage system, depending on physician preference.

Dressings

All gauge 4x4 dressings are used and opened all the way. Six-inch self-adhesive bandages with mild compression and two elastic bandages are applied.

Postoperative Care

One day after surgery, all patients are put on CPM (continuous passive motion) machines.

On day two, all patients receive physical and occupational therapy. The average length of stay in the hospital is about 1 week. After patients go home, they receive physical therapy about two to three times a week. □

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