COMPUTER-ASSISTED TOTAL KNEE REPLACEMENT ARTHROPLASTY

S. DAVID STULBERG, MD, FREDERIC PICARD, MD, and DOMINIQUE SARAGAGLIA, MD

The reliability of techniques to position a total knee replacement (TKR) is still limited by the relative inaccuracy of the instrumentation. The main obstacle encountered by mechanical instrumentation systems is the inconsistency of the reference points. These reference points are the centers of joint articulation that will allow the establishment of the mechanical axis for the lower limb. These references guide the placement of the bone-cutting guides. At present, it is impossible to accurately locate these articular centers preoperatively. This handicaps the accuracy of the mechanical instruments and limits their accuracy. The goal of the total knee instrumentation procedure is to achieve cuts that are perpendicular to the mechanical axes of the femur and the tibia. The longevity of total knee arthroplasty is closely related to its intraoperative positioning. The computer-assisted procedure offers an effective and novel positioning method that improves the accuracy of the surgical technique of the TKR. We have chosen to present the steps of the computer-assisted TKR technique next to the corresponding steps of a currently available, mechanically based technique that is representative of many that are presently in use.

KEY WORDS: TKR, surgical technique, computer-assisted surgery

The success of total knee replacement (TKR) surgery depends on several factors, including proper patient selection, appropriate implant design, correct surgical technique, and effective perioperative care. The outcome of TKR surgery is particularly sensitive to variations in surgical technique.[1-6] Incorrect positioning or orientation of implants and improper alignment of the limb can lead to accelerated implant wear and loosening and suboptimal functional performance. A number of studies have suggested that alignment errors of greater than 3° are associated with more rapid failure and less satisfactory functional results of total knee arthroplasties.[7-11]

Mechanical alignment guides have improved the accuracy with which implants can be inserted. Although mechanical alignment systems are continually being refined, errors in implant and limb alignment continue to occur. It has been estimated that errors in tibial and femoral alignment of more than 3° occur in at least 10% of total knee arthroplasties, even when performed by experienced surgeons using mechanical alignment systems of modern design.[1,2] Mechanical alignment systems have fundamental limitations that limit their ultimate accuracy. The accuracy of preoperative planning is limited by the errors inherent to standard radiographs. With standard instrumentation, the correct location of crucial alignment landmarks (eg, the center of the femoral head, the center of the ankle) is limited during the performance of a TKR. Moreover, mechanical alignment and sizing devices presume a standardized bone geometry that may not apply to a specific patient. Even the most elaborate mechanical instrumentation systems rely on visual inspection to confirm the accuracy of the limb and implant alignment.

Computer-based alignment systems have been developed to address the problems inherent in mechanical total knee instrumentation. Although a number of computer-assisted TKR approaches are currently being developed,[12-17] we have chosen to describe in detail a technique that

- Incorporates the use of a currently available and clinically validated state-of-the-art mechanical instrumentation system
- Uses commonly available, relatively inexpensive computer equipment (eg, a desktop computer, low-end optical localizer)
- Is currently available for clinical use
- Has available preliminary multicenter results comparing the use of the system with a mechanical system. These results confirm that the system is safe, that limb and implant alignment is superior to that achieved with the mechanical system, and that initial function is equivalent to that obtained with the mechanical system.[17-21]

We have chosen to present the steps of the computer-assisted TKR technique next to the corresponding steps of a currently available, mechanically based technique, representative of many that are presently in use. Because a computer-based surgical technique introduces concepts and equipment not currently familiar to surgeons who perform TKR surgery, we hope that the juxtaposition of the 2 techniques will allow surgeons to more readily understand the rationale and the function of these new tools. Moreover, by juxtaposing the 2 techniques, we wanted to

From the Section of Joint Reconstruction and Implant Surgery, Northwestern University, Chicago, IL; and the University Department of Orthopaedic Surgery, Grenoble, France.

Address reprint requests to S. David Stulberg, MD, Professor Clinical Orthopaedic Surgery, Director Section of Joint Reconstruction and Implant Surgery, 680 N. Lake Shore Drive, Suite 1206 A, Chicago, IL 60611.

1048-6666/00/1001-0005$10.00/0

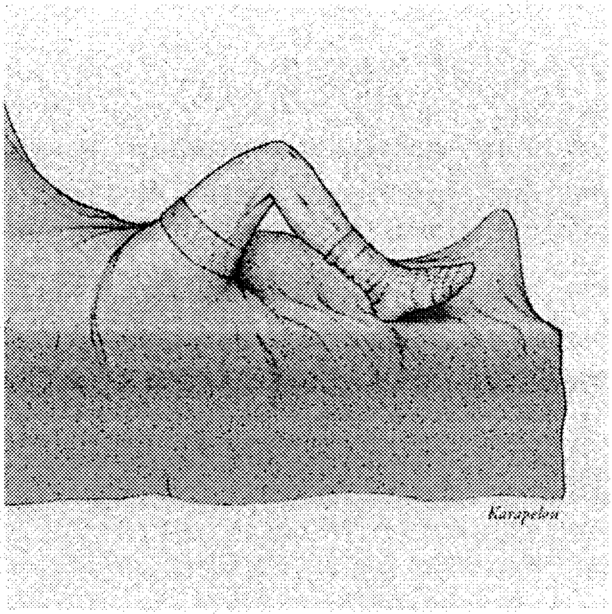

Fig 1. Positioning of the patient for surgery.

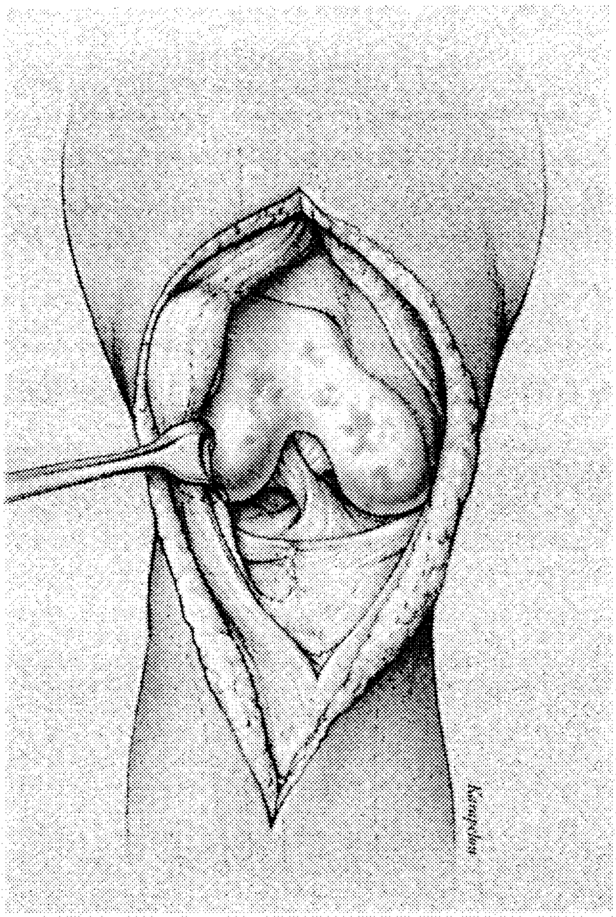

Fig 2. Incision and exposure.

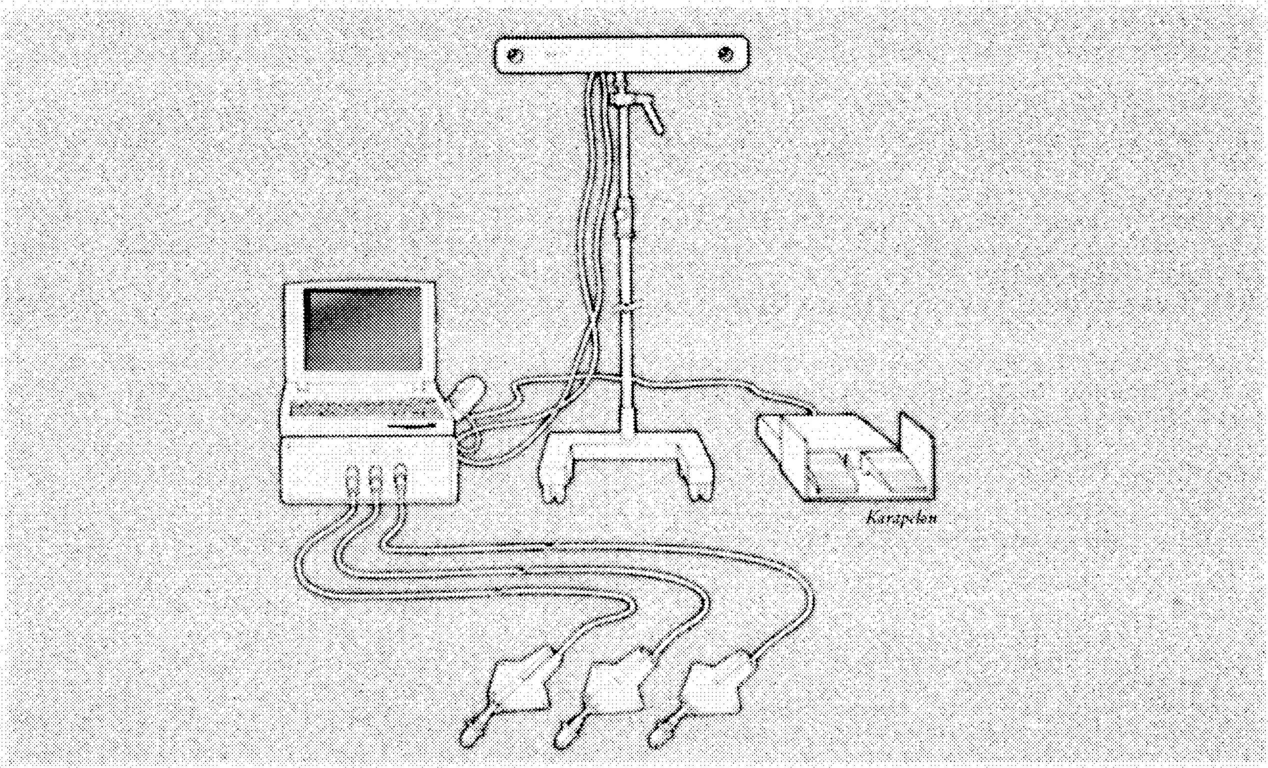

Fig 3. Computer system set up: localizer, laptop or desktop, footpedal control.

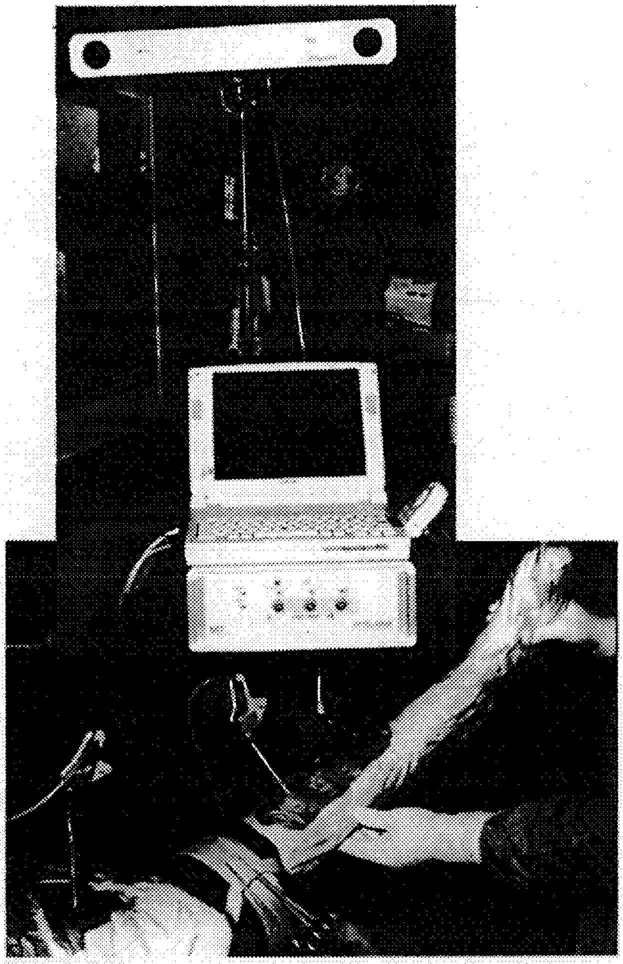

Fig 4. Computer system in the operating room.

emphasize that the alignment objectives of the 2 techniques are identical. The goal of the computer-assisted system is to increase the accuracy and reproducibility with which the objectives of a mechanical alignment system are achieved.

SURGICAL TECHNIQUE

PREOPERATIVE PLANNING

Although the 2 techniques have very similar approaches to preoperative planning, they do differ in one significant respect. Both approaches require that the surgeon determine the desired anatomic alignment (femoral-tibial angle) on a full-length (including hip and ankle joint), standing anterior-posterior (AP) radiograph. Some surgeons may also wish to determine the desired posterior slope of the tibial cut by using a lateral radiograph. This measurement can be used during either procedure. Many surgeons also find it helpful to estimate the desired size of the femoral and tibial implants by holding scaled templates of these implants against AP and lateral radiographs of the knee. The computer-assisted technique eliminates the need for this preoperative step because measurements are made during the procedure to determine the most appropriate implant size.

PATIENT POSITIONING AND SURGICAL EXPOSURE

The mechanical alignment and computer-assisted surgical techniques use similar approaches for patient positioning and surgical exposure (Fig 1). Leg holders and pneumatic tourniquets, routinely used with mechanical instrumentation, can also be used for the computer-assisted technique. The computer-assisted technique requires that the ipsilateral iliac crest be sterilely washed and draped to allow placement of a screw to hold one of the rigid bodies.

No alterations in the surgical incision usually used for TKR surgery need to be made for the computer-assisted technique. Although this procedure will require the placement of rigid body holding screws in the proximal tibia and distal femur, the sites for these screws can be reached through a conventional incision and exposure (Fig 2).

We prefer a straight midline skin incision and a medial para patellar exposure of the knee. This exposure extends distally along the medial-most edge of the quadriceps tendon and patella to a point just medial and distal to the patellar tendon insertion on the tibial tubercle. The superficial and deep medial collateral ligament is elevated around the anterior medial half of the tibia, and the infrapatellar fat pad. The ligamentum mucosum and anterior lateral capsule are elevated from the anterior-lateral surface of the tibia. The patellar is everted laterally, and the knee is placed in 90° of flexion. The anterior cruciate ligament is resected, the osteophytes are removed, and the fat pad trimmed to allow adequate exposure of the tibia.

LOCATING THE CENTERS OF THE HIP, KNEE, AND ANKLE JOINTS

The mechanical surgical technique uses jigs and alignment rods to locate the centers of the hip, knee, and ankle joints. These determinations are made during the surgical procedure. The computer-assisted technique requires that the centers of these joints be determined before the positioning of the rods and jigs. To determine these joint centers, equipment unique to computer-assisted surgery must be used. This equipment is also used to guide the positioning of the cutting blocks during knee replacement.

The equipment includes: (1) an optical localizer; (2) rigid bodies containing diodes; (3) 3.5-mm stainless steel bicortical screws specifically designed to hold one of the rigid bodies on the bone; (4) a metal plate to hold a rigid body to the foot; and (5) a computer, a monitor, and a foot control. The localizer consists of cameras that detect the infrared radiation emitted by the diodes contained in the rigid bodies (Fig 3). The rigid bodies are securely affixed to the bones by using the bicortical screws so that they do not move relative to the bones when the leg is flexed, extended, and rotated. The localizer is connected to the computer and the monitor. The position of the leg and bones can be seen on the computer screen when the surgeon activates the foot control. To correctly determine the centers of the hip, knee, and ankle joints, it is necessary to place rigid bodies on the pelvis, femur, and tibia. The presence of the rigid body on the pelvis assures that any pelvic motion that occurs when the leg is moved is monitored. The position of the leg relative to the pelvis, therefore, is always known. When this combination of rigid bodies is used, it is possible for

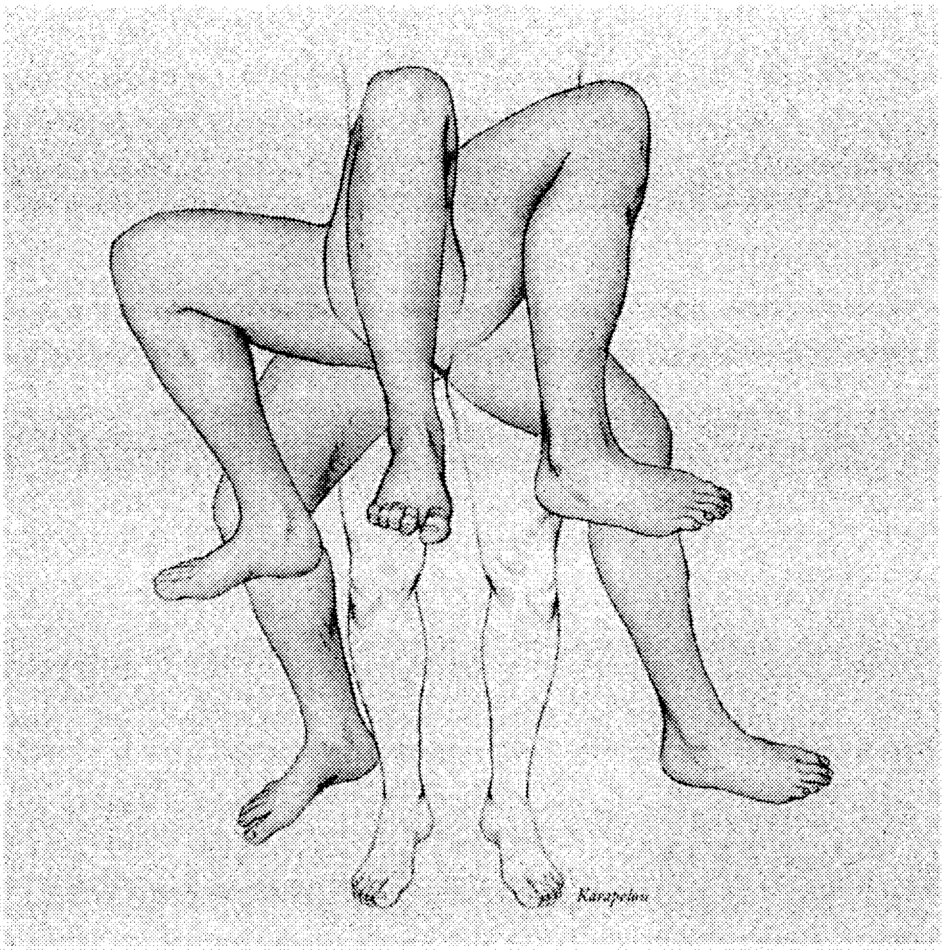

Fig 5. Rotational technique to determine the center of the femoral head.

the localizer to determine the center of the joints to within 1 mm (Fig 4).

The screws that hold the rigid bodies are inserted at the beginning of the surgical procedure. The pelvic screw is placed in the ipsilateral iliac crest through a small stab incision. The femoral and tibial screws are placed immediately after making the skin incision and exposing the knee joint. The femoral screw is inserted into the medial cortex just proximal to the medial femoral condyle at a 45° angle to the long frontal axis. The tibial screw is inserted into the anterior-medial cortex approximately 5 mm below the tibial plateau. The heads of these screws have been specially designed to hold the rigid bodies.

The center of the femoral head is determined by securing rigid bodies to the pelvic and femoral screws. The femur is then flexed, extended, abducted, adducted, and rotated. This movement generates a cloud of points on a sphere. The center of the sphere (ie, the femoral head) that created this array of points can then be imputed (Fig 5).

The center of the knee joint is determined by securing rigid bodies to the femur and tibia (Fig 6). The knee joint is then flexed and extended and internally and externally rotated in 90° of flexion. This movement allows the center of rotation of the knee joint to be calculated (Fig 7). A surface registration technique is then used to confirm the center of knee joint rotation. The surgeon selects a series of points with the registration probe on the posterior medial and lateral femoral surfaces, and the anterior distal femoral cortex. The rotational center of the distal femur can then be calculated and compared with the location determined by flexing, extending, and rotating the tibia on the femur.

The surface registration step also provides the surgeon with information to be used later in the procedure. The optimal size of the femoral component, which is the size that most closely corresponds to the AP dimensions of the femur as measured by palpating the posterior surfaces of the femoral condyles and the anterior femoral cortex, is automatically calculated. The frontal plane of the femur can also be defined when the location and orientation of the posterior femoral condylar surfaces are determined. The size of the femoral component and the frontal plane of the femur are stored in the computer and provided to the surgeon during the preparation of the distal femur.

The center of the ankle joint is determined by attaching a metal plate and an elastic band to the sole of the foot. A rigid body is attached to this plate. A second rigid body is placed in the tibial screw. The ankle joint is then flexed and extended. This movement allows the center of rotation of the ankle joint to be calculated (Fig 8). A surface registration technique is used to confirm this center of ankle rotation. The middle of the medial and lateral malleoli and the center of the talus are palpated with the registration probe. These points allow the center of the ankle joint to be calculated. This center is compared with the location determined by flexing and extending the joint (Fig 9). The surface registration of the ankle also provides the surgeon

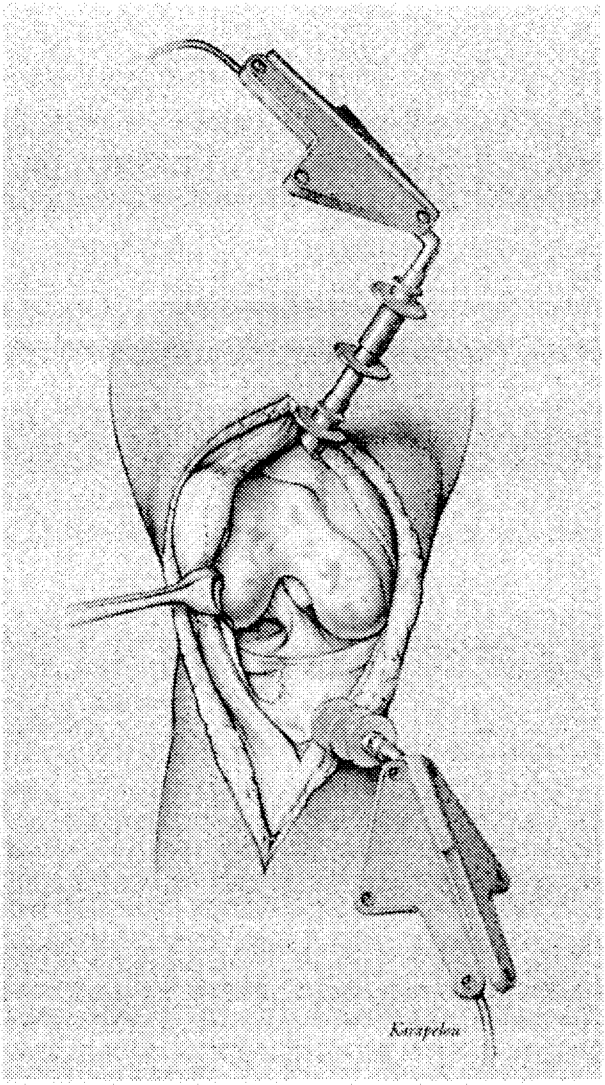

Fig 6. Rigid bodies secured to the femur and tibia.

with information that will be used later in the procedure. The location of the midpoints of the malleoli and the center of the ankle joint allow the sagittal and frontal planes of the tibia to be calculated. This information is stored and provided to the surgeon during the preparation of the proximal tibia. Once the centers of the hip, knee and, ankle joints are determined, the femur and tibia can be accurately prepared.

PREPARATION OF THE TIBIA AND FEMUR

The sequence of preparation is the same for the mechanical and computer-assisted techniques.

Tibial Preparation

Mechanical technique. An intramedullary or extramedullary alignment device is placed into or on the tibia. The medial-lateral midpoint of the tibial plateau is determined. The center of the tibial spine is often selected to represent this point. The proximal portion of the tibial instrumentation system is placed in such a way that the intramedullary or extramedullary rod intersects the proximal medial-lateral midpoint of the tibial plateau. An ankle clamp helps position the distal portion of an extramedullary rod over the midportion of the talus. This point represents the medial-lateral midpoint of the ankle joint. An intramedullary rod completely inserted into the tibia also rests over the midpoint of the talus (Fig 10).

If an extramedullary alignment system is used, the device is placed in a position that brings the rod parallel in the sagittal plane to the long axis of the tibial shaft (Fig 11). If an intramedullary alignment device is used, the completely inserted rod will be parallel to the long axis of the tibia in the sagittal plane.

A proximal tibial cutting block attached to either the intramedullary or extramedullary alignment rod is placed along the anterior surface of the tibia proximal to the tibial tubercle. A stylus attached to the cutting block allows the surgeon to determine the desired level of the tibial resection. The posterior slope of the proximal tibial cut is determined by selecting a block with or without a predetermined posterior slope (eg, 5°).

The rotation of the proximal tibial cut is made by placing the entire tibial device (rod and cutting block) so that it is directed along the AP line of the spine of the tibial plateau or, alternatively, so that it is directed toward the medial one third of the tibial tubercle. The cutting block is secured to the tibia with pins. The proximal tibial cut is then made.

Computer-assisted technique. The tibial alignment guide used in the computer-assisted technique is virtually identical to that used in the extramedullary mechanical alignment technique described previously. This guide is positioned against the leg and secured at the ankle with clamps and at the knee with 2 threaded pins inserted through holes on the cutting block (Fig 12). Once the alignment device is positioned, the computer technique is used to determine the orientation of the frontal and sagittal cuts and the depth of the resection. Rigid bodies are attached to the screw in the proximal tibia and to the cutting block. The position of the cutting block relative to the tibia can, therefore, be calculated and depicted on the monitor.

The location of the cutting block on the tibia is depicted on the screen of the monitor as a red line. A green line represents the desired orientation of the cutting block, (ie, perpendicular to the mechanical axes in the frontal and sagittal planes). A series of wheels on the alignment guide allow the surgeon to tilt the cutting block until the red and green lines overlap (Fig 13). The block is then locked to the alignment guide in this position. The surgeon uses a probe to palpate and record the level of the medial or lateral plateau. The surgeon uses this information to determine the level of the tibial resection (eg, 2 mm below the most involved side). The cutting block can then be positioned, by using the wheels and the graphical depiction on the monitor, at this desired level. Once the position of the cutting block is determined, the device is fixed to the proximal tibia with 4 threaded wires. A standard tibial cut is made with an oscillating saw (Fig 14).

DOCKET ALARM

Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

Real-Time Litigation Alerts

Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

Advanced Docket Research

With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

Analytics At Your Fingertips

Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.

WHAT WILL YOU BUILD? | sales@docketalarm.com | 1-866-77-FASTCASE

fastcase®
Smarter legal research.