Reprinted from CLINICAL ORTHOPAEDICS, April, 1986
Volume 205

Technical Considerations in Total Knee Arthroplasty

LAWRENCE D. DORR, M.D.* AND RICHARD A. BOIARDO, M.D.**

Results with total knee arthroplasty as published in this issue show few mechanical failures in knees correctly aligned. If the principles of technique are respected, the narrow limits for margin of error can be met. To provide optimal results, the following measures are recommended. The tibia should be cut no more than 5 mm from the medial subchondral bone, if the posterior cruciate ligament is sacrificed, and between 5 mm and 8 mm, if the posterior cruciate is saved. Fill a defect as necessary with bone graft. The tibia should be cut 90° to its axis in the medial-lateral plane and with 5° posterior tilt. Maintain the anterior-posterior height of the femur to ensure flexion stability. Use the distal femur as the "adjustment cut" even if the joint line is elevated. If the posterior cruciate ligament tension is tight, lengthen the ligament or convert to a sacrificing design. Deformity should be corrected with soft tissue release and not angular bone cuts. The patella cut should be performed so that the result is a symmetrical patella that is not increased from its anatomic height. If these principles are followed, the instrumentation use and order of osteotomy of the distal femur or tibia do not matter.

CONTROVERSIES IN TECHNIQUE

Several significant variables affecting prosthetic loosening come under the direct control of the surgeon both preoperation and at the time of the index arthroplasty. These variables include alignment of the extremity and prosthetic components, achievement of proper soft tissue and ligament tension, level of tibial bone resection, and cement technique. If these variables are optimized, mechanical failure secondary to component loosening will decrease.

Coventry[3] has noted that the most critical factor in preventing loosening is correct axial alignment. Lotke and Ecker[14] have correlated good clinical results to good limb alignment. In this study, the level of proximal tibial bone resection and overall leg and prosthetic alignment were the most important factors in the prevention of loosening.[4] Reviews of the Geomedic,[18] total condylar,[11] Duopatellar,[17] (ICLH™),[8] and University of California, Irvine (UCI™),[6] support the contention that malalignment is the number one cause of loosening.

Malalignment causes failure of fixation because of abnormal loading of bone. The subchondral bone of the tibia has been wholly or partially removed during bone preparation of the proximal tibia. The underlying cancellous bone will therefore assume much higher loads after total knee arthroplasty. Tolerance of this cancellous bone for overload will be significantly decreased.[15] In a normal knee, the load vector during gait falls medially, resulting in a varus moment arm and increased medial loads (thus the increased density of medial subchondral bone). If limb alignment postoperation is less than 3° of valgus or tibial component is in 5° or more of varus, the load on the unprotected medial cancellous bone is

* Consultant in Orthopaedics, Rancho Los Amigos Medical Center, Downey, California, Associate Clinical Professor, Department of Surgery/Orthopaedics, University of California, Irvine, California, and Associate, Kerlan-Jobe Orthopaedic Clinic, Centinela Hospital Medical Center, Inglewood, California.

** Fellow, Kerlan-Jobe Orthopaedic Clinic, Centinela Hospital Medical Center, Inglewood, California.

Reprint requests to Lawrence D. Dorr, M.D., Rancho Los Amigos Medical Center, 7601 East Imperial Highway, 138 HB, Downey, CA 90242.

Received: February 27, 1985.

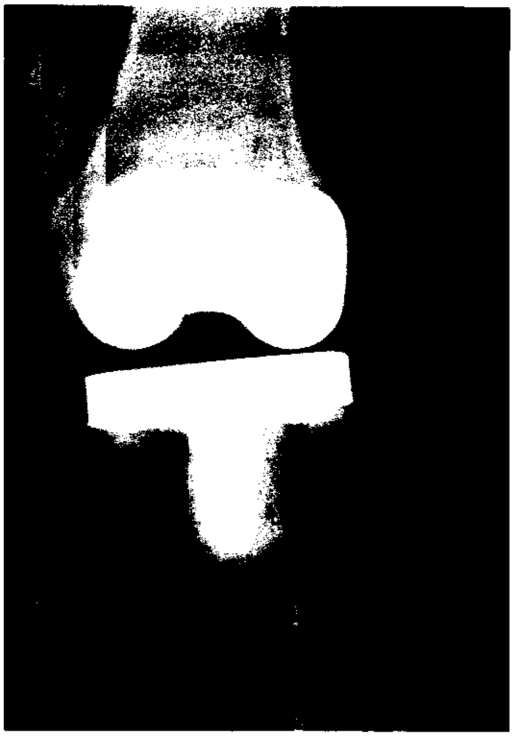


FIG. 1. Asymmetrical loading seen on roentgenograms. The femoral component contacts only one tibial plateau.

high. The incidence of trabecular fractures may occur at a rate such that the bone cannot maintain the same rate of healing. Failure results at the bone–cement interface, with possible sinkage and subsidence of tibial component. The situation is further complicated in the presence of soft tissue imbalance so that asymmetrical loading of the tibia is present (Fig. 1).

Attainment of proper lower extremity and prosthetic alignment is therefore essential. The anatomic axis is the angle formed by the axis of the femoral and tibial bones. Standing alignment of the lower extremity varies slightly with somatotype, but is defined by Kapandji[12] as 5°–7° of valgus for the anatomic axis. Recommended anatomic axis for total knee arthroplasty is 7° valgus by Kettelkamp and Chao,[13] 6°–9° by Insall,[10] 3°–7° valgus by Lotke and Ecker,[14] 3°–9° valgus by Dorr *et al.*,[4] and 3°–10° valgus by Ewald *et al.*[7]

Many surgeons prefer to reference the mechanical axis for limb alignment. The mechanical axis is defined as a straight line joining the center of the femoral head to the center of the knee joint to the center of the ankle joint. The mechanical axis has been shown to have a 2°–3° varus angulation rather than be a straight line.[9] The Porous Coated Anatomic (PCA™) Knee System advocates the use of a 3° varus tibial cut to reproduce the mechanical axis and keep the joint parallel to the ground during stance. All other knee systems have tried to cut the tibia 90° to the axis of the bone to prevent any tilt of the component. Prosthetic obliquity increases the shear forces on the cement–bone interface and can predispose to loosening. Hungerford believes that prosthetic tilt will be present during stance and gait if 3° varus is not cut into the tibia. Freeman, Insall, Ranawat, and Sledge, among others, believe the knee can be parallel to the floor during gait with a 90° axial cut. Further controversy exists as to whether the tibia or femur should be cut first to obtain ideal results. These conflicting views confuse many surgeons and will be discussed.

PRINCIPLES OF TECHNIQUE

The principles of technique of total knee arthroplasty are based on achievement of proper alignment of the components and limb, stability of the knee, and satisfactory range of motion for activities of daily living including stair-climbing and sitting-to-standing transfers. Total knee arthroplasty is a precise operation because of the narrow limits for a satisfactory result. Limb alignment must be between 3° and 9° of valgus, which means that one should try to attain 5°–7° of valgus to allow a 2° margin of error. The mechanical axis or the anatomic axis can be used as a reference for correct limb alignment. Instrumentation that provides for 5°–7° of valgus will permit a good result.

Alignment of the limb can be within satisfactory limits when alignment of the components is not. If 7° of limb valgus is achieved with a 12° valgus femoral component and a

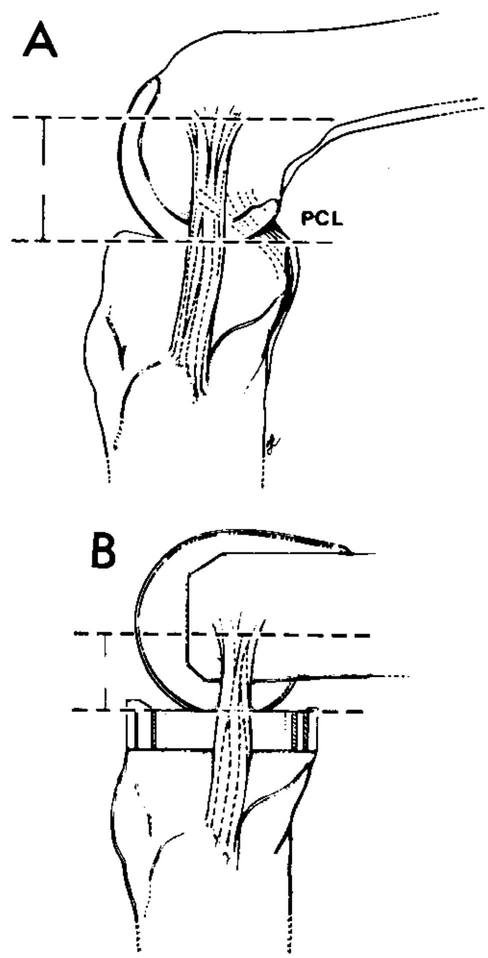
5° varus tibial tray, the arthroplasty is not ideal. A 12° femoral valgus cut will not permit correct tracking of the extensor mechanism in the trochlea. The patella will ride against or on the lateral runner of the femoral component. The tibia should be within the limits of 2° valgus to 3° varus and the femur 5°–8° valgus. Incorrect component placement may also result in instability. Excessive varus or valgus of the components or incorrect rotational placement may cause asymmetrical loading and translational (side-to-side) subluxation.

Instability is also a reflection of soft tissue balance, both medial-lateral and anterior-posterior. Soft tissue balance in extension can always be achieved by cutting more distal femur or proximal tibia and filling the space created with the appropriate tibial plastic height. The tension of the posterior structures and medial collateral ligament will provide stability. However, improper or excessive bone cuts will compromise ligament function in flexion.

For soft tissue stability in flexion, the most important factor is the maintenance of the length of the medial collateral ligament to the joint line (Fig. 2A). Correct medial collateral ligament tension in flexion can only be present if the height of the posterior condyles of the femur are maintained (Fig. 2B). If the posterior condyles are removed, the medial collateral ligament becomes lax in flexion and both medial-lateral and anterior-posterior stability is compromised. If the posterior cruciate ligament is sacrificed, the knee may sublux or dislocate. If the posterior cruciate ligament is saved, the knee may "hang" on the posterior cruciate with asymmetrical loading and posterior pain.

Finally, range of motion is not optimal unless the patient attains 105° of flexion to permit easy stair descent and standing from a chair. Posterior tilt of the tibia must be reproduced. This is done by either cutting the tibia with a 5°–10° posterior angulation or using a tibial component with a posteriorly sloped tibial polyethylene.

To achieve optimal results with alignment, stability, and motion, does the sequence of



FIGS. 2A AND 2B. (A) A normal knee illustrating the length of the medial collateral ligament (MCL). Note the length of the MCL from its femoral insertion to the joint line. (B) Excision of the bony posterior femoral condyles at the time of arthroplasty significantly shortens the radius of the MCL to the joint line.

bone cuts make a difference? Does preservation of the posterior cruciate ligament require special considerations in technique?

TECHNIQUE AND SEQUENCE OF BONE CUTS

Whether or not to cut the tibia first and use the distal femur as an adjustment cut or to cut the distal femur first and adjust with the tibia? This question is currently the focus of much

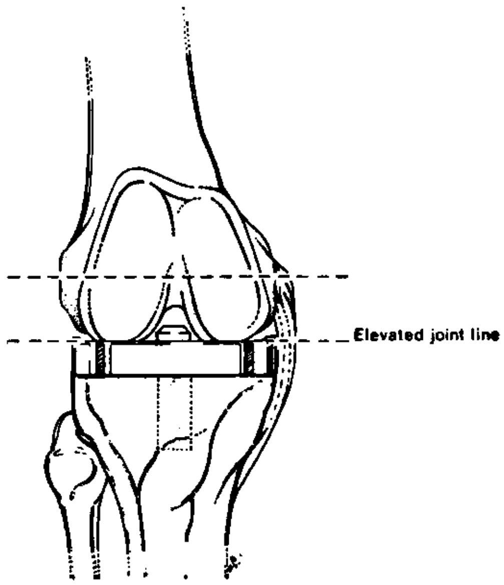


FIG. 3. Elevated joint line caused by excision of excessive distal femoral bone, most commonly in a knee with a flexion contracture of 20° or more.

discussion. Furthermore, technique is somewhat different depending on whether the posterior cruciate ligament is saved or sacrificed.

Ideally, bone cuts should be done to provide a "surface replacement" of the knee. This means the depth of bone removed is no more than that replaced with metal or plastic. All bone cuts would be done independently so that only the correct amount of bone is removed and ligament tension is anatomically maintained. Unfortunately, deficits of the bone and angular deformities that require soft tissue release prevent this ideal from often being available. What technique then will most often provide predictable and reproducible results?

FEMORAL CUT

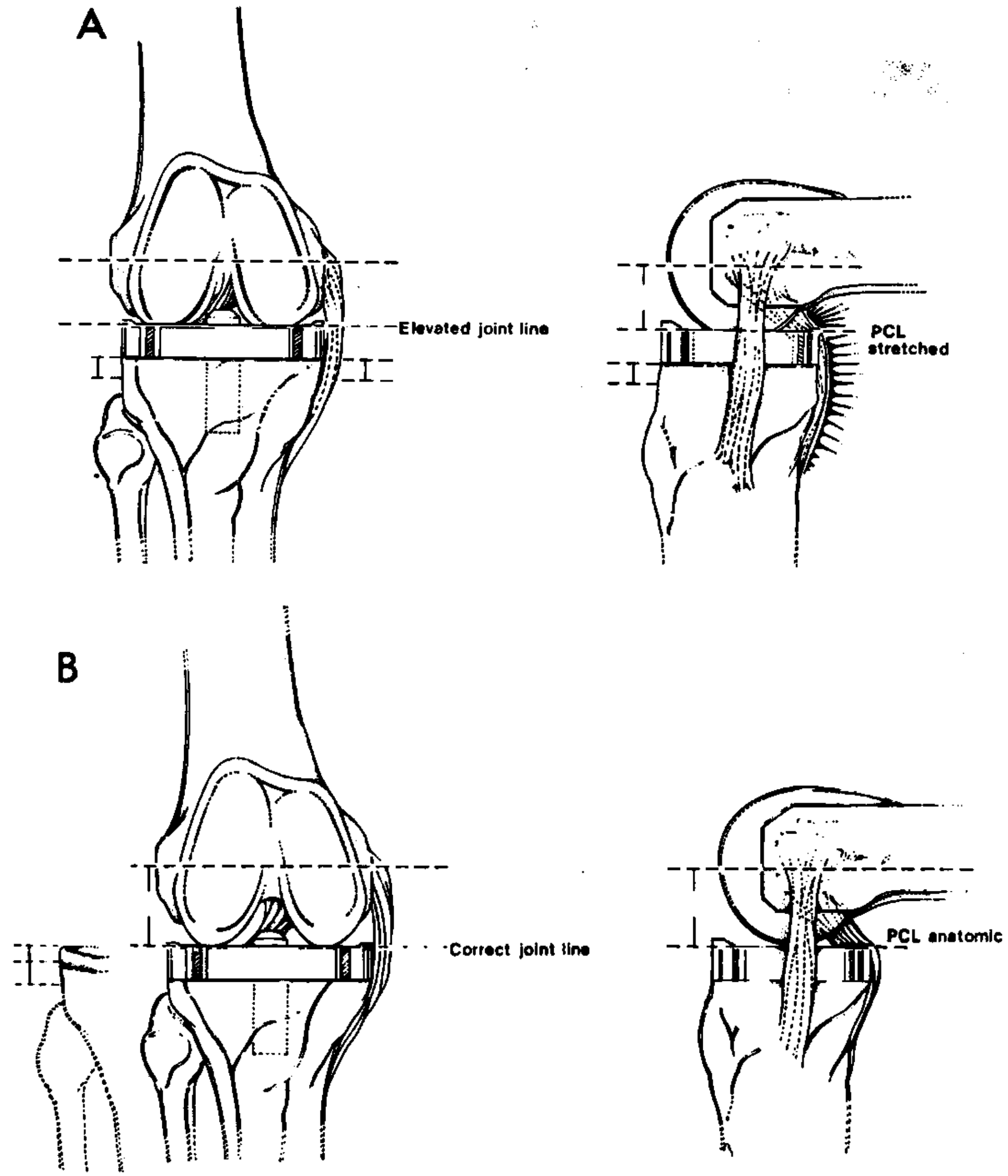
For optimal function with preservation of the posterior cruciate ligament, maintenance of the length of the medial collateral ligament and the posterior cruciate ligament to the anatomic joint line is critical. Therefore, bone removal from the distal and posterior femoral condyles must not be much more than that replaced by the component. If the posterior cruciate ligament is saved, the femoral cuts are done first to insure that the level of the joint line is proper. The ligaments are dependent on the femoral bone height because the femur has the radii of curvature that allows the knee to roll. The cruciate tension must not be too tight (by lengthening the distal femur or posterior femoral condyles) or the knee will be stiff and painful; likewise, if excessive distal or posterior femoral bone is removed, the knee can be unstable because the joint line is elevated (Fig. 2).

Although the great advantage of controlling the depth of the femoral cuts is maintenance of correct ligament length to the joint line, the primary disadvantage is using the tibia as the adjustment cut. With flexion contracture or severe angular deformity, excessive tibial bone may be sacrificed during balance of the flexion and extension space. Already described is the decreasing strength of the tibia distal to the subchondral bone,[2,19] and the potential for loosening caused by excessive tibial bone removal.[4]

Emphasis must be placed on the depth of the tibial cut as the only drawback to initially making all femoral cuts. No problem is present if one is willing to make all cuts, limiting the tibia to no more than 8 mm of proximal bone, and then balancing the knee when necessary by recutting the distal femur. Hungerford[9] has suggested this solution. If the resultant elevation in joint line position increases the tension on the posterior cruciate ligament, he recommends lengthening the ligament. The authors would prefer conversion to a posterior cruciate sacrificing design.

TIBIAL CUT

The tibia is the site of almost all component mechanical failure. For this reason, many surgeons believe this cut is inviolate. The tibial cut must avoid excessive varus and depth. Furthermore, femoral bone is twice as strong as tibial bone,[2] so that one sacrifices less strength of bone when using the femur as the adjustment cut. If the posterior cruciate ligament is sacrificed, 5 mm or less of tibial bone



FIGS. 4A AND 4B. (A) Elevated joint line caused by removal of only 2–3 mm of bone and retention of the posterior cruciate ligament (PCL). The space marked under the tibial component indicates the amount of bone that should have been removed with PCL retention. The PCL is stretched and the knee may be stiff and painful. (B) The correct level of tibial cut has been made to maintain the anatomic joint line. The inset illustrates that 5–6 mm of bone resection when added to the normal 2–3 mm of articular cartilage will allow a 7 or 8 mm tibial tray to articulate at the joint line.

is all that ever needs to be removed. Cutting the posterior cruciate ligament opens the flexion space an additional 3–4 mm, so that satisfactory space is available for the tibial component. However, in a tight knee or one with a flexion contracture, more distal femoral bone

FIG. 5. The patella is cut symmetrically, rides centrally, and shows no evidence of loosening.

will be removed than is replaced with metal, thus elevating the joint line (Fig. 3). Elevation of the joint line by 1 cm or more is not detrimental if the cruciate is sacrificed.[5]

If the posterior cruciate is saved, the tibia must be cut deeply enough to keep the joint line anatomic (Fig. 4). Therefore, to use a 7–8 mm component, at least 5–6 mm of bone will be removed. If a flexion contracture is present, an even deeper cut will be required to allow the tibia to be brought to full extension: do not make this cut on the tibia, but rather return to the distal femur.

The greatest technical controversy at this time is whether or not to cut the tibia 90° to its axis or with a 2°–3° varus cut. A 2°–3° varus cut does not adversely affect results. In fact, reviews of total knee arthroplasty reveal that in attempting a 90° cut the average result is 2° of varus.[7] This inability to consistently, precisely cut the desired angle is the danger of the 3° varus cut. Too often a 5° cut will result and this amount of varus jeopardizes results. Rand and Bryan[16] found that in attempting to achieve 3°, the average cut was 4.5° varus, which left the limb aligned in less valgus than desired. The joint line will be parallel to the floor with a 90° tibial cut and a 7° valgus femoral cut. For this reason, almost all total knee centers use a 90° tibial cut.

An important factor in tibial bone preparation is to limit the depth of the cut. This means that deformities and bony deficits are not corrected by deep tibial cuts. Do not cut the tibia at the bottom of a bony deficit to insure a flat surface. Control the level of tibial cut and if the defect remains, treat the defect. The authors recommend bone grafts (see article on bone grafts in this issue). Bartel *et al.*[1] suggest custom components, and Scott and Walker have developed metal wedges.

Finally, little controversy remains about the importance of a posterior tilt to the tibia for good range of motion. Townley[20] has advocated cutting the tibia with an 8° posterior tilt. Insall–Burstein have provided a 7° posterior tilt in the tibial tray, so that a 90° anterior-posterior cut is done. Even with a sloped plastic, a slight (2°) posterior tilt to the tibial cut is suggested. This will insure that no anterior tilt is created. Anterior tilt of the tibia causes posterior wedging, which will prevent good flexion range of motion. If the posterior cruciate ligament is saved and anterior tilt is created, severe loss of flexion can occur. A posteriorly angled cut does not endanger the cement–bone interface, as does a varus cut. The posterior bone is strong in the proximal tibia and absorbs the applied load well. Further, because the tibia has an anatomic posterior tilt, minimal posterior bone is removed with a posteriorly angled cut. The range of motion of total knees (using standard total condylar) improved from 90° flexion to 110° flexion by simply using a 5°–10° posterior tilt.

PATELLA CUT

The most common cause of painful total knees is extensor mechanism imbalance and poor tracking of the patella. For this reason patellar bone preparation and tracking balance must be done with strict attention to detail. Two factors must be remembered in making the patella cut.

Firstly, the bone cut should produce a symmetrical patella (Fig. 5). To achieve this cut, more bone is removed medially and centrally than from the lateral facet. A flat cut results with equal thickness (which can be confirmed by palpation) of the medial and lateral patella. The incidence of tilting is minimized if an uneven cut is avoided.

Secondly, the height of the patella is critical, particularly if the posterior cruciate ligament is retained. Just as with the tibia, more bone must be removed when this ligament is saved. If minimal bone is removed so that the implant increases overall height of the patella, the extensor mechanism during flexion becomes tighter than normal. With the posterior cruciate ligament saved the posterior rollback of the knee can be restricted, tension on the posterior cruciate increased, and a stiff knee results. When the posterior cruciate is sacrificed, patellar height is less important. Increased height may in fact increase anterior-posterior stability. The average height of the patella is 25 mm, and this can be measured by opening a tonsil clamp across the anterior-posterior diameter of the bone plus implant then placing the open jaws on a ruler. A large bony patella will be 25–30 mm, and a small, 20–25 mm.

REFERENCES

1. Bartel, D. L., Burstein, A. H., Santavicca, E. A., and Insall, J. N.: Performance of the tibial component in total knee replacement. Conventional and revision designs. J. Bone Joint Surg. 64A:1026, 1982.
2. Behrens, J. C., Walker, P. S., and Shoji, H.: Variation in strength and structure of cancellous bone at the knee. J. Biomech. 7:201, 1974.
3. Coventry, M.: Two part total knee arthroplasty. Evolution and present status. Clin. Orthop. 145:29, 1979.
4. Dorr, L. D., Conaty, J. P., Schreiber, R., Mehne, D. K., and Hall, D.: Technical factors that influence mechanical loosening of total knee arthroplasty. *In* Dorr, L. D. (ed.): The Knee. Papers of The First Scientific Meeting of The Knee Society. Baltimore, University Park Press, 1985, pp. 121–135.
5. Dorr, L. D., and Yee, L.: Preservation of the joint line in total knee arthroplasty. *In* Dorr, L. D. (ed.): The Knee. Papers of The First Scientific Meeting of The Knee Society. Baltimore, University Park Press, 1985, pp. 75–82.
6. Ducheyne, P., Kagan, A., and Lacey, J. A.: Failure of total knee arthroplasty through loosening and deformation of the tibial component. J. Bone Joint Surg. 60A:384, 1978.
7. Ewald, F. C., Jacobs, M. A., Walker, P. S., Thomas, W. H., Scott, R. D., and Sledge, C. B.: Accuracy of total knee replacement component position and relation to bone–cement interface reaction. *In* Dorr, L. D. (ed.): The Knee. Papers of The First Scientific Meeting of the Knee Society. Baltimore, University Park Press, 1985, pp. 117–120.
8. Goldberg, D., and Henderson, B.: The Freeman-Swanson ICLH total knee arthroplasty, complications and problems. J. Bone Joint Surg 62A(8):1133, 1980.
9. Hungerford, D., Krackow, R., and Kenna, R.: Total Knee Arthroplasty: A Comprehensive Approach. New York, Williams & Wilkins, 1983.
10. Insall, J. N.: Technique of total knee replacement. *In* Dorr, L. D. (ed.): The Knee. Papers of the First Scientific Meeting of The Knee Society. Baltimore, University Park Press, 1985, pp. 23–26.
11. Insall, J. N., Scott, W. N., and Ranawat, C. S.: The total condylar knee prosthesis—A report of 220 cases. J. Bone Joint Surg. 61A(3):173, 1979.
12. Kapandji, I. A.: Physiology of the Joint. London, Churchill-Livingston, 1970.
13. Kettlekamp, D., and Chao, E. Y.: Method for quantative analysis of medial and lateral compressive forces at the knee during standing. Clin. Orthop. 83:202, 1972.
14. Lotke, P., and Ecker, M.: Influence of Position of Prosthesis in Total Knee Replacement. J. Bone Joint Surg 59A:77, 1977.
15. Malluche, H. H., Faugere, M. C., and Dorr, L. D.: Static and dynamic bone histology in primary and revision total knee arthroplasty. Trans. Orthop. Res. Soc. 9:105, 1984.
16. Rand, J. A., and Bryan, R. S.: Alignment in porous coated anatomic total knee arthroplasty. *In* Dorr, L. D. (ed.): The Knee. Papers of the First Scientific Meeting of The Knee Society. Baltimore, University Park Press, 1985, pp. 111–116.
17. Scott, R. D.: Duopatellar total knee replacement–Brigham experience. Orthop. Clin. North Am. 13(1): 89, 1982.
18. Skolnick, M., Coventry, M., and Ilstrup, D.: Geometric total knee arthroplasty, a two-year follow-up study. J. Bone Joint Surg. 58A:749, 1976.
19. Snepper, O., Christianson, P., Larson, H., and Jong, P. S.: Mechanical testing of trabecular bone in knee replacement. Int. Orthop. 5:251, 1981.
20. Townley, C. O.: The anatomic total knee: Instrumentation and alignment technique. *In* Dorr, L. D. (ed.): The Knee. Papers of The First Scientific Meeting of The Knee Society. Baltimore, University Park Press, 1985, pp. 39–52.