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Knee Arthroplasty

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Thesis submitted for the Degree of Ph.D.,
University of Surrey, Guildford, September 1982.
Summary

In November 1971, following two years basic design work, the first semi constrained knee implant was inserted in a patient. The following decade has seen enormous technological advances in this field both in relation to design, surgical techniques, indications, contraindications for surgery and instrumentation.

This work summarises the pioneering work in the development of a knee prosthesis which has established its reputation in the world literature.

Mechanical and design modification have occurred as a result of the analysis of failures. Advances in material science have helped produce more durable prostheses with greatly improved wear characteristics.

Above all, a detailed follow up of 450 patients with knee prostheses personally implanted have allowed documentation and analysis of the problems associated with this most complex form of surgery.
Acknowledgements

I would like to acknowledge my since thanks to the many people who assisted me with this work since 1969.

To the staff of the Department of Engineering in the University of Surrey and in particular to Mr. Frank Hayden who helped enormously with the initial design work.

To Professor Ian Allison for his help and advice with the preparation of this thesis.

To Professor Zarek for his help and encouragement since 1969 and for the enthusiasm which he himself showed and transmitted to those around him and in particular for his help as supervisor of this project.

To my colleagues, Mr. Joseph Gallagher, FRCSI, for his help and comments on the clinical applications.

To Mr. Anthony Browne, FRCSI, for his help in the latest review of patients.

To Mrs. N. O'Connor, my secretary, who has typed and retyped this text on numerous occasions.

To Mrs. Yvonne Shirley for the photographic work.

To the staff of Zimmer Deloro and in particular to Dr. Ian Browne for his technical help and advice.

To the numerous surgeons who have collaborated in the clinical trial.

And above all to my wife, Rosemary, for her constant help and encouragement with this work.
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Introduction

The knee joint is characterised by a high degree of stability and a wide range of movement while bearing body weight. Arthrodesis of the knee is a safe, simple operative procedure, which results in a stable pain-free outcome. This is achieved at the expense of movement and occasionally of social acceptability. In proposing arthroplasty one must be confident that the advantages of arthrodesis will be retained with the added bonus of a functional arc of movement.

The knee joint has long been recognised as a ginglymus or hinge-type joint and the earliest attempts at prosthetic replacement were based on this simple principle. However, the incidence of biological and mechanical problems following hinge arthroplasties was high, and in a number of instances the risks and complications of surgery proved prohibitive.

It took some years for clinicians to appreciate that the human knee was a much more sophisticated apparatus and that the design of a knee mechanism should ideally simulate the joint it replaces as closely as possible. This does not necessarily imply that the exact anatomical configuration of the intact joint should be copied and in fact this approach can have its own specific disadvantages, e.g., the implantation of an excessive bulk of foreign material in a superficial location. Instead adequate movement and stability can be restored by a mechanical device having a different form but achieving the same function as in the normal knee.

In recent years the knee replacement field has become more complex because surgeons and designers have advocated different appliances for varying degrees of collapse, deformity, or instability of the joint. Ideally any knee replacement should be applicable to all degrees and varieties of pathological disorders involving the joint. No knee should be considered too destroyed, too unstable or too angulated for reconstruction. In addition, reconstruction should be an easy, safe and reliable procedure.
Because of the difficulties encountered in salvage procedures for large hinge replacements, the pendulum has swung in the opposite direction, so that the current trend in prosthetic knee joint replacement is towards safety should failure occur. This has resulted in a very large number of prostheses appearing on the market that involve minimal bone resection, so that in the event of failure a salvage procedure, i.e., arthrodesis, is technically possible without gross shortening. Such surface-mounted prostheses without intramedullary fixation achieve their stability from the compressive forces acting across the joint. No form of inherent stability can exist in such joints, as their design does not permit tensile forces to be applied without a major risk of dislocation.

The phenomenal success of hip arthroplasty in the latter part of the 1960s emphasised all the more the lack of adequate knee prostheses. In particular, patients with polyarticular disease who had hip arthroplasties performed still remained grossly disabled by their knee arthropathy, and patients with knee arthropathy alone remained unoperated upon as very few surgeons were willing to subject their patients to the fairly major risks entailed in the insertion of a massive hinge prosthesis.

The results of hinge arthroplasty even in the most competent hands were at best only moderately satisfactory. Improved design and better operative technique had certainly increased the success rate, but the comments of Young (1963)¹, an enthusiast in this field, were of special interest. "It should be emphasised that on the basis of available evidence the hinged prosthesis method for arthroplasty of the knee should neither be used promiscuously nor be abandoned because of the failures observed. It is well established that the tissues can tolerate a large mass of inert inorganic material. It behoves us to work out the proper mechanics and design of the prosthesis."
In the same year, Aufranc recognized the complexity of the normal knee mechanism. "The knee joint is such a functionally complicated mechanism that to substitute a joint with only a hinge factor of motion seems a little less than desirable. In the motion of flexion, the knee has a rotatory element; in the motion of complete extension, it has a locking element through the two arcs of motion that are normally allowed by the femoral condyles. The femoral condyles are rounded in the anteroposterior and lateral planes. I think these shapes need to be incorporated into any prosthesis if we are to get a greater and freer range of motion."

The first departure from the traditional hinge type mechanism was in 1968 when Gunston introduced his hingeless polycentric arthroplasty. This was the first real effort to simulate the normal knee mechanism, and heralded a new era in knee reconstruction. The early success in such patients aroused great enthusiasm, but the disadvantages were soon apparent - the technical difficulties encountered in inserting four separate components, the inability to correct varus, valgus, or flexion deformities of any great magnitude, and the difficulties with fixation of the components if bone destruction had occurred - and these and other problems stimulated two other, distinct lines of thought:

1) The development of surface-mounted prostheses without inherent stability.
2) The development of intramedullary prostheses with some inherent stability, i.e. semi-stabilised prostheses.

The latter group of prostheses were designed to provide a means of reconstructing not only the moderately involved knee but also the knee with gross destruction where there is a shortage of bone on the articular surface and reliance cannot be placed on the integrity of the ligamentous structures.
The prosthesis to be described in this thesis was the original prosthesis in this group and was introduced into clinical trial in 1971. This was preceded by two years work devoted to bio-engineering and design considerations, and was largely carried out in the Department of Engineering in the University of Surrey. 4
Chapter 1.

History of Knee Arthroplasty

The earliest recorded attempt at joint reconstruction was made by Julius Wolff in the latter part of the 18th century. He opened up an elbow joint and without resection separated an ankylosis by knife and chisel and then by continuous motion sought to obtain mobility. Good results were reported by him and by Von Eiselberg.

The formation of a pseudoarthrosis or false joint consists of osteotomy or section of the bone, or the removal of part of the bone in the neighbourhood of an ankylosed joint. It was first attempted at the knee in 1826 by Barton.

Understandably the first operations in which surgeons attempted to produce mobility in ankylosed joints were in those conditions in which the lack of motion imperilled the life of the patient, for example, ankylosis of the jaw, or tempromandibular joint.

Early attempts using simple resection usually met with failure as the bone ends reunited. In 1860 Verneuil suggested the interposition of soft tissue between the cut bone ends to prevent their becoming adherent and for the following century this method or a minor modification of it remained the standard method arthroplasty. Every conceivable biological tissue was tried with widely varying success rates. Ferguson in 1861 reported successful function of a knee five years after joint resection and this is the earliest report in the English literature of a knee arthroplasty.
In 1900 Chlumsky performed animal experiments using absorbable and non-absorbable inorganic materials, such as tin, zinc, rubber, silver, celluloid, collodion, decalcified bone, and magnesium plates and decided that the latter were the best. Orlow soon followed with the use of metal plates in man. Over the next forty years, (1900-1939), skin, gold foil, fascia, pigs bladder, bursae, wax impregnation, were all tried successively, and even heterograft transplants of entire knees were performed.

In 1939 Smith Peterson reported the use of chrome-cobalt cups for hips and in 1942 applied the technique to the knee as did Campbell about the same time. In 1943 Burman described the properties of nylon and plastic and suggested their use in orthopaedics. Seven years later (in 1950) Kuhns and Potter described the use of nylon plaques in the knee. Three years later Taylor described the use of polytetrafluoroethylene. Sporadic reports still appear in the current literature on the results of interposition arthroplasty.

Campbell in 1921 stated "More attention should be give to reconstructing a perfect mechanical joint and less to material interposition." He was certainly right.

The death knell of the interposition era sounded in 1947 when Judet reported the first attempt at total replacement of the knee joint with an acrylic prosthesis. For the following twenty years numerous attempts were made to insert hinges of all sizes and shapes.

D'Intignano (1950) and Walldius (1953) reported the use of acrylic prostheses. Shiers (1954) was the first to report on the use of a stainless steel hinge and his report was rapidly followed by the reports of Merle D'Aubigne, Young, Anstett, Von Hellens, and MacAusland.
Buchman\textsuperscript{38} in 1953 described the use of a massive knee joint replacement eleven years previously for actinomycosis of the femur. Zarek\textsuperscript{39} in 1955 also used a hinge type joint replacement to replace a tumour of the lower femur.

The use of partial or hemiarthroplasties is a variant of the interposition method where either the lower femur or upper tibia are replaced. This method was reported in 1954 by Kraft and Levinthal\textsuperscript{40} who replaced a lower femur with an acrylic prosthesis but was popularised by McIntosh\textsuperscript{41} who advocated the use of tibial plateau plates. Platt and Pepler\textsuperscript{42} and Jones\textsuperscript{43} and Aufranc\textsuperscript{2} on the other hand replaced the lower femoral condyles.

In 1968 Gunston\textsuperscript{3} introduced his hingeless polycentric knee arthroplasty and this heralded a new era in knee replacement surgery. (Fig.1)
The principle of low frictional materials was utilised for the first time, axial rotation was permitted as well as both rolling and sliding movements, and in addition a dependence on the existing collateral and cruciate ligaments which was hitherto considered impractical. The advantages as well as the disadvantages of his design were apparent.

It was difficult to insert 4 separate components and ensure correction of alignment. There was no inherent stability in the joint and anchorage of the components in severely destroyed joints was not practical. Also correction of severe degrees of angular deformity or instability was impossible.

(a) In 1968 when the original concept of the current design was first formulated, the choice of total knee prostheses available was very limited. The Gunston prosthesis was not available commercially and three rigid hinges, the Walldius, Shiers and McKee prostheses were the only total joints available. The need for a Gunston type prosthesis without its disadvantages was obvious and thus the evolution of the current design.

Basic designs evolved independently in other centres and before introduction of the currently described prosthesis to clinical use in November 1971, the Guepar hinge was introduced in January 1970 followed by the Freeman Swanson prosthesis in April 1970 and the Geomedic Knee in March 1971.

Since 1971 numerous variations of the above designs have been introduced (Fig.2) and currently there is in excess of 400 different prostheses either at the design or clinical trial stage throughout the world.
Examples of Currently Available Prostheses

<table>
<thead>
<tr>
<th>Surface</th>
<th>Hinge</th>
<th>Semiconstrained</th>
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<tbody>
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<td>Gunston</td>
<td>Guepar</td>
<td>Sheehan</td>
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<tr>
<td>Low Angle Inlay</td>
<td>Stanmore</td>
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<tr>
<td>(Charnley)</td>
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<td>Marmour</td>
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<td>St. George</td>
<td>Shiers</td>
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<td>Geomedic</td>
<td>Young</td>
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<td>Duo-Condylar</td>
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<td>Freeman-Swanson</td>
<td>Devas</td>
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<tr>
<td>Total Condylar</td>
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<td>Leeds Knee</td>
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<td>Polycentric</td>
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<td>Kodawa &amp; Yamamoto</td>
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<td>Robert Brigham</td>
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All current knee prostheses fall into one of three basic types:

(1) The rigid hinge - this only allows flexion extension movement.

(2) The surface prosthesis - following the Gunston principle. These range from simple runners on the condylar and tibial surfaces to complex reproduction of the normal anatomical configuration as in the "Leeds Knee".

(3) Semiconstrained joints attempt to reproduce the motion and mobility of the normal knee and at the same time to offer a degree of constraint. Thus reliance on the normal ligamentous structures is diminished. However, preservation of these structures when possible diminishes the stresses to which the prosthetic joint is subjected and thus minimises the risk of failure.

It is this group of joints which demonstrate the major advances in knee prostheses over the past decade.
Establishment of Knee Design Criteria

A prerequisite to formulation of design criteria for a prosthetic knee replacement, is an understanding of knee function, anatomy, and biomechanics. A brief review of the relevant data is presented to summarise the salient features of knee function, anatomy, kinematics and static and dynamic loading.

Why do we Require a Knee Joint at all?
Biomechanically the knee's main purpose is to alter the total length of the lower extremity. This allows locomotion to proceed with minimal displacement of the centre of gravity of the body. Knee flexion also minimises the muscle energy required to move the lower limbs in space against the inertial reactions involved. The mass moment of inertia of a body is dependent not only on the mass of the body but upon the distribution of the mass of the body about the axis of rotation, (in fact upon the square of this distance). The greater the concentration of mass away from the axis of rotation, the greater the mass moment of inertia and thus the more difficult it is to change the angular velocity of the body, i.e. for the body to undergo angular acceleration. This is in fact a complicated way of stating a simple well known fact that it is more difficult to push a heavy pendulum with the weight low down (figure 3A) than it is to push a similar pendulum with the weight nearer the axis of rotation (figure 3B).
In the former the fact that the mass moment of inertia is high, is what keeps the pendulum swinging once it has been energised. The mass moment of inertia is thus dependent upon the mass and its distribution about the axis of rotation in question. In ambulation the most important moment of inertia is that about the axis of the hip joint. This inertia changes, as the knee flexes. With increasing knee flexion the moment of inertia diminishes since the distance between the hip and centre of gravity of the calf diminishes (figure 4 A & B), and thus a greater angular acceleration can be achieved when the quadriceps muscle contracts in order to propel the body forwards.

The direct converse of this principle is used by athletes in training when they use shoes with lead soles. This greatly increases the moment of inertia of the lower limb in view of the distribution of the mass and requires much stronger muscle action, and thus increases the overall efficiency of the muscles.

The lower limb of each individual - like a pendulum - has its own inherent frequency of oscillation depending on the mass moment of inertia of the limb. If the rate of ambulation approaches this frequency then minimal energy is required to propel the body just as a pendulum will swing with minimal expenditure of energy.
Human locomotion is designed to translate the centre of gravity of the body through space with minimal consumption of energy. If the centre of gravity of the body moves appreciably up and down during ambulation then considerable energy is expanded. This would in fact occur if the knee was stiff in extension. Thus knee flexion - extension not only diminishes the energy required to move the lower limb but also minimises the energy expenditure of the entire body. When the limb is thrown forwards and becomes weight bearing the body can only advance by displacing the centre of gravity. In normal gait as the body is drawn forwards on the extended leg, knee flexion gradually occurs so that minimal alteration in height of the centre of gravity occurs and thus minimal expenditure of energy (figure 5).

A limb in a pathological disorder looks unsightly. It is also accompanied by increased energy expenditure. If a point is approached where the energy expenditure is increased 50% then oxygen debt occurs and frequent rests must be taken.
Major Disadvantages of a Stiff Knee

1) Loss of energy absorbing mechanism of the knee. A rigid column when loaded vertically deforms and the energy stored is determined by the load deformation curve (figure 6).

![Diagram of load deformation curve]

The energy absorbed to failure of a femoral neck has been found experimentally to be 60 kg.cm. whereas a 50 kg. woman falling to the floor develops 2700 kg.cm. of kinetic energy which must be dissipated when she hits the floor\(^4\). A major factor in energy dissipation is muscle action and elastic and plastic strain energy in the muscles and bones. Such energy dissipation in the lower limb is largely dependent on controlled knee flexion. The extreme loss of energy dissipation in the lower limb can be readily demonstrated by jumping off a low step with both knees in full extension. Loss of this energy absorbing mechanism places increased stress on the hip, ankle and spinal joints. In addition due to loss of knee movement greater movement is required at these other joints. Such increased stresses may predispose to the development of early degenerative changes in adjacent joints as has been shown in the case of subtaloid arthrodesis where early ankle joint arthropathy frequently ensues\(^4\).

2) Difficulty ascending or descending stairs or steep incline.
3) Difficulty sitting or driving.
4) Inability to kneel.
5) Difficulty with shoes, stockings, toenails or care for foot hygiene.
The degree of joint flexion at various parts of the walking cycle and for the activities of daily living is readily studied by the technique of gliding chronocyclography using strobe photography as shown in figure 7.

Greatest flexion of the joint during walking occurs in the swing phase and is of the order of $75^\circ$. For most of the stance phase flexion is less than $20^\circ$ but increases to about $55^\circ$ at toe off. During normal walking full extension of the knee does not occur. Murray$^{50}$ studied the degree of knee extension in free walking and found that it is rarely as much as the knee extension assumed by the subject in the standing posture, whereas Frankel$^{51}$ states that the knee requires full extension, both in the beginning of the stance phase at heel strike and at the end of the stance phase during toe off.

Kettlekamp$^{52}$ et al described the knee as virtually fully extended just before or at heel strike in the majority of normal subjects examined. These somewhat different findings regarding the degree of knee extension in walking have been resolved by Van der Straaten$^{53}$ who has shown that the maximal degree of knee extension during walking is always less than the active hyperextension; in other words, the knee is never fully extended in walking. The difference between the maximal extension of the knee in slow walking and passive hyperextension of the knee varied from $10^\circ$ to $110^\circ$. 
When the speed of walking increases the knee extension correspondingly decreases and knee extension at 7 km/hour is significantly lower than that at 2 km/hour - the difference varying between 3° and 23°. Since the collateral ligaments of the knee are only taut when the knee is fully extended and the screw home movement only occurs at the end of extension he inferred that during gait the stability of the normal knee is primarily due to the actions of the muscles that surround the knee joint. He also concluded that during normal walking the screw home movement never occurs.

At heel strike the knee is extended in order to lengthen the forward-reaching extremity. At this time the knee has already begun its first and lesser phase of flexion. The peak of this 17° excursion occurs early during single limb support (at 15° of the cycle time). Then as the trunk and contralateral limb move forward, the knee extends reaching the peak of extension at 40% of the cycle. At this time while the ipsilateral foot is still in contact with the floor the knee begins to flex preparatory to the relative shortening of the limb which accompanies swing. This initiation of knee flexion precedes the initiation of hip flexion. The toe, however, does not leave the floor until more than half of the rapid knee flexion excursion has occurred. Peak knee flexion is reached early in swing at 70% of the cycle. The knee then reverses direction and extends rapidly, reaching its straightest position shortly before heel strike (figure 8).
The excursions of knee flexion extension recorded by Murray were almost identical in the various age and height groups, and the average value for maximum knee extension in sixty subjects was $16^\circ$ short of the vertical.

Sutherland in an electromyographic study of the plantar flexors and quadriceps muscles found that the knee begins to extend well before the line of weight bearing falls in front of the knee joint. He concluded that a dual effect of both muscle and extrinsic forces maintains extension of the knee during the stance phase in normal subjects. Gravity fixes the foot to the floor. The plantar flexors decelerate dorsiflexion of the ankle or act as a brake.

Kinetic force moves the body forward over the fixed foot bringing the centre of gravity in front of the point of support. The resultant extrinsic force extends the knee with the restraining action of the plantar flexors making an essential contribution to the stability of the knee.

At walking speeds of 2 km/hour maximum knee flexion of $60^\circ$ occurs but as the speed increases to 7 km/hour, knee flexion increases to approximately $90^\circ$ (Van der Straaten).

Activities other than level walking require increased knee flexion. Getting up from an averaged sized chair requires $100^\circ$ to $110^\circ$ of flexion. Unless the foot can be placed below the centre of gravity of the body, difficulty in getting up will be experienced (figure 9).

![Fig. 9](image)
The average height step requires $80^\circ - 90^\circ$ knee flexion for the trailing leg ($98^\circ$ Max.). Thus to cope with all eventualities, including getting up from a sitting position, a range of knee flexion of not less than $110^\circ$ should be the aim following arthroplasties.

Axis of Rotation for Flexion - Extension
Up to 1969 many authors had remarked on the curvature of the femoral condyles and the resulting variable axis with flexion (figure 10) - Maquet.$^{55}$

No recorded dimensions for the condylar curve or its locus were documented. Not only is the axis of rotation important but also the direction of motion at the articular surface, i.e. surface velocity. The line representing the surface velocity should be a tangent to the contact point of the femoral articular surface.$^{48}$ (figure 11)
If it is not a tangent then irregular motion between the articular surfaces occur at that point. The technique of determining the instant centres was first described\textsuperscript{56} in 1971. If the knee joint functioned as a simple roller then sliding between the surfaces would not occur and the instant centre of rotation would be found on the surface at any one instant. If, however, sliding as well as rolling occurs between the two surfaces then the instant centre is no longer on the surface and the distance between the points A B C D on both surfaces differ. The greater the tangential sliding becomes then the greater the distance between points A B C and D on the convex body (figure 12A & B)

\[\text{Fig. 12} \quad \text{B}\]

In normal knee function tangential sliding occurs and thus sliding friction is generated\textsuperscript{57}. If for any reason tangential sliding is interfered with, i.e. replacement of the joint with different radius of curvature and yet retaining the collateral ligaments - then the joint surface particles are forced into or away from the surface and not only interfere with the motion of the joint but also cause increased friction and wear of the surfaces (figure 13)

\[\text{Fig. 13.}\]
If during arthroplasty one wishes to retain the collateral ligaments then the surface geometry and instant centre of the transverse axis of the normal knee should be reproduced as accurately as possible. In prosthetic design it was felt that this could best be achieved by reproducing the normal anatomy as accurately as possible. As a cam shaped surface is difficult and expensive to reproduce with accuracy in a prosthesis the surface profile of the cam was resolved by the author in 1969 into two main radii as in figure 14.

![Figure 14: Patellar Movements in Flexion](image1)

Patellar Movements in Flexion

Radiology with multiple exposures of intact knee specimens showed that the relationship between the degree of flexion and the actual movement of the patella was not a linear relationship - this again is directly related to the changing transverse axis of rotation. Figure 15 illustrates the actual movement of the tip of the patella for 30° increments of knee flexion.

![Figure 15](image2)
If the patella continued to move at the initial rate of 23 mm. as over the first 30° arc, then total distance moved would equal 23 x 4 = 92 mm. The actual difference moved is 76.5 mm. Thus a difference of 15.5 mm.

A fixed hinge cannot allow differential rates of movement of the patella and quadriceps apparatus. To achieve 120° of flexion with a fixed hinge 15.5 mm. additional movement of the patella would be required.

Axial Rotation
In normal walking the knee rotates axially between 10° to 13°58,59. Most of the rotation appears to occur in the range between 0° to 30° flexion.59,60,61,56

External rotation of the tibia on the femur appears to reach its peak value just before heel strike. This external rotation of the tibia has a two fold action:

a) It prevents the toes coming in contact with the opposite leg during the swing phase.

b) The amount of rotation for ascending and descending stairs and sitting showed greater variation than for walking and appeared to be related to foot placement (Kettlekamp59). These findings suggest that tibiofemoral rotation may in part compensate for body position in relation to foot placement.

Locking of the normal knee mechanism depends on internal rotation of the femur on the fixed tibia. This rotation is poorly understood but is largely thought to be the result of condylar shape and cruciate action. As previously mentioned it does not occur in level walking.

Anatomical Site of Vertical Axis
Considerable controversy exists as to the site of this axis of axial rotation. Campbell60, Valls63, Gray64, and Wood Jones65 all state that it is located through the lateral condyle, whereas Fick66 and Brantigan67 deny this. Two distinct axes of rotation probably exist:

a) Medial rotation of the femur occurs about the vertical axis in the final phase of extension.
This is largely controlled by the bone architecture of the joint. In the beginning of flexion the lateral femoral condyle rolls backwards considerably further on the lateral tibial plateau than does the medial femoral condyle on the medial plateau. The greater backward displacement of the lateral femoral condyle indicates the rotation of the femur.

b) In the post mortem specimen when the knee is fully extended no further rotation is possible but as the joint is flexed slight degrees of rotation are possible. This rotation reaches a maximum between 45° and 90° of flexion and varies between 6° and 24° according to specimen58. The tibia rotates on the femur more in a lateral than in a medial direction. The axis for this rotation has not been established but is probably central.

Lateral Gliding
The prominence of the intercondylar eminence and tibial spines in the presence of intact ligaments prevents motion in this direction.

Antero-Posterior Gliding
This is virtually nil in intact joints and is dependent largely on the intact cruciate and collateral ligaments.

Control of Hyperextension
Normally in full extension both collaterals and cruciate ligaments are tense in particular the anterior cruciate ligament. The portion of the femoral condyles that articulate with the tibial condyles has a smaller radius than the portions that articulate with the patella. This abrupt change of radius appears to tighten all the ligaments58. If the femoral condyles are cut away then the joint will go into some hyperextension.

But Last68 maintains that bony contours contribute little to the overall stability of the joint and that muscle action is an indispensable factor. The medial ligament from its tibial attachment slopes upwards and backwards as it passes superiorly to be inserted behind the axis of flexion of the femoral condyle. The lateral ligament is also attached behind the axis of flexion and both are thus taut on extension.
The centre of gravity of the body is in front of the axis of the knee joint in full extension and this tends to hyperextend the knee. However, "locking" of the joint is not necessary to ensure stability in the erect posture because the joint is not fully extended and it can be extended voluntarily still further until the limit of the movement is reached.

The normal tendency to hyperextend due to the position of the centre of gravity is resisted by tension on the posterior part of the fibrous capsule, the oblique ligament, the cruciate and collateral ligaments and the hamstring muscles.

Forces in Normal Knee
Morrison\(^69,70\) in 1968 published the first calculated forces acting in the knee joint. The design of this prosthesis is based largely on his figures. The maximum force transmitted with normal activity is approximately three to four times body weight and this force acts in a vertical direction. The forces calculated by Morrison acting on the knee are as follows:

Cruciate Ligaments
- Posterior - Mean Maximum Force - 74 lbf.
- Anterior - Mean Maximum Force - 35 lbf.

The calculations neglect the friction force and this is of the order of 9 lbf. at maximum joint force.

Collateral Ligaments

It is of interest to note that the forces in a lateral direction are not as great as expected. Also in the current knee design, since the collateral ligaments are preserved, it is assumed that they will be available to largely deal with lateral forces.

Experimental results of all subjects indicated that during the stance phase of walking the centre of pressure was positioned over the medial condyles. It follows that the greater part of the joint force was transmitted by the medial condyles at this part of the cycle.
Steindler\textsuperscript{71} states that the greater amount of pressure is borne by the lateral condyles "because of obliquity of the anatomical axis of the femur". It is maintained by Morrison\textsuperscript{70} that the obliquity of the axis of the femur cannot possibly affect the force system acting at the knee joint and consequently the distribution of pressure between the condyles. The force system acting at the knee is dependent rather on the position of the centre of gravity of the body and the external forces acting upon it.

The alternating force transmission between the medial condyle during the stance and the lateral condyle during the swing phase gives rise to obvious design difficulties if one attempts to anchor surface prostheses to the bone. The see-saw effect transmitted to the cement bone junction loads the cement with an alternating tension - compression cycle, figure 16. This predisposes to loosening of one or both components as acrylic cement is particularly unsuited to cyclical alternating stresses.

![Fig. 16](image-url)
Abduction - Adduction Movements (Valgus - Varus)
The main reason for these movements is probably to alter the weight transmission between the femoral and tibial condyles depending on the position of the centre of gravity relative to the knee. The degree of abduction and adduction occurring at the knee during normal activities has not been established but in prosthetic design if it is not allowed to occur in the prosthesis then abnormally high stresses will occur at their point of attachment to the skeleton.

In fresh intact joints $2^\circ$ to $5^\circ$ of abduction - adduction in complete extension is possible. This increases to between $4^\circ$ and $9^\circ$ at $90^\circ$ flexion. When either or both collateral ligaments are cut there is practically no change in the lateral motion if both cruciate ligaments are intact. When both collateral ligaments are intact and either anterior or posterior cruciate ligament is cut there is no change in lateral motion. If all ligaments are cut there is a variation of lateral motion of $2^\circ$ to $11^\circ$ in extension and $12^\circ$ to $32^\circ$ in $90^\circ$ of flexion. Lateral motion of the joint in extension is controlled by the capsule, both collaterals and both cruciate ligaments.

Abduction - adduction also occur during knee flexion - extension as a result of the anatomical arrangement of the knee. If the normal valgus knee angle is $2^\circ$ - $8^\circ$ in extension and disappears in full flexion, then this can only occur as a result of varus deviation with flexion.

According to Brantigan and Gray, part of the reaction required to resist abduction or adduction may be transmitted by the cruciates. The experiments of Brantigan and Voshell showed that when the knee is in extension the collateral ligaments are capable of preventing movement in this direction. No instability occurred when the cruciates were severed. In flexion, however, due to the slackening of the lateral collateral, absence of the cruciates resulted in increased instability of the joint. This would indicate that the assistance of the cruciates in checking abduction or adduction is more significant in positions of flexion.
The large forces calculated to be acting in the lateral ligament occurred in the stance phase of walking, and hence at positions of the joint in which this ligament would normally be taut. Thus in walking the collaterals rather than the cruciates provide the major reaction to moments of abduction or adduction acting on the joint. Therefore removal of the cruciate ligaments should not materially alter lateral stability. Forces in the lateral collateral ligament will most likely be carried partly as tension in the ilio-tibial tract.

It may also be possible that the large adduction force acting on the joint during the stance phase is partly equilibrated by differential action of the lateral and medial hamstrings or of the lateral and medial heads of the gastrocnemius. Figure 17 shows increasing inward torque acting on the knee during the stance phase of walking. The moment action about the long axis of the tibia must be balanced mainly by force actions in the ligaments and will alter the distribution of ligament forces calculated in the analysis. From mechanical considerations the oblique posterior fibres of the medial collateral ligament would be most favourably placed to resist the inward torque and it is suggested by Morrison that the greater part of the torque acting at the knee will be balanced by tension in this ligament. The side or sheer force acting on the condyles is very small and the mean maximum value calculated for twelve subjects was 0.26 times body weight.
Static Analysis of Knee Forces in Frontal Plane

The Centre of Gravity of a body must be on a vertical line passing through its area of support. Thus for bipedal stance the gravity vertical line will fall between both lower limbs (figure 18 A) When supported on one leg then the gravity vertical line passes through the bearing area of the foot. This fact determines the posture of the body as a whole including the posture of the lower limb and its individual joints (figure 18 B).

Thus the gravity vertical line passes through the medial aspect or medial to the knee joint. This produces a varus deformity of the leg which is counteracted by tension in the lateral ligament and iliobial tract - the latter structure can be actively tensed by the tensor fascia lata and the gluteus maximus\(^6\). (figure 19)
In the normally aligned limb the transmission of the weight of mechanical loads from the main body mass to the floor passes through the hip, knee and ankle joints and when these three points are joined a straight line should be obtained. (figure 20)

If, however, structural deformity results in these 3 points no longer falling in a straight line, then abnormal bending moments are produced and the lower limb is no longer loaded like a straight column. (figure 21 A)

Once bending of a column has occurred then a slight increase in load will cause considerable deformation (figure 21 B).
The resultant force passing through the knee joint varies from moment to moment during the gait cycle and arises as a result of both the force transmitted due to the position of the centre of gravity and the muscle force due to contraction of the gluteus maximus and tensor fascia lata.

In a static situation with the body in equilibrium this resultant should ideally pass through the centre of the knee, thus distributing the force equally between both compartments, (figure 22 a)

Fig. 22

This resultant can be determined from the perpendicular from the centre of gravity of the body and the force and direction of the iliotibial tract. The joint will remain in equilibrium as long as the resultant remains within the rotational centres of both condyles. If the resultant falls outside these centres of rotation, then the body will tend to rotate and thus the collateral ligaments are brought into play, (figure 22 b )
Minor degrees of shift of the resultant can cause increased loading of either the medial or lateral aspect of the knee. Thus an increase in body weight or slight varus deformity of the knee or relaxation of the iliotibial tract can cause a medial shift of the resultant with increased loading of the medial condyle. Similarly increased tension of the iliotibial tract, genu valgum or lateral shifting of the body weight can cause a shift of the resultant to the lateral compartment. (figure 22 c)

Thus a shift of the resultant can occur either as a result of slight structural variations, i.e. mild genu varum or valgum or as a result of dynamic loads causing an alteration in the loading pattern.

Abnormal adductor muscle action can cause overloads of a normally aligned knee (Frost72). During the stance phase of gait these muscles apply a dynamic adducting force on the knee which has two components, one a vertical acting in line with the femur and a horizontal medially directed force tending to pull the knee medially during each stance phase. This causes an increased compression force on the lateral compartment of the knee (figure 23 a)

![Diagram](image-url)
Static analysis of mild genu varum and genu valgum suggests that the resultant is always shifted to one of other compartment. In the dynamic situation this is not always the case since additional muscle action, i.e. adductor action can cause a shift of the resultant to the lateral side in a knee which tends to be overloaded due to mild structural varus (figure 23 b & c).

However, from a clinical point of view mild structural varus or valgus deformities predispose to the development in later life of degenerative changes in one or other compartment in a large number of cases. In a sagittal plane the resultant constantly changes under dynamic conditions as a result of knee flexion and alternating muscle activity thus loading different points of the tibial plateau depending on the stage of the gait cycle.
Summary of Movements and Stability Required in Prosthesis to Simulate Normal Knee Movements (figure 24, a, b, c, d, e).

(a) Flexion/Extension

(b) Rotation about a vertical axis. Nil when fully extended. Gradually increases to reach maximum of 20° (total) when knee semi-flexed.

(b) Rotation

(c) Lateral Movement

Fig. 24, a, b, c.
Summary of Other Design Criteria for Knee Arthroplasty

1) Accurate simulation of normal knee movements.
2) Adequate fixation even in soft osteoporotic destroyed joints.
3) Low frictional bearing surfaces.
4) Preservation of collateral ligaments and lateral and medial margins of the femur and tibia for two-fold purpose.
   a) To allow normal collateral function and thus preserve their contribution to knee stability.
   b) To permit subsequent arthrodesis without shortening if sepsis supervenes and necessitates removal of the implant.
5) Anchorage by cement or alternative method to permit early mobilisation with suitable tapered stems on the implant.
6) Minimal skill required for insertion.
7) Plastic component interchangeable in case of long-term wear.
8) Implant largely buried in bone.
9) Preservation of patella as an essential component of the extensor apparatus.
The Prosthesis

Introduction:

The final knee prototype as described in "Knee Arthroplasty" thesis\textsuperscript{4}, University of Surrey, 1970, was cast in chrome-cobalt alloy and introduced into clinical trial in November 1971. (Fig. 26 & 27)

Minor modifications were made to both the femoral and tibial components during the following twelve months. From 1972 to 1977 virtually no changes were made in either component. A deliberate policy of minimising any changes has been adopted since the introduction of this prosthesis. It was felt that a minimum follow up period of five years should elapse before a major review could establish the long term results and problems. Following such a review in Summer 1977, design modifications were considered - the major change being the introduction of the broad condyle pattern in August 1979.
Since that date a partial patellar replacement and subsequently a total patellar surface were introduced in October and April '81 respectively.

In Autumn 1980 modifications were designed to increase the strength of the tibial stud. (Endoskel model). Subsequent to this date the total range of prostheses has been further consolidated by the introduction of a 90% size for extra small patients, i.e. Stills disease, and a revision pattern for patients with loss of the surrounding soft tissue support.
Modifications to Initial Prototype

Femoral Component

Following implantation of the first knee, it was realised that the anterior rim of the femoral component was impinging on the patellar area, Fig. 28, particularly if the patient was small and removal of the metal in this area was undertaken. Fig. 29.

Due to marked variability in the geometry of the patellar groove - particularly in pathological states, it was realised that extensive contouring of the femoral component would greatly facilitate the fit of the component into bone. The optimum dimension in this region was determined only after some 100 implantations and the current profile is shown in fig.30.
In the initial design linkage of femoral and tibial components existed until approximately 130° flexion. At surgery this was found to cause transmission of tensile forces to the femoral component when flexed beyond 90° and with the patella laterally dislocated a "pistoning" effect was noticed in view of the even taper of the femoral component.

To overcome this problem the even taper of the femoral component was broken by a smooth curve in its lower part so that a blob of cement could prevent distraction occurring. Fig. 31

![Fig. 31](image1)

At the same time the retaining grooves in the femoral component that located with the tibial stud were largely removed so that stability still remained in the fully extended position.

![Fig. 32](image2)
This design of femoral component was inserted in seven patients (no. 3 - 9 in series) before the current design of stability to approximately 90° was decided upon and has been used unaltered since that time. (Nov. 1972).

Apart from reduction in the external dimension, the femoral component was significantly reduced in the intercondylar region to allow access to the posterior aspect of the joint to permit removal of excess cement. Fig. 33

The lateral profile of the condyles was altered so that the posterior cortex of the femur fits into the notch and this obviates the necessity of removing a large part of the posterior cortex to insert the prosthesis. Fig. 34 & 35
Tibial Component

Due to difficulties with lateral x-ray measurements of the upper tibia, the overall dimension of the tibial component proved excessive. Six tibial components of the initial design were used and apart from some difficulty incorporating the implant in the bone, no difficulty has been recognised on follow up. The location of the plastic tibial component in its metal container was based on the bayonet type fit of a light bulb into its socket. Fig. 36

Rotation of the plastic was prevented by two screws which acted as shear pins. Medio-lateral forces transmitted to the tibial plastic were transmitted to the cylindrical section of the metal housing. Shear failure of the plastic in the metal container occurred at loads of 9.85 kn i.e. 2210 lbf.
Reduction in size of the tibial component was achieved by reduction of the upper cylindrical section from 20mm. to 10 mm. Fig. 37,a,b,c.
This reduction caused transfer of the medio-lateral forces from the cylindrical section to the locating pins. Forty nine prostheses of this latter design were inserted.

Due to loosening of the tibial plastic, this design was modified to the use of a transfixion screw Fig. 38a and subsequently a rivet. Fig. 38b

It was initially hoped that the plastic could be readily interchanged if wear problems occurred but due to mechanical loosening it was felt that a more permanent bond should be made at this interface and should the plastic require changing for any reason, then the entire tibial component could be replaced.
Following insertion of the first two implants, a small size tibial component was introduced (38mm in diameter as against 42mm.) Fig.39. This was more suitable for smaller sized patients and up to the introduction of the broad condyle pattern, the small size tibia was used in 68% of cases.

The stem length of the tibial component was increased from 10 cms. to 12 cms. to ensure better alignment in the medullary canal.
Description of Standard Prosthesis (1972-1979)

Femoral Component: Fig. 41

The femoral component has two separate bearing surfaces with a gap for the stabilising stud of the tibial component to interlock between the femoral wheels by engaging the inner radii. The external radius has two components - the former up to 50° flexion and the latter from 50° to approximately 130°. The combination of these two radii blending at 50° and with their centres 9 mm. apart gives a similar anatomical outline to the normal femoral condyle. The prosthesis is increased in overall size to allow the condylar surfaces to protrude 5 mm. from the bony surface. An external locating rim is positioned 5 mm. from the most prominent point of the bearing surface. This ensures that the prosthesis will not be too deeply seated.
Internal Femoral Radius: Fig. 42

This surface engages in the groove of the tibial stud. It simulates cruciate stability by preventing anterior or posterior movement but at the same time permits a combination of sliding and rolling motion to occur between the bearings.

Collateral stability is also achieved by this mechanism and permits approximately 2°-3° side to side rock in the extended position - increasing to 6°-7° rock when the knee is semi-flexed as in the normal mechanism.
Function of the Prosthesis:

When the knee is fully extended the tibial stud fits the intercondylar notch of the femoral component. This prevents axial rotation in the extended position. The $30^\circ$ flexed position of the condyles show gradually increasing flats on the inner surface of these radii and thus gradual widening of the intercondylar gap. Fig. 43 a & b

This allows increasing degrees of axial rotation from the $30^\circ$ position with approx. $20^\circ$ axial rotation possible with the knee flexed to $90^\circ$. 
These inner radii gradually taper in a superoinferior direction from 50° so that they gradually blend with the external radius at 90°. Thus with the knee flexed beyond a right angle no direct linkage is present between the components. Fig. 44 a & b.
Thus if apposition of soft tissues occurs posteriorly by the calf and thigh coming in contact then the tibial stud is free to sublux anteriorly and thus prevents a tensile or distraction force applied to one or other component. This problem is frequently encountered with rigid hinge prostheses and distraction may result from either soft tissue apposition or direct bony contact between the cut surfaces of the femur and tibia.

The possibility of dislocation occurring spontaneously with this current design is minimal as increasing flexion causes tension in the quadriceps apparatus and the reaction force between the patella and femur thus increases with flexion and will not permit anterior displacement of the tibia.

The line of the intramedullary stem is located 15 mm. anterior to the centre of rotation of the larger arc corresponding to the relationship of the normal condylar arc to the mid shaft of the femur. Fig.45 The prosthesis anterior to the bearing surface blends gradually into the stem and ensures that the prosthesis does not protrude anteriorly.
Patello Femoral Articulation:

There is no patellar surface as such on the prosthesis but the patella approaches the bearing surfaces at app. 50° flexion and remains in contact with them for the remainder of the range. By a combination of design and accurate placement of the prosthesis the transition point where the patella passes from the lower femur onto the prosthesis is very smooth Fig. 46 and beyond 50° flexion a hemiarthroplasty of the patello-femoral joint has in fact been achieved.

Fig. 46

Provision of a patella surface on the femoral component means the introduction of a large mass of metal in a relatively superficial location and in the current design a distinct intercondylar approach is considered advantageous so that the prosthesis - both femoral and tibial components - can be almost completely enclosed in bone apart from the bearing surfaces. This approach hopefully minimises the amount of soft tissue reaction to the implant materials and interferes to a minimal extent with the extensor apparatus. Other advantages of the intercondylar approach apart from incorporation of the prosthesis in the bone are:

a) A large bony buttress is preserved on either side of the joint and does not preclude the possibility of a subsequent arthrodesis with minimal shortening should the need arise.
b) The collateral ligaments are preserved and the bone adjacent to the ligaments is undisturbed thus interfering to a minimal extent with the sliding action of the soft tissues about the joint.

c) An intercondylar approach permits ease of insertion of both components as the tibial component can be readily inserted with subluxation of the knee and the femoral component can slide into position with the tibial component in situ. Thus far less soft tissue damage is caused than with other more conventional approaches.

Tibial Component: Fig. 47

The UHMWPE of the tibial component has 2 bearing surfaces and an expanded intercondylar stud. Fig. 47a & b The stud is ellipsoidal when viewed from the lateral aspect. Fig. 47c
By an accurate selection of radii the required movement and stability is achieved. The radius of the main weight bearing surface is 50 mm. Thus even when the larger femoral arc is in contact, the surfaces are not congruous in an anteroposterior direction but total contact in a medio-lateral direction is achieved.

This arrangement creates a relatively high contact stress, higher than the contact stress in a 22 mm. Charnley hip joint, but has the advantage in view of rolling and sliding movements both occurring at the interface, that different areas of the plastic are loaded from any one instant to the next, thus distributing the stress over a wider area.

If a similar tibial bearing radius to the larger arc of the femoral component is used then the prosthetic replacement no longer simulates the normal knee mechanism and in effect the arthroplasty could be considered a modified ball and socket joint.

In addition if both radii are similar an increased shear stress is transmitted with increasing flexion, Fig 48, and there is an increased risk of loosening of the tibial component.
Intramedullary Fixation:

The current trend in prosthetic knee replacement is towards safety should failure occur. This is frequently at the expense of stability, accuracy in alignment and ease of insertion. In soft osteoporotic bone as is frequently encountered in rheumatoid arthritis, the ideal method for both fixation and alignment is the use of intramedullary stems. In patients with normal bone density the use of intramedullar fixation greatly facilitates the ease of insertion and accuracy of alignment. In addition the degree of destruction or collapse of the condyles does not influence the final stability of the joint.

It is totally impractical to consider a semistabilised prosthesis depending on surface fixation and if any inherent stability exists in the prosthesis itself - other than the stability achieved by compressive loading - then intramedullary stems become mandatory.

In order to achieve ideal stress transmission an evenly tapered stem is cemented into bone. If the stem taper is less than 5° then the taper is described as a locking taper and such a component requires moderate force to dislodge it. The stem taper of both components is similar to a morse taper, i.e. 0.65 ins./ft. giving a taper angle of approximately 2° thus exhibiting good locking characteristics.

In order to prevent rotation of the stem within its cement bed, particularly of the tibial component, flats are applied to the stem. These flats are then blended with the stem so that no points of stress concentration remain. Fig. 49
At first sight the stem may appear cylindrical but on closer examination it is virtually triangular. The only way that such a stem could rotate is by splitting open its cement bed.

Fatigue failure of femoral hip stems is now becoming a major problem and the importance of adequate stem design has been appreciated for some years but only very recently has it been put into practice. Sharp angles form points of stress concentration and these predispose not only to failure of the stem through fatigue but also cause failure of the acrylic cement with crack propagation starting at these sharp points.

This latter problem, if it occurs, causes loosening of the stem in its cement bed and thus imposes high loads to certain areas of the stem and this in turn predisposes to stem failure by fatigue.

The stem design of the knee arthroplasty described depends for its success on the medullary canals being firmly packed with cement. A minimal introduction of cement as some surgeons are noted to use in hip arthroplasty, will prove quite inadequate if applied to the knee in view of the very extensive cancellous bone of both the lower femur and upper tibia.
Stem Lengths

The ideal stem length is still unknown. Ideally it should be long enough to give adequate cement fixation and alignment and at the same time short enough to allow cement to be introduced to its tip and also to permit its removal and the accompanying cement if infection ensues. An additional consideration of femoral stem length is that frequently patients requiring knee arthroplasty also require hip arthroplasty and both stems must be accommodated in the same bone.

In view of the width of the lower femoral canal a stem length of 25-30 cms. is required to give optimal alignment (but as mentioned on many counts this is impractical and a compromise situation results). An overall tibial length of 10 cms. did not give accurate alignment, Fig. 50A, in all cases as the stem tip still lay in cancellous bone but by extending the overall length to 12 cms. very good alignment can be routinely achieved. Fig. 50B.
Short stubby stems should be avoided particularly in the lower femur in view of increasing the risk of supracondylar fractures due to the sudden change in elastic modulus between the bone and implant. Fig. 51

![Fig. 51](image_url)

The junction of the lower expanded condylar part of the femur with the thin cortical region is already a weak area as evidenced by the occurrence of supracondylar fractures in this region. If a stem is to be used in bone then it should pass well into the cortical region of the bone to obviate stress concentration at an already weakened area.

When stress is transmitted through a straight taper to a surrounding cylindrical structure so called hoop stresses, Fig. 52 are developed in the bone and the transmitted stress, if excessive, may tend to cause longitudinal cracks.

![Fig. 52](image_url)
To obviate this danger in the tibial component the upper expanded portion which receives the UHMWPE component is suitably tapered ($20^\circ$) so that the stress is transmitted to the expanded upper tibia as well as to the cortex and cancellous bone below. Fig. 53

![Fig. 53](image1)

This direct compressive stress transmitted to the upper cortex minimises the hoop stresses in the tibia and acts as an internal collar on the prosthesis to prevent sinking of the component. On cursory examination of the tibial component this appears to be a major design fault since it is not appreciated that the upper expanded part of the tibial component replaces an external rim or collar. Fig. 54

![Fig. 54](image2)
If excessive cement is placed around the upper tibia then the problem is to seat the tibial component adequately rather than to worry about sinking of the component subsequently. With the tibial component adequately seated direct point contact between the prosthesis and upper tibial cortex frequently occurs. Fig. 55

The lower surface of the UHMWPE is hemispherical and transmits the stress evenly to the metal holder. The locating plates are non stress transmitting so the entire force is transmitted to the seating and not to the cylindrical wall of the holder. Fig. 56
The Standard Prosthesis  
(1972 - 1979)

The major five year review prompted further development in five areas.

(a) Increase in the medio-lateral width of the prosthesis - broad condyle pattern.

(b) Development of a patellar replacement - patellar flange model.

(c) Special prosthesis if collateral ligaments ruptured or if previous surgery has caused extensive soft tissue damage - Revision Prosthesis.

(d) Small sized prosthesis for unusually small individuals - Stills type Prosthesis.

(e) Improved tibial stud design: Endoskel Prosthesis.
The major changes in this design increased the overall width of the bearing surface from a radius of 3 mm to a radius of 4.5 mm. This increased the metal to plastic contact area by 50%. In addition it had the advantage of increasing the width of the prosthesis about the neutral axis and thus minimised the effects of incomplete correction of angular deformity. The overall dimensions of the prosthesis other than the condylar surface were retained, Fig.58, and this permitted the use of all existing instrumentation.
Increased condylar width also created additional depth to the outer track on the condylar surface, Fig. 59, and this acted as an additional safeguard to sinking of the femoral component and at the same time allowed for an increased shelf to gauge the femoral prosthesis during insertion.

Additional cement retaining grooves, Fig. 60, were also incorporated into this new dye to give added fixation but at the same time retaining the tapered stem principle.
Broad Condyle Tibia  Fig. 61

Up to 1977 large and small tibial components were available - both freely interchangeable with the single femoral component (Diameters 42 mm. and 38 mm.) The large size component proved suitable for most males and larger size females. The small tibial component proved easier to insert and in the collaborative trial was inserted in 80% of patients as against 68% in my own series.

The advantages of the large size component were:
(a) The increased stud strength.
(b) The larger hemispherical seating permitted greater rigidity of fixation.
Ideally one size component should fit the great majority of patients so that a choice is no longer available and a single sized tibia was designed. Previously the large 42 mm. component could always be incorporated in the medio-lateral direction but it was in the antero-posterior dimension that difficulties arose. Fig. 62

![Diagram](image1)

**Fig. 62**

In smaller patients 38 mm. proved to be the maximum dimension that would comfortably fit without loss of either the anterior or posterior cortex. By suitable modification of the existing 42 mm. diameter metal component both the increased broad condyle surface was incorporated as well as the reduced antero posterior dimension. Fig. 63

![Diagram](image2)

**Fig. 63**
Replacement of Patello-Femoral Articulation

Arguments for and against: In an ideal total knee prosthesis one would hope to replace the patello-femoral articulation as well as the femoro-tibial surfaces. This has many inherent difficulties.

1) If the collateral ligaments in a knee are to function in the presence of an implant then the implant must be carefully aligned from the posterior surface of the femur. This ensures that the ligaments are relatively taut both in the flexed and extended positions. Fig. 64

2) If a prosthesis is inserted so that it lies flush with the anterior aspect of the femur then the tension of the collateral ligaments is adjusted so that they are taut with the knee extended and thus no control over the ligaments is possible as the knee is flexed.

If the axis of rotation of the prosthesis happens to correspond to the normal knee axis - which is constantly changing with flexion - then the ligaments will remain taut. This will rarely occur unless a very considerable range of femoral components are available in order that the anteroposterior measurements correspond to the actual bone being replaced.
If a patellar surface is incorporated in the design then this surface must be implanted flush with the anterior femoral surface and thus no account is taken of the accuracy of placement of the prosthesis in relation to the collateral ligaments. This in itself can be a serious problem particularly with surface mounted prosthesis in that abnormal forces may be applied to the tibial plateau during flexion and may be responsible for loosening and tilting of the tibial component.

3) Anchorage of a prosthetic component to the patella is also a further problem. The patella is not a smooth concave arc but consists of 3 separate bearing areas, superior, middle and inferior, subdivided into medial and lateral compartments by a vertical ridge. The inferior facet articulates in extension and the contact area gradually changes with knee flexion so that the superior facet articulates in full flexion.

Any replacement component on the posterior surface of the patella is thus subject to alternating tensile and compressive stresses with the consequent risk of loosening, as discussed, with alternating stresses applied to surface mounted prosthesis of the femoro-tibial surfaces.

These considerations led initially to the development of the hemi patellar surface and subsequently to the total patellar prosthesis, i.e. anterior flange model.

**Hemi Patella: Fig. 65 A & B**

To minimise the problems associated with a total patellar replacement this concept was introduced in 1979. The five year follow up in 1977 showed that patellar symptoms were most noticeable in flexion when the patello-femoral forces were at a maximum.
Thus if the superior patellar facet was replaced the normal patello femoral relationship would remain in extension, Fig.65 A and allow use of the standard femoral component. In addition the patellar plastic could be largely incorporated into the patella and permit maximum stability of the implant and minimum risk of loosening. Problems with tautness of the collateral ligaments would also be avoided.

Six such implants were inserted but were superseded by the total patellar replacement.
Anterior Flange Prosthesis: Fig. 66 & 67

This development permitted replacement of both the femoral and patellar surfaces. A standard broad condyle pattern is utilised and an anterior femoral flange permits replacement of the patellar groove of the femur. The initial design introduced into clinical trial in April '81 was used in 7 cases.
The major clinical problem was subluxation or dislocation of the prosthetic patella from the femoral groove. Fig. 68

This has been counteracted by a further design modification, Fig. 69 with:

a) Increased offset of the femoral groove to 8°.

b) Elevation of the lateral aspect of the femoral surface by 3 mm. above the medial surface.

This provides a bob sleigh effect as the knee is flexed. This model is still at the manufacturing stage and has not been introduced into clinical practice.
Revision Prosthesis

Introduced to clinical use in 1981 Fig. 70. Again based on the broad condylar design with similar geometry of the bearing surfaces. The major design difference is that the bearing surfaces are spread apart by 22 mm. as against 12 mm. in the standard design.

Fig. 70

This allows for an increase in stud dimension from 4.5 sq.cms. cross section to 9.5 sq.cms. Fig. 71

Fig. 71
This greatly increased stud is to permit the use of this prosthesis in patients where collateral function is uncertain for any reason. This occurs in two circumstances:

1) Spontaneous rupture of a collateral ligament due to gross deformity - usually valgus in type. Fig. 72 A, B, & C.

2) Revision operation where a surface or standard type prosthesis has failed and there is significant bone loss with or without loss of supporting soft tissues. Fig. 73 A & B

Fig. 73 A - Wear of medial aspect stud

B Replaced with Revision Prosthesis
To accommodate the increased intercondylar width the tibial component is expanded superiorly and additional side flanges provided to permit increased stability and fixation.

The upper spherical component is, however, still based on an external diameter of 42 mm. which is the maximum that can be incorporated into a normal size tibia.

90% Model or Stills Disease Type

In very small patients the limiting dimension is the antero posterior width of the upper tibia and occasionally the patellar area of the femur: (see Clinical Results):
Patients with Stills disease (Juvenile Rheumatoid Arthritis) are severely stunted in growth, Fig. 74, and also frequently require hip arthroplasties. The standard femoral stem length is thus often 2 cms. oversize.

Fig. 74
A reduction of the prosthesis by 10% is entirely satisfactory in all dimensions for such cases and the standard broad condyle variety has been adopted for this purpose. Fig. 75 A & B

75 A Pre-operative film

75 B Post-operative 90% knee replacement
Deficiencies in stud design became apparent as early as 1973 when a female patient with gross valgus deformity and rupture of her medial collateral ligament returned with fracture of the H.P.D. stud. Subsequent stud failure although rare (1.1% of cases) showed that it invariably occurred in patients with absence of one or other collateral ligament. Based on the initial design date, the stud should normally withstand such stresses and destructive tests both in tension, Fig. 76, and shear showed adequate safety margins.
Estimated Forces during Normal Walking

1. Assuming that the prosthesis and limb are perfectly aligned and that the ligaments are just slack when there is no force acting on the knee: Lateral collateral ligament force = 190N, tibial stud force = 1085N. These forces occur during the push off phase of a normal walking cycle.

2. Conditions as above, but assuming that the ligaments were stretched 2.5 mm. during insertion of the prosthesis (i.e. well into their operating force range): lateral ligament force = 295N, medial ligament just slackens, stud force 810N.

3. Conditions as in (1), but assuming a defective lateral ligament: stud force = 1560N.

4. As in (3) but with 5° misalignment of knee: stud force = 1940N.

Results of destructive tests on stud:
The tensile and shear tests were carried out using an Avery multi-range universal testing machine: the loading ranges employed were 0 - 50 kN and 0 - 20 kN, and the load was applied to the samples at the rate of 5kN per minute and 2kN per minute respectively.

Results:

(1) Tensile Loading Tests

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<th>Maximum Load</th>
<th>Remarks</th>
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<tbody>
<tr>
<td>kN.</td>
<td>lbf. (equivalent)</td>
</tr>
<tr>
<td>6.0</td>
<td>1350</td>
</tr>
<tr>
<td>8.5</td>
<td>1910</td>
</tr>
<tr>
<td></td>
<td>Test rig fractured</td>
</tr>
<tr>
<td></td>
<td>Shear failure of polyethylene</td>
</tr>
</tbody>
</table>

Table 1

(11) Shear Test
Shear failure of the polyethylene stud did not occur. The maximum load sustained by the component was 9.85 kN.
This major discrepancy between laboratory testing and clinical behaviour demanded a much closed investigation of the behaviour of H.D.P. which hitherto had not been used under tensile loads in a physiological environment.

Properties of Ultra High Molecular Weight Polyethylene:

Polyethylene is a viscoelastic material, meaning that under constant load it progressively deforms. When the load is removed - depending on its magnitude and duration of action - the material will return to either its original dimension or to a slightly elongated condition compared to its original state. This return to its original dimension may occur very slowly - indeed at a greatly diminished rate compared to the deformation with applied stress. The recoverable strain represents the elastic and the permanent strain the plastic element in the material.

An increase of temperature increases the rate at which deformation occurs and such materials are known as thermoplastics. Thermoplastics in particular exhibit the property of creep, i.e. deformation over a period of time even at low temperatures and under relatively slight load stress.

The viscoelastic character must always be taken into account when a new component is being designed. Thus for example a fundamental requirement in precision engineering is that within a given time under load, the deformation of a given structural component should not exceed 0.25%. This requirement represents a definite load level. Should a greater deformation within the same period be permissable, a higher load level may then be chosen.
Thus, the mechanical properties of a plastic material are dependent on three basic parameters:

(1) Time
(2) Temperature
(3) Stress level

Because of the viscoelastic nature of plastic materials and particularly of the thermoplastics, the results of loading tests under compression, tension, flexure and torsion depend on the temperature as well as the rate of deformation. At low rates of deformation such materials behave as plastic, highly viscous substances which are subject to creep, while at higher rates, elastic behaviour predominates.

The yield stress, i.e. the stress at which permanent deformation occurs increases as the rate of deformation increases. A material which at low straining rates, exhibits tough properties, may fracture without any break elongation in tensile impact testing at straining rates of up to 10,000% per second and thus appear to be a brittle product.

Information on the toughness characteristics of plastic materials at high rate of deformation is obtained from a combination if impact strength, tensile impact strength tests and by the rapid ultimate tensile test. This becomes a most complex problem when applied to the design of artificial components for human implantation.

The rate of loading under physiological condition of the UHMWPE stud is unknown and the load transmitted by the stud assuming accurate alignment is achieved is minimal in relation to the tensile strength of the stud.
The cross sectional area at the point of load application is 4.54 sq. cms. and with a tensile strength for UHMWPE of 300 kgf/cm² the overall strength of the stud is 1362 kgf. Fig. 77 shows a tibial stud after a tensile force of 9 kN. was applied.

When one compares this to the maximum calculated forces acting in the collateral ligaments and obtained by testing the strength of biological material\textsuperscript{74}, then one realises the high safety factor involved in the design. Despite this, stud failure has occurred.

The elasticity of polyethylene is probably an important design factor in a knee mechanism in that when varus or valgus stresses are applied a certain degree of elasticity is allowed to minimise the stress transmitted to the stems. Any form of rigid linkage allows high stress levels to be transmitted to the stem and increases the risk of failure.
If, for example, a body is suspended by two materials with widely differing elasticity then virtually the entire stress transmission is by the more rigid body, Fig. 78. Thus using a stud with elasticity approaching that of the collateral ligament minimises the stress transmission to the stems as well as allowing the collateral ligaments to exert their normal effect if the knee is stressed.

This effect is further enhanced if the prosthetic stabilising mechanism is placed towards the neutral axis of the bone, i.e. the axis where compression and tensile forces tend to neutralise each other. This arrangement gives the collateral ligaments the opportunity of exerting their maximum stabilising effect even though the stud elasticity may differ somewhat from their own.

Placing the stud mechanism in the neutral axis has the disadvantage, however, of diminishing its stabilising effect and increasing the bending movement applied to the stud if:

(1) The knee is not accurately aligned.
(2) If there is complete absence of bone or either collateral ligament.
Safety Factors in Design:

When components are designed, the characteristic material property values, determined by mechanical tests, are divided by a safety factor. Where the weight, bulk and cost of materials are not major factors then high safety factors can be used, i.e. buildings, etc. However, where weight is at a premium then a low safety factor may have to be used, i.e. aero industry, since if a high safety factor was applied the aircraft would be unable to become airborne!

Such low safety factors in the region of 1.1, where life is endangered, demand minute attention to detail, stress analysis and experimental techniques, i.e. photoelasticity, so that maximum safety can still be achieved despite a low safety factor.

High safety factors in the biological application may be difficult to achieve by virtue of the bulk of material required, i.e. intramedullary stems must fit into a specified cavity.

The safety factor in an individual design is dependent on a number of factors:

1) Material used and methods of processing; i.e. UHMWPE is not a uniform material and tests of individual specimens may vary from batch to batch or may alter with storage, radiation and exposure to a biological environment.

Heat forming and injection moulding can also alter the material properties by altering the degree of crystallinity of the polymer. Thus areas of high crystallinity confer strength and hardness on the material and areas of poor crystallinity confer toughness and compliance on the material.
2) Testing Conditions:
Results obtained from manufacturers state the conditions, i.e. temperature, humidity for individual tests. These conditions may not be strictly applicable to the environmental usage envisaged.

3) Stress Conditions:
The actual stress imposed in practice on a structural part is as a rule not completely known in advance. The rate of stress application is also frequently an unknown entity particularly in the biological environment.

Repetitive stress may cause local changes in temperature and thus the environmental temperature may vary in level and duration, and high deformation rates or multiaxial stress conditions may have an intensifying effect. Even when all environmental variables and all extrinsic forces are accurately known, further stress development, stress maxima and deformation can only approximately be ascertained.

Safety factors differ according to whether the part concerned has to be designed to withstand excessive deformation or to withstand fracture. For the designing of parts subject to a maximum permissible deformation, safety factors of approximately 1.2 are used. For design calculations to provide against fracture, safety factors range from 1.3 to five and even greater. It was felt that under physiological conditions strain rates of the magnitude of 10,000% per second would not occur and that brittle fracture was unlikely.

Experimental work on the strength creep and fatigue properties of UHMWPE cruciate ligament prostheses reports on strain rates of 1 and 100% per second. The occurrence of fracture of the implant at high strain rates has not been investigated.
Fatigue Strength of UHMWPE

Although it is not generally recognised, polymers are subject to fatigue fracture. The study of fatigue in polymers is a relatively new subject because it is only recently that higher strength polymers have been developed by use in applications where fatigue-type loads could be experienced. The primary fracture mode of metallic orthopaedic implants is due to fatigue. This would indicate that polymeric components are also subject to fatigue loads. There is a standard for fatigue testing polymers in flexure. However, this type of test is normally conducted at an unphysiological rate of 30 cycles per second. There is a problem with rate, because of the low heat conductivity of polymers, which is not representative of in-vivo conditions for surgical implant applications.

The possibility of fatigue failure of the stud under alternating stresses must also be considered in design. Fatigue strength includes fatigue strength under alternating stress and under intermittent stress in tension, compression, flexure or in torsion.

For most plastics the fatigue strength is 20 to 30% of the ultimate tensile strength measured in the short term tensile test. It decreases with increasing temperature and stress cycle frequency and with the presence of stress concentration points.

This last factor is particularly important in design and the same care that is applied to metal components to minimise points of stress concentration must also be applied to the design, machining and handling of plastic components.

The fatigue strength of ultra high molecular weight polyethylene is in fact excellent as reported by Saver, who found that specimens of UHMWPE did not fail after ten million cycles of tension-compression, twenty million stress reversals to a maximum stress close to the yield point stress.

One can only conclude because of stud failures that either extremely high strain rates are present in the knee during normal function, that UHMWPE denatures in a physiological environment, or that fatigue fractures occur.
Improved Stud Design:
To minimise the risk of stud failure, two materials were chosen for reinforcement: (1) Metal (2) Carbon fibres.

Metal Reinforcement:
Until recently this proved impracticable since UHMWP used for implant purposes was machined from a block of material. Technology introduced by Zimmer, U.S.A., has allowed moulding of this material into its finished geometry without alteration of the properties of the material. This allows moulding of the plastic about a central metallic core and greatly increases the strength of the stud.

By a combination of these materials it is hoped to largely retain the advantage of elasticity of the plastic and at the same time to prevent brittle fracture of the stud. Inevitably there is significant reduction in the elasticity of the stud and this will have the effect of transmitting increased stress to the femoral and tibial stems.

Carbon Fibres
When many polymer fibres such as those of polyacrylonitrile are carbonised they are converted into carbon fibres (the fibrous forms of polymeric carbon) (Jenkins and Kawamura 1976). The stiffness and strength depend on the degree of preferred orientation in the component carbon ribbons which in turn depends on the degree of stretch and the heat treatment temperature. In the U.K. such fibres are manufactured in rows and continuous lengths by Courtaulds who offer two main grades: High strength with an axial stiffness 260 GN m\(^2\) and an axial strength of 3,000 MN m\(^2\) and high modulus with an axial stiffness of 400 GN m\(^2\) and strength of 2,000 MN m\(^2\). The fibres have a diameter of 8 cm. Qualities sold for surgical use have no surface treatment.

The incorporation of carbon fibres into UHMWP has been used surgically for ankle arthroplasty. It has the advantage of increasing both the tensile strength of the material, the fatigue properties and diminishing considerably the rate of creep as compared to the basic material. It has the disadvantage that its elongation at the yield point is virtually zero compared to approximately 12% for the UHMWPE alone. It also improves significantly the wear characteristics of the UHMWP when bearing against metal.
Prostheses Incorporating Reinforcement

Design studies were undertaken in Autumn 1980 and prostheses incorporating reinforcement are currently in production. Two basic types of tibial component will be available for clinical trial in September 1982.

Type (1) Chrome Cobalt reinforcement with moulded UHMWP. Fig. 79A
Type (11) Similar to type (1) but with the addition of Carbon reinforced UHMWP. Fig. 79B, 80, 81.
A third type was considered but proved impracticable to manufacture confining the carbon fibre reinforcement to the tibial stud region alone and without the use of the metallic support.
Summary of Design Studies

1. - Properties of Materials:

Fatigue strength:

- Cast Cobalt Chrome: 250 N/mm²
- UHMWPE: 15.52 N/mm²
- Poly Two 10% Carbon reinforced UHMWPE (Poly Two): 18.97 N/mm²

Young's Modulus

- Cast Cobalt Chrome: 200,000 N/mm²
- UHMWPE: 713 N/mm²
- Poly Two: 1017 N/mm²

Fatigue Strain Limit

- Cast Cobalt Chrome: \( \frac{250 \times 100}{200,000} = 0.125\% \)
- UHMWPE: \( \frac{2.18}{1} = 2.18\% \)
- Poly Two: \( \frac{1.87}{1} = 1.87\% \)

Shear Strength (Fatigue)

- UHMWPE / Poly Two: approx. 25 N/mm²

No tests have been reported at physiological rates but there appears to be a modest improvement in the endurance limit for the carbon fibre reinforced composites.

II. - Design Strain - Considering the weakest section through the web of the stud - the strain on any material should not exceed the strain produced by fatigue limit stress. This analysis shows that the metal component is the strain limiting phase of the composite implant. No sliding of plastic against metal is allowed hence the plastic strain at the surface of the web is calculated.
II. - Design Strain.

Assume component is designed to withstand fatigue loading (i.e. not individual catastrophic).

For indefinite use strain in either material of the two phase construction must not exceed fatigue strain.

For indefinite use the two materials of the two phase construction should be effectively bonded at their interface, i.e. no slippage - hence interface strain is same in each.

\[
\begin{align*}
\varepsilon_a &= \text{cross section through critical area} \\
\varepsilon_b &= \text{strain distribution through critical area}
\end{align*}
\]

**Fig. 82**

**Poly Two/ Metal Composite**

Assume \( E_a \) is fatigue strain limit for Poly Two i.e. 1.86\% (see appendix 1.).

Hence \( E_b = \frac{1.86 \times 6.8}{12.1} = 1.05\% \)

i.e. interface strain is 1.05\%, strain in metal is 1.05\% if surface strain in Poly Two is 1.86\%

However strain limit for cast cobalt chrome is 0.125\% - hence cast cobalt chrome limits the applied loading.

Assume \( E_b = \text{strain limit for Co.Cr.} = 0.125\% \)

Hence \( E_a = \text{surface stress in Poly Two} = \frac{12.1 \times 0.125}{6.8} = 0.22\% \)

**UHMWPE/ Metal Composite:**

Assume \( E_a \) is fatigue limit for UHM/WPE = 2.13\%

By calculation for Poly Two \( E_b \) would be in excess of limit for Co.Cr. hence limiting factor again is \( E_a = 0.125\% = \text{fatigue strain limit for Co.Cr.} \quad E_b = 0.22\% \).
III. Design Stress - The maximum stresses corresponding to the strain limits determined in Appendix II are calculated for the metal component, UHMWPE and Poly II.

Fatigue loading condition is assumed.
Maximum strain at metal/plastic interface is 0.125%.
Maximum strain at plastic surface is 0.22%.

Maximum stress in Co. Cr. = 250 N/mm².

Maximum stress in Poly Two = \( \frac{0.22 \times 10^{17}}{100} \) = 2.23 N/mm²

Maximum stress in UHMWPE = \( \frac{0.22 \times 713}{100} \) = 1.57 N/mm²
IV. - The cyclic bending moment which the web section can resist is calculated.

Bending moments to produce maximum stresses for fatigue limit loading for two phase components.

Applied Moment \( M = M_{\text{Plastic}} + M_{\text{Co.Cr.}} \)

Where \( M_{\text{Plastic}} \) moment resisted by Plastic phase

\( M_{\text{Co.Cr.}} \) Co.Cr.

\( I \) - 2nd moment of area for Poly Two cross section.

\[
M_{\text{Poly Two}} = \frac{I \cdot f}{y}
\]

\( f \) - Maximum stress \( 2.23 \text{ N/mm}^2 \).

\( y \) - Distance from neutral axis \( \frac{12.1}{2} = 6.05 \).

Fig. 84

\[
I = \frac{38 \times (12.1)^3}{12} - \frac{34 \times (6.8)^3}{12} = 5611 - 891 = 4720
\]

\[
M_{\text{Poly Two}} = \frac{4720 \times 2.23}{6.05} = 1740
\]

\[
M_{\text{UHMWPE}} = \frac{4720 \times 1.57}{6.05} = 1225
\]

\[
M_{\text{Co.Cr.}} = \frac{891 \times 250}{3.4} = 65,414
\]
Total bending strength of
Poly Two / Co.Cr. Composite = 1740 + 65,514
= 67,254 N/mm²
= 67.3 N/m

Total Bending Strength
of UHMWPE / Co.Cr. Composite = 1225 + 65,514
= 66,739 N/mm²
= 66.7 N/m

V.- The cyclic bending movement which the current design
(no metal reinforcement) can withstand is calculated for
comparison, i.e. UHMWPE.

\[ M = \frac{I f}{y} \]

\[ I = 38 \times (12.1)^3 \]
\[ 12 \]

\[ f = \text{fatigue strength of UHMWPE} \]
\[ = 15.52 \]
\[ y = 6.05. \]
VI. - Since the endoskel design could fail through detachment from the metal casting the strength of attachment is calculated. This considers failure of the peripheral groove attachment through both tension and shear failure modes. Also the attachment strength of the plastic infiltration of the holes in the web is calculated. Finally, the total cyclic bending moment which the plastic retention design can withstand is calculated.

Attachment of Stud to Casting

(1) Peripheral Attachment:

(a) Major retention area is in segment AO - BO. Assuming retention interlocking fails in tension-fracture surface is YY. Total area of critical section in plastic in this segment: shown schematically.
\[
\frac{(2\pi r - 4r)1.4 + \frac{Mr^2}{2}}{4} = \frac{(2\pi \cdot 21 - 4 \cdot 3.17)1.4 + \pi (3.17)^2}{4} = (35.9 - 12.68)1.4 + 17 = 32.5 + 17 = 49.5 \text{ mm}^2
\]

Fig. 88

Retention Strength = 15.53 \times 49.5 = 768N.
Bending Moment Resisted = 768 \times 34\text{mm.} = 26.1\text{Nm}.

i.e. if retention interlocking shears in tension then peripheral retention will resist cyclic bending moment of 26.1.

(b) Assuming retention interlocking fails in shear:
2π - shear fracture surface

Total shear fracture surface area:

\[
\text{Area} = 1.5 \left( \frac{2 \pi 21}{4} - 4.3 \right) = 1.5(23.9) = 35.8 \text{ mm}^2
\]

Peripheral shear strength = 35.8 x 25 = 895 N.

Bending moment resisted = 895 x 34
= 30.4 Nm.

Hence from consideration of (a) - fracture of peripheral retention in tension (26.1 Nm) and (b) - failure of peripheral retention in shear (30.4) then the design value is 26.1 Nm for peripheral retention.
Abduct/Adducting bending moment will tend to raise the ball and shear the plastic through the three holes.

Force required to shear the plastic:

Dia. - 4mm.

Total area = $3 \times \frac{\pi (4)^2}{4} = 41 \text{ mm}^2$

Shear strength = $25 \times 41 = 1025 \text{ N.}$

Moment resisted by shear = $1025 \times 16.5 \text{ mm.}$

= $16.9 \text{ Nm.}$

Hence total strength of attachment of stud to casting is a) + b) i.e. 26.1 + 16.9 = 43 Nm.

i.e. stud retention can withstand fatigue cyclic loading imposed by bending moment of 43 Nm.
VII. - This lists the recorded applied adduct/abduction bending movement applied to the knee in normal walking, i.e. in the absence of soft tissue support this would be the bending moment applied to the prosthesis.

Typical Add/Abducting bending moments at the Knee:

(a) From basis of ligament forces:

![Diagram](image)

**Fig. 92**

**Fig. 1.** Shows proximal tibia with normal walking collateral ligament force; force in collateral (500N).

Disposition of collateral from position of centre of condyle above which joint is pivoting. Hence applied moment $500 \times 50 = 25 \text{Nm.}$

(b) From experimental studies: Paul^78

Typical value approx. 30 Nm.
VIII. - Summary of Results:

It should be noted that this is a theoretical consideration of the designs and assumes perfect manufacturing of the composite. Should gaps in the retention be present for example, then the strength of attachment would be impaired. However, several conclusions can be made.

a) The existing design is theoretically incapable of resisting a totally unstable knee.

b) The metal reinforced endoskel design can theoretically withstand the bending moments of a totally unstable knee in normal walking (almost 50% more strength).

c) The endoskel version appears to have more than adequate strength (3 times the current design) for normal use. However, it should be noted that a sudden traumatic load could exceed the retention strength of the stud. Hence the theoretical consideration of the design supports the previously expressed view that the endoskel design should be considered as providing additional safety margin to stud strength and should not be considered as a reason for broadening the range of applications to completely unstable knees. Tensioning of the soft tissues should also continue to be emphasised.

<table>
<thead>
<tr>
<th>Applied Adduct /Abduct Moment</th>
<th></th>
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<tbody>
<tr>
<td>Moment during normal walking</td>
<td>30 Nm.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum bending moment resisted indefinitely under cyclic loading by current stud design</th>
<th>14.4 Nm.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Maximum bending moment resisted indefinitely under cyclic loading by metal reinforced stud (limited by stud retention)</th>
<th>43 Nm.</th>
</tr>
</thead>
</table>

| Maximum bending moment resisted indefinitely in cyclic loading by metal reinforced stud considering only web strength | 67 Nm. |
Current Range of Prostheses and Indications for Use

Standard Broad Condyle
Reinforced Tibia (Endoskel type) (available with UHMWP or carbon reinforced UHMWP) Routine Arthroplasty

Anterior flange prosthesis with patellar replacement. Patients with gross changes in patello femoral and femoro-tibial joints, (usually in O.A.)

Revision Prosthesis Patients with complete destruction of collateral ligament. Revision of failed surface prosthesis

90% Prosthesis Stills Disease Small female patients.

Long Stemmed Femoral Prostheses Patients requiring additional fixation or fracture of shaft of femur in association with arthritic knee.
Instrumentation

A sharp osteotome and mallet to many orthopaedic surgeons are the trademarks of the specialty, and additional instruments are a reflection of the skill with which the basic tools are wielded. Additional instruments are considered extravagant and unnecessary and one is normally taught that any procedure requiring more than a few special instruments should be considered with grave suspicion.

The author firmly believes that if any special instrument will facilitate a particular step in the operation or indeed increase the accuracy of the procedure, then such an instrument is well worth while. It is with this principle foremost in mind that the present set of instruments have evolved with usage of the prosthesis over the past decade.

Femoral Jig and Alignment Rod, Fig. 93.

This instrument allows accurate placement of the femoral component. The dimension from the posterior aspect of the condyles to the central medullary canal is determined with the jig, and the cross section of bone for removal is outlined.

If the collateral ligaments are to be preserved and functional then the prosthesis must be positioned from the post aspect of the femur. If the femoral prosthesis in fact positioned from the anterior aspect then no account is taken of the resultant tension of the collateral ligaments and they will probably be functionless in a large patient, or excessively tight and prevent reduction of the joint in a small patient. Tension in the collateral ligaments is particularly important in extension to provide stability.
The jig is positioned under the condyles when the knee is fully flexed and the knee is gently extended to 90°. Bar (B) is placed in the long axis of the table and this ensures that the drill slot is offset by 8° valgus. The horizontal bar (C) is placed parallel to the table to ensure that the femoral prosthesis is aligned in a neutral position with no tendency for exterior or interior rotation of the prosthesis.

Drill: - 7 mm. Fig. 94.

![Fig. 94](image)

Accurate size drill is necessary to ensure adequate clearance so that the alignment rod can be introduced through the cortex with minimal resistance and thus guided bluntly into the canal.

Osteotome Resistor, Fig. 95.

![Fig. 95](image)

Femoral Reamer and Bar, Fig. 96.

![Fig. 96](image)

This instrument is a bone "impactor" rather than a reamer. The blades are so designed that the leading edge is slightly concave. This has a dual effect:

a) It compresses soft osteoporotic bone and gives a firmer structure for fixation.

b) It prevents splitting of the lower femur unless considerable force is exerted.

If dense bone, it may be difficult to introduce and some cancellous bone may have to be removed with a curette as reaming proceeds.
Trial Femoral Prosthesis, Fig. 97.
This differs from the standard femoral prosthesis in two respects.

Fig. 97

1) The posterior aspect is removed so that it can be inserted despite the presence of the tibial spines which would impinge on a normal prosthesis at this stage.
2) The inner retaining tracts are removed to allow insertion of the tibial guide.

The trial femoral prosthesis is used in conjunction with the set of gauges as described in "Technique of Insertion".

Set of Femoral Gauges, Fig. 98
Tibial Drill Guide, Fig. 99.

A single guide can be used whether using the large or small tibial component. In a large bone the guide is positioned more superficially on the tibial slope and thus the guide hole is displaced posteriorly compared to its position when resting on a smaller bone. Occasionally when the trial femoral component has been inserted it tends to rotate and such rotation can be readily corrected with the tibial guide.

Tibial Spine Retractor, Fig. 100.

This is designed for insertion into the posterior aspect of the tibial spine under direct vision.
Femoral Extractor, Fig. 101.

This is for removing a tightly fitting femoral component on the trial femoral component. The plastic lined cylinder can be introduced in a vertical fashion and then rotated through $90^\circ$ to engage the inner aspect of the lips of the prosthesis.

Tibial Introducer - Extractor, Fig. 102.

When introducing the tibial component with this instrument full flexion of the knee greatly assists the manoeuvre. The self-contained hammer is adjusted to obviate the danger of splitting the tibia.
Femoral Impactor, Fig. 103.

This allows control over the rotation as well as the seating of the femoral prosthesis. As the gap between the femoral condyles widens posteriorly, it is easier to introduce the impactor posteriorly and gently move it anteriorly until a tight fit is obtained. The transverse bar on the handle permits a further check on the alignment of the femoral component when cementing.

Tibial Disc Reamer, Fig. 104.

This fits over the alignment rod and should cut the upper tibia with a reciprocating type motion. This avoids any possible damage to vessels or soft tissue. The cutting edges are work hardened and under normal conditions should not require resharpening.

Tibial Reamer, Fig. 105.

The bar of this fits the hole made by the alignment bar.
Additional Instrumentation for these Prostheses

Anterior flange prosthesis:

Jig and chisel to align patellar surface.

Patellar Instruments

Patellar clamp and reaming tools.

Revision Prosthesis and 90% Prosthesis:

Femoral Jig, Femoral Reamer, Trial Prosthesis.


Femoral Extractor.

Tibial Introducer, Extractor,

as for standard instrument set but modified dimensionally for revision and 90% Model.

Instrument set in tray for sterilisation

Fig. 106
The Operation

Indications for Arthroplasty:
Any patient in whom the only alternative procedure is an arthrodesis.

Contraindications:
1) Severe peripheral vascular disease in the involved limb - including peripheral vasculitis.
2) Peripheral neuropathy.
3) Poor general state as indicated by either cardiac, respiratory or renal disease, suggesting a poor prognosis.

Cardiac disease should receive particular attention due to the increased risk entailed with methymethactrylate and also the additional overload at the time of tourniquet release. Activity of rheumatoid disease is not a contraindication but every effort is made to achieve maximal control of the condition prior to surgery.

4) Multiplicity of problems suggesting that numerous major procedures be undertaken and the patient possibly already adapted to a wheelchair existence for some years prior to surgery does not preclude excellent return of function and one patient to date was in a chair for 5 years prior to arthroplasty and has excellent return of quadriceps function. However, over-enthusiasm for long term gross disability should be resisted at this stage of the clinical usage of knee arthroplasty. It is frequently felt that at least the most grossly disabled patients cannot be further disabled. It is, however, better to gain experience in a technique with lesser degrees of pathology and in particular knee problems without gross fixed deformity. The more difficult major problems can subsequently be tackled when more experience has been gained in the technique rather than vice versa.

5) Previous patellectomy. Such patients at this stage should be approached with caution. This also applies to any patient with a major disorder of the quadriceps mechanism as the result of knee arthroplasty is entirely dependent on muscle function and a destroyed or non functioning quadriceps from whatever cause is a contraindication.
6) Previous Arthrodesis. The results of hip arthroplasty following a hip arthrodesis are frequently excellent but in the case of the knee to convert a sound painless knee to an arthroplasty at the present time is contraindicated.

7) Previous infection of the knee from whatever cause is at the present time a contraindication to arthroplasty. It is still too early to assess the long term usefulness of antibiotic additives to cement.

8) Degenerative osteoarthrosis with medial compartment disease where an osteotomy may give an excellent result. Coventry's (1973) criteria are still very adequate in assessment of patient suitability for osteotomy versus arthroplasty. McIntosh hemiarthroplasty has been used for many years for unicompartmental disease and more recently replacement of the femoral and tibial surfaces of one compartment - unicompartmental replacement has been introduced. I feel that unicompartmental arthroplasty of either type is illogical in that function of any one knee compartment is directly related to the 2nd tibio-femoral compartment and if replacement is contemplated, i.e. after depressed plateau fractures with secondary O.A., then total replacement rather that unicompartmental replacement should be performed.

9) Congenital bow legs where the shape of the bones precludes the use of intramedullary stems and grossly abnormal varus strains would be transmitted to the prosthesis.

10) Uncorrected angular deformities of the limbs at sites other than the knee, i.e. due to old trauma. Arthroplasty can be undertaken as a secondary procedure when such abnormal angulation has been corrected by a primary osteotony.
Pre-Operative Assessment:

a) Pre-Operative assessment of gait.

In rheumatoid disease patients frequently have hypermobile joints and the major disability is due to instability rather than pain. Observance of the gait frequently indicates the exact status and a stiff knee gait indicates that the joint surfaces are no longer functioning adequately despite the patient's ability to fully flex such a joint when non weight bearing. Some patients, however, retain some flexion - extension in the swing phase but in rheumatoid disease as well as in severe Osteoarthritis there is a decrease or loss of stance phase flexion - extension. During normal level walking the knee is extended prior to heel strike and then flexes rapidly to approximately 20° early in the stance phase and then subsequently extends while weight transmitting. Loss of this stance phase flexion - extension is in indication in most instances of bearing surface disruption.

b) Patients Receiving Steroids:

Additional steroid cover is given for 48 hours to patients on steroids pre-operatively and then reduced to the patients' normal pre-operative level. (Steroid cover is also given to patients who were receiving steroids but had therapy discontinued within 12 months of surgery). It is important following surgery that no effort is made to reduce maintenance therapy for some months as mobilisation of the operated knee is frequently interfered with by such attempts. In addition a generalised flare-up of the condition may occur with consequential reduction in mobility of the patient.
c) Radiology Prior to Arthroplasty: Fig. 107, 1.11.111.1V.V.V1.
The following x-rays are recommended.

1. A.P. both knee, supine.

111. Left knee full extension

11. Left knee, erect.

1V. Left knee full flexion
1. & 11. A.P. Both knees supine and erect (weight bearing). It is better to take weight bearing films of one knee at a time with patient transmitting full weight through the knee under examination. If weight bearing films are taken of both knees at the same time it has been observed that the patient frequently does not transmit much weight through the painful or unstable knee if the opposite knee can weight-bear normally.

111. Lateral view both knees in extension.

1V. Lateral view both knees in full flexion.

V. A.P. both hips and pelvis. The film must not be omitted particularly in patients with rheumatoid arthritis as frequently fairly advanced changes can occur in a hip without any major symptoms particularly if the ipsilateral knee is seriously involved.

VI. Skyline view both patellae.
d) Pre-Operative Physiotherapy Instruction:

The strength of quadriceps contraction is recorded and instruction in strong static quadriceps contraction as well as ankle plantar flexion against resistance is taught. The importance of the latter measure in relation to the prevention of venous stasis and possible thrombosis is stressed. Instruction is also given re deep breathing exercises.

e) Body Weight:

Excessive body weight may be a contraindication to surgery and if possible patients should be instructed on weight reduction prior to surgery. In grossly disabled patients, weight reduction may prove very difficult.
Total Knee Replacement and the Anaesthetist

In the majority of cases surgery is performed on the elderly or high risk patient. Appreciating the effect of anaesthesia in such cases, in conjunction with Dr. Richard Nolan, Anaesthetist, significant emphasis has been placed on the technique of anaesthesia.

Patients for total knee replacement present a challenge to the anaesthetist, pre-operatively, intra-operatively and post-operatively. The majority of these patients fall into two groups; firstly those with osteoarthritis who frequently have degenerative disease not only of other joints but of other systems; and secondly those with rheumatoid arthritis, who apart from having a generalised disease of connective tissue, with cardiac involvement in 50% of cases, may have the further complication of current or previous steroid therapy.

A large proportion of patients in both groups but more particularly the osteoarthritics are obese, whether as a causative factor in the development of the arthritis or as a consequence of the enforced inactivity. For some of them, food and drink may be the remaining pleasure left to them. The product may be a sluggish patient who does not breathe well, does not cough well, with an increased tendency to circulatory stasis and thrombo-embolic disease.

A concerted approach to the problem by physician, surgeon and anaesthetist makes weight reduction a necessary prerequisite for surgery and utilises surgery with its promise of pain relief as the incentive for the patient to persist in a controlled diet. All incentives are to be utilised, for in many of these patients "the flesh is weak" metaphorically as well as literally. So a programme of weight reduction and exercise within their current limits pre-operatively is important. The decision on "fitness for surgery" is complex, with no simple solution. Their disability limits the usefulness of their exercise tolerance in the assessment of cardio-respiratory function.
Because of this, other objective tests become all the more important, not so much in contraindicating surgery and anaesthesia, but in showing how the patient's condition may be further improved before embarking on the stress of surgery. An E.C.G. is mandatory.

One must think of myxoedema in these heavy older patients, because if you do not think of it initially it may easily be missed, as one accepts the patient's customary appearance as the norm. The myxoedema heart withstands major surgery poorly. Anaemia or any element of heart failure should be corrected in advance of surgery and any electrolyte imbalance consequent on treatment also rectified. On the other hand, polycythaemia may increase the risk of phlebothrombosis and call for some dilution during surgery.

Hypertension may cause undue operative blood loss, post-operative bleeding and haematoma formation with an increased risk of infection. Anti-hypertensive agents alter the patient's ability to respond appropriately to blood loss. B-blockers in particular prevent the normal increase in heart rate in response to haemorrhage, and if combined with atropine during the course of anaesthesia, leaves the heart "freewheeling" like a motor car on a mountain road without clutch or brake. However, abrupt cessation of B-blockers or anti-hypertensives leaves the heart and circulation more than usually sensitive to endogenous catecholamines, and susceptible to paroxysmal hypertension or arrhythmia. On balance it may be wiser to continue anti-hypertensives, but reduce B-blockers as far as possible prior to surgery.

It would be a pity if the anaesthetist were the first person to look in the patient's mouth and discover severe gingivitis, giving rise to bacteraemia with each chew, and endangering the survival of an implant.

Elevation of the legs and the wearing of anti-thrombosis stockings will reduce dependent oedema but prolonged bed rest prior to surgery is to be avoided, as it encourages venous stasis and calf thrombosis.
Pelvic pathology should be ruled out, as an ovarian cyst will encourage venous stasis, and in the male, bacteraemia following catheterisation may prejudice the success of an implant, so significant prostatic obstruction should be ruled out.

A variety of pre-medications have been used successfully. The two extremes to be avoided are undue depression of cardiorespiratory function and undue stimulation of heart rate. An opiate such as papaveretum 10 mg. to 20 mg., depending on build, together with 0.3 mg. of atropine sulphate are used, unless there are manifestations of an allergic diathesis, such as asthma, when pethidine 50 mg. and promethazine 25 mg. are typical examples of combinations used. Apart from sedating the patient and providing a background analgesia, these particular premedicants afford an opportunity of assessing the likely effect of one's post-operative analgesic regime, which may be modified accordingly. This opportunity is lost if a simpler sedative, such as diazepam, is used; and the discovery that one's dosage has been, for this patient, excessive, is of less importance prior to a general anaesthetic with controlled ventilation than it would be if respiratory inadequacy appeared for the first time back in the ward as a result of postoperative medication. The combination of pethidine and atropine both vagolytic, may produce unacceptable tachycardia in the elderly, increasing cardiac work and shortening diastolic time for coronary perfusion.

For patients on current or recent steroid therapy, appropriate supporting dosage must be given. On arrival in theatre the pulse and blood pressure are measured and the effect of the premedication noted. The appearance of the superficial veins is a useful guide to anxiety, as sedation is related to forearm blood flow and the degree of anxiety is in proportion to the time it takes the anaesthetist to find and cannulate a suitable vein.
Hypnosis is induced with thiopentone 2.5% and relaxation obtained with pancuronium bromide. After topical anaesthesia of the larynx with lignocaine the trachea is intubated with a cuffed tube and mechanical ventilation commenced with nitrous oxide and oxygen. An effort is made to match the time constant of the inspiratory cycle of the ventilator to the individual, as otherwise we achieve over-ventilation and under-perfusion of the most easily ventilated alveoli, while less than adequately ventilating those alveoli whose perfusion is greater. If analgesia is inadequate this is supplemented either by a short-acting specific analgesic intravenously or by addition of trichlorethylene to the inspired gases. If trichlorethylene is used it must be discontinued during closure to avoid delayed recovery. Undue rises in blood pressure are relieved by minimal supplements of halothane.

Before surgery commences an exsanguinating Esmarch tourniquet is applied to the leg and exsanguination of the limb maintained with a pneumatic tourniquet high up on the thigh. Effectively this accomplishes a sudden infusion into the trunk of 15% of the normal total blood volume, with a consequent rise in central venous pressure and arterial pressure. Intermittent positive pressure ventilation tends to protect the lungs from congestion which might follow this infusion, particularly in the elderly. For this reason we have so far avoided spinal anaesthesia in this series. The tourniquet prevents the removal of molecules of relaxant from the limb, so that relaxation persists and protects the rest of the body from toxic effects of the cement used in fixing the components of the prosthesis.

There are three groups of patients in whom this is less true. Remembering that the pneumatic tourniquet is effective in compressing only those vessels outside the femoral shaft, exsanguination may not remain adequate in patients with Paget's disease, in those who are acromegalic, or in those few whose limbs derive a major portion of their arterial inflow through the femoral canal. In these last, the condition may be bilateral and circulatory changes associated with cement immediately follow its insertion.
Even satisfactory exsanguination and control of arterial inflow is not an absolute guarantee of protection, as entry to the circulation may still be gained by the venous intramedullary sinuses.

The tourniquet, by compressing nerves, may also provide a degree of analgesia in the limb. Cement effects may be divided into non-specific and specific. The non-specific are those which occur when any composition is pushed into the medullary cavity of a long bone, and include fat, marrow, and air embolisation. Even plasticene pushed into a reamed out femoral canal in the cat produces a fall in blood pressure with histological evidence of embolisation at the time of insertion. This can produce a concomitant fall in arterial oxygen tension.

Specifically, the cement through its liquid component, the monomer of methyl methacrylate, produces a fall in peripheral resistance, but also changes electrical conduction in the heart. Earlier papers have suggested that the E.C.G. changes are secondary to the hypotension but we have seen typical E.C.G. changes occurring without significant hypotension, indicating a more direct action of the monomer on the conducting system in the myocardium. Further, these changes have been observed some minutes after insertion of the cement but before release of the tourniquet, indicating an absorption of the monomer through the venous sinuses in the femoral canal. These changes occurring under such circumstances suggest that the conducting system in the heart may be susceptible to lower concentrations of monomer than those which produce the peripheral vasodilation with its corresponding fall in blood pressure.

The monomer is relatively insoluble in blood and enters the alveoli in gaseous form, being excreted in the patients expired air, transiently lowering the $pO_2$ via the "second gas" effect. This is transient unless the anaesthetist uses a closed circuit with $CO_2$ absorption, in which case the monomer remains in the circuit and the hypotension persists.
The E.C.G. changes are variable, ranging from scattered ventricular extrasystoles, to a nodal type rhythm, as the P wave alters, becoming shorter and flatter, and may disappear, or the P–Q interval becomes progressively shorter over five or six beats and nodal rhythm supervenes with the P wave occurring on the end of the R–S segment, indicating reversal of the normal sequence of atrial and ventricular contraction. This reversal may reduce ventricular filling and cardiac output.

The two factors we have seen to increase the hypotensive and conduction effects respectively are hypovolaemia and cold. For the first, we aim to have more than replaced blood loss before exposure to cement; and for the second, since sterile air enclosures with rapid air changes are inevitably cooling to the patient, all intravenous fluids are first channelled through a blood warming coil set at 40°C centigrade. (Higher temperatures may damage cells and clotting factors.)

A variety of factors affect the evolution of monomer from the conglomerate. Left to itself, the monomer evaporates. Mixed with the polymer, the liquid polymerises, locking the grains of powdered polymer together. This is a strongly exothermic reaction and is also temperature dependent. As it warms up due to the heat of its own reaction, the monomer on the inside reacts more rapidly, while that on the outside tends to evaporate more rapidly.

More complete mixing ensures polymerisation of more monomer, leaving less available for hypotensive action and similarly the longer the time between mixing and insertion, the less hypotension ensures. It is our routine to mix polymer and monomer briskly for at least 210 seconds, rather than 150 seconds as some earlier writers have recommended.

The more complete the reaction, the less monomer remains to evolve, so it is our routine to leave the tourniquet in place for fifteen minutes after insertion of the cement. This time is based on clinical observation and on a study of the entry of isotopically labelled monomer into the circulation of dogs following the insertion of cement into their femurs.
The delay in releasing the tourniquet results in the tourniquet being in place for an average approximately 65 minutes. In this time the body has adapted to or corrected the hypervolameia resulting from the exsanguination of the limb. Release of the tourniquet leads to post-ischaemic vasodilation in the limb so that the vascular space is now significantly greater than before application of the tourniquet. Furthermore, accumulated acid metabolites and potassium ions which have leaked from the ischaemic cells and a bolus of monomer, all reach the circulation at the same time. The degree of hypotension which ensues can be minimised both temporally and in degree by preloading the circulation with fluid, prophylactically giving 50 m.Mol. of NaHCO₃ and tilting the patient foot upwards to minimise the amount the trunk bleeds into the dilated leg vessels.

The bicarbonate not only counteracts the acidosis but also tends to return the excess potassium to the intracellular compartment. Where these precautions have been observed, hypotension following release has not been a problem. Where they have been neglected, considerable anxiety has arisen.

The closure is the most protracted part of the procedure and is a time when little is demanded from the anaesthetist, apart from an immobile patient. If a respiratory drive is evident the relaxant may be reversed and spontaneous ventilation restored. Post-operative analgesia is ordered, bearing in mind the individual's response to the pre-operative medication. An opiate combined with an anti-emetic, or where depression has been noted, Pentazocine combined with Promethazine has proved very satisfactory. 500 ml. 70,000 molecular weight Dextran is given per-operatively for the prophylaxis of deep venous thrombosis, and repeated on the third and fifth post-operative days. An intravenous line is maintained for the first forty-eight hours to allow for replacement of blood loss.

Because of the limited mobility post-operatively, particular attention must be paid to maintenance of pulmonary function and prevention of venous stasis.
Patients apart from their regular physiotherapy are instructed to cough hourly "on the hour", both to remove secretions and to expand any alveoli which are tending to collapse, and secondly to dorsi and plantar-flex their feet, to decrease venous stasis in the calves. They start this on the table before they are lifted onto their beds.

To prevent post-operative hypoxaemia, 28% oxygen is given for some hours post-operatively. Blood loss is carefully monitored during and after surgery. A haemoglobin and haematocrit estimation is desirable on the third post-operative day so that any further blood needed may be given while the Dextran drip is established.

In knee replacement, problems arise for the anaesthetist due to the quality of the patients, the nature of the surgery, and the use of methyl methacrylate. Like anything else, attention to detail is the key to success.
Post-Operative Management of Knee Arthroplasty

Day 1
Foot of bed elevated 12"
Active foot exercises including plantar flexion against resistance commenced from time patient awakes. Deep breathing exercises also commenced on awakening.

Day 2
Static quads and straight leg raising commenced as soon as patient is comfortable, usually between twenty four to thirty six hours. Suction drains removed at 36 hours without disturbing the dressings.

Day 3-4
The Jones Bandage is removed on third or fourth post-operative day and gentle knee flexion commenced. This should only be encouraged after inspecting the wound and noting that there is no undue tension, etc. In revision cases in particular where there are previous scars and the risk of devascularisation, great care in mobilisation is exercised. Only simple skin dressing is applied.

Day 4-14
Crutch walking with partial weight bearing commenced on the fourth or fifth day progressing to full weight bearing over a few days if comfortable and there is no obvious effusion. Change to stick when good quadriceps control has returned.

Quadriceps contractions against the resistance of the physiotherapist’s hands are commenced as is also gentle assisted knee flexion. A small pillow can be placed under the knee and the patient extends his leg working his quadriceps in their inner range. The height of the pillow is gradually increased. This can progress to a triangular hassock. No pillow must remain under the knees except while in physiotherapy otherwise it predisposes to the development of venous thrombosis.
Active knee flexion concentrated on after two weeks when the sutures have been removed and provided wound healing is satisfactory. Up to the two week stage active flexion is not forced but the patient is encouraged to flex the knee from the time of surgery - initially within the confines of the bandage and more actively when this is removed. Normally they will not flex the knee beyond the limit of comfort and thus put very little strain on the suture line - provided that the incision is correctly placed and that the vastus medialis has not been detached at the musculo-tendinous junction.

Day 14 onwards. If approximately 90° is not achieved by two to two and a half weeks then manipulation under anaesthesia is performed. The range of knee movement is recorded weekly. If the limb at the end of surgery remains in some degree of fixed flexion then early physiotherapy is concentrated on active quads exercises and assisted active extension. The use of muscle relaxants, i.e. Valium 5 mgs. b.i.d. or t.i.d. is occasionally used during the post-operative period.

Walking
Although walking is achieved easily and early, some patients do not use their range of knee movement and walk stiff-kneed. This may be due to habit, having had limited movement before surgery. They should be taught to walk heel and toe and to bend their knee in a normal fashion during the gait cycle.

Stairs
Are negotiated at approximately fourteen days using a stick and banister.

Hydrotherapy is frequently used after two weeks in patients with severe rheumatoid arthritis but its use has not as yet been proven.
Technique of Knee Arthroplasty

Medial parapatellar incision, Fig. 108, starting at level of patella approximately 1/2" from medial border and passing vertically upwards for 3" - 4" and downward with slight lateral inclination to end 1/2" below and 1/2" medial to the tibial tubercle. The superficial branches of the medial inferior geniculate artery in the lower part of incision are diathermised.

![Fig. 108](image_url)

The incision is deepened throughout its extent without undermining and the capsule in the tibial region is incised onto bone. The incision is extended upwards to muscular fibres of vastus medialis. The medial inferior geniculate vessels beneath the capsule and lying on the tibia are carefully diathermised as otherwise they may be troublesome when the tourniquet is released.
The muscle and synovium are cut with a scissors to the superior aspect of the suprapatellar pouch and the muscle incised above this level to the limit of the incision, Fig.109. No attempt is made to follow the line of the muscle insertion laterally. The upper part of the incision in the vastus medialis can frequently split muscle fibres without cutting them. The patella is grasped with a swab and gentle lateral dislocation attempted. It is rarely possible to dislocate the patella at this stage as further tissue release is necessary.

a) In the area of the suprapatellar pouch.
b) Extending laterally into the fat pad and the anterior attachment of the menisci.
c) Subperosteal exposure of the upper tibia to expose the attachment of the ligamentum patella. This is performed with a sharp knife and the periosteum is reflected laterally as far as the attachment of the ligamentum patella.
As an attempt is made to dislocate the patella any remaining tight structures are placed under tension and can be readily divided. When the patella can be rotated laterally by approximately 100° then commence knee flexion and the patella will rotate fully laterally with flexion so that its articular surface points laterally, Fig. 110. If the patella is not laterally dislocated in this fashion but displaced over the side of the lateral condyle then the skin margin remains in the wound and may be a possible source of contamination of the implant. During this latter manoeuvre observe constantly the attachment of the patellar ligament as this may be torn off its attachment if the dislocation is too vigorous. If this ligament starts to tear then extension of the incision superiorly is necessary.

Flex the knee as fully as possible and adjust the lights to the new position as the knee will remain in this position until closure. Wound edge towels are applied with clips inserted into the fascial layers. The use of skin clips should be avoided as they may damage the already delicate skin.

Release the attachment of the capsule anterio to the upper tibia so that the full width of both femoral condyles is visualised. This may not be necessary and usually minimal release in this area is required.
No attempt at synovectomy is performed and possible synovectomy at the time of arthroplasty is I feel contraindicated and may well jeopardise the early return of movement.

Locate the femoral jig behind the condyles of the femur, Fig. 111. Even in patients with severe degenerative changes the posterior aspect of the condyles are well preserved. A patellar guide was used in a number of cases but has since been discarded since if the patella has been displaced laterally for some time the original patellar groove can not be located and this may result in lateral placement of the jig.
The handle of this jig should be held in the long axis of the operating table Fig.112, and the cross bar aligned so that it is parallel with the surface of the table and at right angles to long axis of the table, Fig. 113.
No attempt is made to place this parallel to the femoral condyles since if one or other condyle has collapsed it is impossible to visually estimate to what extent collapse may have occurred, then the valgus offset of the drill will be inaccurate (Fig.114.)

Place the drill in the drill guide and drill to a depth of approximately 1". It is not necessary to drill deeper as the bone is soft in the subcortical region and it is safer to push the aligning rod into the cancellous bone as there is very little chance of piercing the cortex if alignment is not quite accurate. Using a fine osteotome mark the outline of the femoral prosthesis on the lower femur (Fig.115). Take care that the osteotome is not driven into the bone as it may easily split the bone. Also mark the anterior edges with a curved gouge otherwise the bone may split where two edges meet at a point.
Ensure that the osteotome lies parallel to the outline on the jig Fig. 115. In small bones it may be necessary to tilt the gouge posteriorly so that a reasonable amount of bone remains anteriorly otherwise there is danger of the thin lip of bone fragmenting and the prosthesis following its insertion is thus virtually uncovered anteriorly. This latter step is unnecessary with the modified femoral jig now used as this is taken into account in the design.

Remove the femoral jig and alignment rod and using a reciprocating saw cut the inverted U shaped area, Fig. 116, to a depth of approximately 1". The original drill hole in the femur serves as a useful point for entry of the saw and the drill hole serves as an anterior guide to the level of resection. If the bone is cut anyway hard it will be impossible to cut around the corners with the saw and separate vertical cuts should be made with the saw and joined to the anterior cut with a small curved gouge. An end cutting oscillating saw is not suitable for the bone resection.

With the saw blade engaging in the condyle prolong the saw cut backwards through the posterior part of the condyle until the blade emerges on the upper tibial table. This latter procedure is perfectly safe provided that the saw is not displaced posteriorly more than 1" to 1 1/2". If this latter step is omitted it will prove difficult to remove the block of bone. Fig. 117.
Insert the "osteotome resistor" into the anterior saw cut. It may be necessary first to insert an osteotome to widen the crack but in soft bone the resistor can be inserted directly by a gentle tap with a mallet. Then insert a 25 mm. osteotome alongside the resistor to a depth of approximately 1 - 1.5 cms. and as the operator levers the block of bone inferiorly, the assistant applies increasing pressure to the resistor and thus prevents cracking of the anterior femoral surface which frequently is thin in this situation Fig. 118.

The cruciate ligaments are still intact but do not prevent the bone block rotating about them. Fig. 119.

Grasp the bone block anteriorly with a heavy Kochers forceps and rotate it forcibly forwards. At the same time insert a Tudor Edwards type periosteal elevator through the gap and further rotate the bone block until the cruciate ligaments come into view Fig. 120.
Once visualised the cruciate ligaments are cut at their femoral attachment with a knife. Provided the sharp dissection is confined to the femoral attachment then there is no danger of damaging the popliteal vessels. The cruciates can be clearly visualised once the bone block is removed and they can now be trimmed flush with the tibial spines. Great care should be exercised in removing the posterior cruciate ligament and it is safer to only partly detach it from the tibial spine with a knife and then with a curved periosteal elevator to push it posteriorly without necessarily excising it completely. Any proliferative synovium about the attachment of the cruciates is also best excised and is amenable to sharp dissection.

A taper pin reamer is inserted into the central drill hole of the lower femur and by varying the position of the handle in an eccentric fashion the medullary canal in the lower femur is widened. Any marrow or fat is suctioned from the medullary canals.

The femoral reamer is inserted, Fig. 121. The cross bar in the handle should be parallel to the table and the prominence on the handle directed anteriorly. If one or other femoral surface is destroyed there is a tendency to insert this instrument obliquely. The cross bar is the guide to its insertion and this should be held at right angles to the long axis of the table.
The reamer should be inserted deeply until the marked on the handle, Fig. 122, is approximately in line of the most prominent part of the femoral condyle. Try to avoid rotation of the reamer or otherwise the eccentric area will be reamed. The trial femoral type prosthesis is now inserted. The posterior aspect of this prosthesis has been removed to allow its insertion in the presence of the intact tibial spines. In addition the inner lips have been partly removed to allow placement of the tibial guide. The trial femoral component is gently hammered using the special punch and mallet.

No attempt is made to fully seat both lips against the femur Fig. 123, since varus or valgus collapse of a condyle will cause unequal condylar surfaces. When the first lip gently rests against the condyle, measure with the set of feeler guages the gap between the remaining condyle and the lip of the prosthesis. This gauge will subsequently be inserted in a similar position during cementing of the prosthesis.
With the knee flexed to 90° or somewhat beyond, the tibial jig is inserted and located in the femoral component, Fig. 124. The jig should rest against the anterior tibial surface. If any large osteophytes are present anteriorly they should be removed otherwise the placement of the jig will be inaccurate.

Fig. 124

The vertical alignment bar of the jig should be held by the assistant in the long axis of the tibia. Usually when the knee is flexed to 90° or beyond, subluxation of the tibia which may have been present in the extended position is corrected. However, if gross subluxation is present then the assistant may have to forcefully align the tibial condyles under the femoral condyles, Fig. 125.

Fig. 125
It is also essential at this stage to correct rotation deformity Fig. 126, since if the tibia is externally rotated then the drill hole will be made eccentrically as rotation does not occur about the mid axis of the tibia. In such a case the drill hole will be made towards the medial aspect of the tibial plateau and may result in subsequent valgus positioning of the implant.

The upper tibial surface is drilled to a depth of approximately 1". The guide and femoral prosthesis are then removed. The posterior part of the condyles is now resected Fig. 127. The swan neck retractor is inserted behind the condyle and the junction posteriorly of the condyle with the posterior cortex of the shaft is identified.

The tip of a reciprocating saw is introduced parallel to the shaft at approximately the junction of the anterior one-third and post two-thirds of a line joining the most prominent point of the condyle and the junction of the condyle and shaft Fig.128. With the blade directed parallel to the tibial surface, a single cut is made through the medial condyle. This cut should not pass completely through the medial cortex as the collateral ligament may be damaged and it is better to complete the cut with 1/2" osteotome introduced anteriorly. The retractor may be removed at this stage.
The same osteotome may be used to lever the posterior part of the condyle anteriorly. Care should be taken not to split the main condyle with over-enthusiastic force. Once the detached part has been levered anteriorly, it is grasped with a large Kochers forceps. There is frequently a fringe of synovium attached to the medial aspect and this may require division with a knife, taking care that the collateral ligament is not damaged. The process is repeated for the lateral condyle and here it is particularly important not to carry the saw cut laterally into the soft tissues or indeed to retract the soft tissues vigorously for fear of damage to the lateral popliteal nerve.

The alignment rod is then passed through the drill hole in the upper tibia to a depth of 4" - 5". This ensures that the cortex is not pierced. This rod should pass in readily and if any resistance is encountered it is almost certainly malaligned and impinging on the cortex.

The tibial spine retractor is now engaged in the posterior tibial spine and this both displaces the tibia gently forwards and protects the vessels at the back of the knee during reaming of the tibia, Fig.129.
The disc shaped reamer is introduced over the alignment rod and with the knee fully flexed is passed through the gap already cut in the femur, Fig. 130. With a reciprocating motion the upper table of the tibia is cut. This cut is often incomplete due to variations in height of the tibial surface but adequate marks are normally left to serve as a guide line. The disc reamer is removed but the alignment rod left in position.

If a large tibial component is to be used, Fig. 131, the disc reamer will not fit through the gap already cut in the femur. However, if the knee is fully flexed only the posterior part of the femoral notch is removed by the reamer and thus provides access to the upper tibia, Fig. 132.
The large curved gouge is driven through the cortex to deepen the already existing cut. If the handle is held vertically due to its curved shape it cuts a hemispherical type area of bone from the upper tibia. This gouge also forms an arc of a circle of 40 mm. so that very little difficulty is encountered in removing the upper aspect of the tibia.

When the gouge has been introduced around the circumference it can then be used to lever out the block of bone. This manoeuvre can also be assisted by moving the alignment bar to one side to increase the leverage.

The tibial reamer is then inserted and with a reciprocating movement the upper cancellous bone is removed to allow seating of the tibial component. Reaming continues until the blades are completely enclosed in the bone, Fig. 133.

![Fig. 133](image)

If a large tibial component is being inserted then commence reaming with the small tibial reamer and follow with the large reamer. The loose particles of bone are removed with a curette and prevented from passing into the medullary canal. All fat and marrow is removed from the canal and upper tibial region.
A trial fit of the tibial component is attempted using the special introducer and the anterior plastic flange should rest on the anterior tibia when the prosthesis is correctly seated. The normal AP plane of the knee axis is $20^\circ$ internally, (Fig. 134,) rotated relative to the foot with the knee extended. In practice, better correction of external rotation, which is invariably present with a valgus knee deformity, is obtained by lining the tibial stud only in slight internal rotation relative to the foot.

![Fig. 134](image)

It is important to ensure full correction of rotation at this stage and to mark the approximately position of the tibial stud on the anterior aspect of the tibial. The femoral component is now introduced, Fig. 135, and with the knee flexed to $90^\circ$–$100^\circ$ it readily slips over the tibial component.

![Fig. 135](image)
The femoral component may not readily fully seat itself and gentle hammering with the plastic lined impactor or gradual extension of the knee will fully seat it. This latter movement should be done with caution as one or other condyle may be cracked by excessive force. If extension cannot be achieved and the femoral component adequately seated, then further seating of the tibial component is performed.

This is a trial and error technique and it is not necessary to shorten the lower femur as all the shortening can be performed on the tibial side. The knee is then put through a full range of flexion - extension movements and the degree of flexion of the knee noted at which the femoral component tends to distract. The femoral component prior to cementing is readily removed with the knee flexed and using the special extractor. Removal of the tibial component requires the use of the introducer - extractor instrument.

On occasions it may be necessary to nibble the posterior femoral cortex in the mid line area as if the cortex is prominent it may impinge against the tibial stud in full flexion, Fig. 136. Usually the cortex breaks at a fairly constant level when removing the block of bone from the femur and nibbling is not normally required.

Fig. 136
In order to obtain the femoral component adequately a transverse groove is cut with a small gouge approximately 1/2" from the surface. This corresponds to a similar depression on the anterior aspect of the femoral prosthesis and allows the cement to protrude both into the bone and prosthesis. A double mix of cement is prepared and the tibial component Fig. 137, is cemented first. The cement is mainly introduced into the medullary canal and only a small amount left in the upper cancellous bone to form a seating for the hemispherical plastic holder. If too much cement is left in the upper area then it will be difficult to drive home the tibial component.

A suction drain is introduced into the medullary canal of both femur and tibia during cementing and both canals are sucked dry before introducing the cement. Cement is now inserted into the femoral medullary canal. Avoid excess cement posteriorly and tend to place it anteriorly where the retaining ridge was cut in the anterior femur and straight up the canal. The femoral prosthesis is driven home by gradually extending the knee.
To remove excess cement from the back of the joint, flex the knee to approximately 40° to 50° and with a small curette remove the excess cement while it is still in a plastic stage, Fig. 138. This stage should be rapidly completed and the knee extended and maintained in this position provided no fixed angular deformity was present. Normally, however, it is better to cement each component separately and maintain the knee in a flexed position until the cement has set. If previous angular deformity existed see further operative details under section on fixed deformities.

Assuming no fixed deformity existed and the knee is held straight until the cement has set, reduce the patella to its normal position during setting so that the quadriceps will not exert a valgus strain. The knee should not be flexed until the cement has fully set otherwise slight movement of the femoral component may occur when the knee is flexed beyond 90° as the cement in the retaining groove will no longer have a firm hold if it has been altered in shape as a result of movement of the prosthesis before setting of the cement.

Polybactrin in Ringers solution is irrigated into the joint during setting of the cement to ensure that overheating in the region of the vessels does not occur and also to clear any particles of cement and bone from the joint. The knee is put through a full range of movement when the cement has set with the patella dislocated and then with the patella reduced and both figures recorded.
Any marginal osteophytes are removed from the patella prior to release of the tourniquet. If the patella is dish shaped due to wear then a cut with the reciprocating saw is made tangential to the deepest point of the concavity, Fig.139. Marginal osteophytes on the lower femur are also removed as they may give rise to restricted knee movements due to interference with capsular mobility.

![Fig.139](image)

Special instances of patellar problems are outlined in the sections dealing with varus and valgus problems.

The head of the table is tilted downwards and the tourniquet released (see separate instructions). Very careful haemostosis is achieved using diathermy prior to closure. The synovium from the suprapatellar pouch downwards to the joint line is closed with continuous 0 catgut. Below the joint line it is not possible to close the synovium separately but the fat pad and periosteum over the upper tibia are approximated with 0 catgut.

Two deep suction drains are inserted and brought out proximally and medial to the incision. One of these is passed into the posterior aspect of the joint between the femoral and tibial components.

The muscle in the upper half of the wound and the capsule in the lower half are closed with 0 chromic catgut. Firm closure of the capsule is particularly important over the condyles so that early mobilisation may be achieved. These sutures are placed approximately 1/4" to 3/8" apart.

Ensure that one of the deep drains lies on the upper tibia as this is the area most likely to bleed post-operatively.
A superficial suction drain is inserted in the subcutaneous layer and the inferior aspect of this again passes to the inferior extremity of the incision. 2/0 catgut sutures are used at 1/2" to 3/4" intervals in the subcutaneous tissues.

Multiple 4/0 nylon Allgower sutures, Fig.140, are used in the skin at approximately 1/4" intervals. Position of skin can best be judged by flexing the knee and placing a few marking stitches towards the centre of the incision and the remainder inserted with the knee straight. The knots of all sutures are placed on the medial aspect, i.e. the better vascularised side of the wound. The suction drains are not stitched in place. Acrylic spray, etc., is used to seal the wound and a Melanin dressing applied. A Jones type bandage is finally applied.
Modification to the Standard Techniques of Insertion

1) Mobile Varus and Valgus Deformities
No special precautions are taken and the knee following cementing is straightened and maintained in a neutral position until the cement has set. The knee should be tested pre-operatively to see if full correction of angular deformity can be readily achieved.

In the extended position the tibial spines lock in the intercondylar eminence and correction cannot readily be achieved on the conscious patient. If, however, the knee is fully flexed and a varus or valgus strain applied as it is gently extended then correction is readily achieved and the degree of fixed deformity easily estimated. If the slightest tension exists in either a varus or valgus direction then it is better to cement both components separately and to hold the knee in flexion until the cement has set.

2) Fixed Varus
This is frequently present in osteoarthritis. If the condition is bilateral it is difficult to say whether the patient always had slight genu varum deformity which subsequently predisposed to degenerative disease. A study of photographs from earlier years before the onset of arthritis suggests that this is not the case in the majority of instances. If the genu varum deformity is not corrected then eccentric loading of the prosthesis will occur.
To correct fixed varus it is necessary to release the medial attachment of the capsule to the upper tibia. Usually following release of the capsule the neutral position can be achieved. If this is not readily achieved and the leg cannot in fact be slightly over-corrected then it is better to cut the lower attachment of the medial collateral ligament, tangentially at its attachment to the upper tibia, Fig. 141.

The medial ligament has quite an extensive inferior attachment to the medial surface of the tibia immediately in front of the upper part of the medial border. Its attachment is approximately 2" long by 1 1/2" wide. It is thus allowed slide and will reattach at a higher level. It is not necessary to release any muscular attachments to obtain full correction. Fig.142.
Both components are cemented in place separately. Only when the cement in the tibial component has set is the femoral component inserted. This prevents a fixed deformity from tilting the prosthetic stems before hardening of the cement and thus loosing the full correction.

Following cementing of the femoral component the knee is held in a flexed position until the cement has set. Gentle pressure should be maintained on the femoral prosthesis by the impactor otherwise it may migrate slightly outwards during setting. Normally no gross rotatory deformity accompanies varus angulation. Some internal rotation deformity, however, may co-exist and ensure that the tibial component is accurately aligned so that no resultant internal deformity ensues following cementing.

3) Fixed Valgus

The correction of this deformity and restoration of function in such a patient is undoubtedly the greatest single challenge in knee arthroplasty. Usually fixed valgus deformity is accompanied by external rotation of the tibia and this may be as great as $70^\circ$ or $80^\circ$. In addition fixed flexion is frequently present and makes the estimation of the degree of valgus virtually impossible.

Do not fall into the error with fixed valgus of thinking that sinking the prosthesis into the bone will allow one to correct the fixed deformity, since even if the deformity is corrected, the muscle vectors are incorrect and will thus predispose to mechanical failure.
If external rotation in particular is not fully corrected at the time of arthroplasty, then the tibial tubercle is laterally displaced and the resultant pull and alignment of the quadriceps mechanism places a valgus stress on the knee. This predisposes to persistent valgus deformity following arthroplasty when the patient weight bears. Fig. 143.

Fig. 143

Patients considered for a tibial tubercle transplant following surgery are patients with incompletely corrected tibial rotation. As previously mentioned the gravity vertical line passes medial to the knee joint. This produces a varus deformity of the leg which is counteracted by tension in the iliotibial tract and the lateral ligament. The former structure can be actively tensed by the tensor fascia lata and gluteus maximus and thus alters the position of the resultant. The natural tendency is for the medial condyle to transmit a greater load than the lateral condyle during the weight bearing phase and this has been shown to be the case by Morrison. Thus with ageing the degenerative changes are more likely to affect the medial joint compartment.

Tibial osteotomy in such conditions with normalisation of the load axis has proved very satisfactory in the management of this problem. Why then does valgus knee deformity occur in such a large proportion of patients with knee arthropathy — particularly in rheumatoid disease? Also, in the past, why have the results of osteotomy for lateral compartment disease generally proved so unsatisfactory?
McGrother\textsuperscript{79} has analysed the joint force transmitted by the knee in patients who required hip surgery. The curves of knee joint force variation with time before and after hip surgery showed little major difference. However, the variation in the position relative to the knee joint of the resultant force transmitted at the tibio-femoral articulation was striking.

In the stance phase in the normal individual it is concentrated almost exclusively in the medial condyle and as illustrated before hip surgery the resultant force was transferred to the lateral condyle. Following hip surgery the resultant knee force was again transferred to the medial condyle thus illustrating the significant effect that either ipsilateral or contralateral hip disease can have on the loading of the knee (Fig. 144).

From theoretical considerations a medial displacement of the upper femur such as with a medial displacement osteotomy of the hip will cause a similar transfer of the resultant knee force to the lateral compartment, Fig. 145 A.

This is a well recognised clinical finding and frequently a source of considerable trouble. Similar overloading of the lateral compartment can also occur as a result of increased adductor spasm, Fig. 145 B.
This again is seen clinically as valgus knee deformity in spastic children. Adduction deformity of the ipsilateral hip causes a similar shift of the resultant to the lateral compartment. Thus there are numerous mechanical reasons for lateral compartment disease. Frequently in rheumatoid disease, however, valgus collapse of the knee occurs despite apparently normal hips and for no obvious mechanical reason. Analysis of this group proves of particular interest specifically for the possible aetiological factors.

Anatomy of the Ilio-Tibial Tract

As this is the principal lateral muscular stabiliser of the knee revision of its anatomy is worthwhile: Lasts 68 Anatomy - This is a thickening of the fascia lata that commences at the level of the greater trochanter, where three-quarters of the gluteus maximus and the tensor fasciae latae are inserted into it. It passes vertically down the posterolateral aspect of the thigh, crosses the lateral condyle of the femur and is inserted into a smooth circular facet one centimetre in diameter on the anterior surface of the lateral condyle of the tibia, Fig.146.
When the knee is straight the tract passes in front of the axis of flexion; thus it maintains the knee in the extended position. It is not an extensor of the flexed knee but in the right-angled knee it passes behind the axis of flexion. The lateral intermuscular septum in the lower part of the thigh is attached to the ilio-tibial tract and the mass of vastus lateralis can be seen bulging in front of it. The tract is an inch wide and its chief value lies in the stabilising influence it has on the knee joint. It is in action particularly when the slightly flexed knee is bearing the weight of the body (the reader can confirm this by palpating it in the living), it is thus constantly in use in the appropriate phases of walking and running and in rising from the sitting position.

In leaning forward with the knee slightly flexed the ilio-tibial tract may provide the only antigravity force stabilising the knee joint. The antigravity pull on the ilio-tibial tract increases as the body leans further and further forwards at the hip. This elongates the powerful gluteus maximus which contracts more and more strongly as the movement proceeds. In this posture the quadriceps can be quite relaxed and if the patella is palpated it can be moved freely from side to side, while in the thigh the relaxed vastus lateralis bulges prominently beyond the groove indented by the taut ilio-tibial tract.

A strong band diverges anteriorly from this tract to be attached to the upper part of the lateral edge of the patella forming a superior patellar retinaculum. Less definite fascial expansions sweep down over the patella and on each side of it, towards the upper part of the tibia, Fig. 147. The fact that the ilio-tibial tract passes over two joints further complicates the situation.
In analysing muscle function one must also remember that the brain knows nothing of individual muscle, only of movements. If for any reason, extension at the knee is limited then the ilio-tibial tract is prevented from passing anteriorly to the knee axis and thus acting as a knee extensor, Fig. 148. The closer the position of the tract approximates to the knee axis the more it becomes an abductor.

Thus a point of knee flexion is reached when the antigravity effect of the ilio-tibial tract is no longer used to stabilise the knee. The converse, however, applies at the hip since the greater the degree of fixed knee flexion that occurs so also the greater the corresponding increase in hip flexion. As previously mentioned, the greater the flexion of the trunk at the hip so also the greater the contraction exerted by the gluteus maximus in its antigravity effect on the hip to prevent the body rotating anteriorly, Fig. 149.
Thus the abductor pull on the knee is increased and as the knee flexes the medial collateral ligament is somewhat slackened allowing for a greater range of abduction to occur at the knee region. Early limitation of extension can occur in the knee with rheumatoid disease as a result of synovial swelling and effusion and this alone may prevent the ilio-tibial tract passing anterior to the knee axis. Early flexion at the knee causes a corresponding flexion at the hip region and to maintain balance necessitates greater activity of the gluteus maximus and thus increased tension in the ilio-tibial tract which with knee flexion is now acting as an abductor of the knee thus causing overloading of the lateral knee compartment. Continual strong action of the ilio-tibial tract in the semi-flexed knee will also have the effect of creating an external rotational force of the tibia on the femur.

Once external rotation of any degree occurs then the line of action of the quadriceps is laterally displaced and this too now has the effect of increasing the valgus drift. The same sequence of events could also apply if for any reason flexion deformity of either hip occurred. Then the knee in turn would adopt a similar flexed position to maintain the centre of gravity over the foot and thus again displace posteriorly the line of action of the ilio-tibial tract in relation to the knee axis.

If the synovitis and effusion settled after some time then the condition could revert to normal if no permanent structural damage has occurred. If, however, early wear of the lateral compartment has occurred, then a permanent shift of the resultant to the lateral side occurs with continuing overloading of the lateral compartment. Alternatively, if synovitis and effusion have caused slackening of the medial ligament and allowed slight external rotation to occur then continuing action of the ilio-tibial tract even with the knee virtually extended will have a major abducting effect on the knee. This could possibly occur in view of the close proximity of the ilio-tibial tract to the knee axis and even a small amount of external rotation could possibly largely negate its antigravity effect on the extended knee.
The exact action of the thigh adductors is not known but assuming over activity of the ilio-tibial tract and this tending to abduct the leg, then abduction could be resisted by the adductors which, however, do not pass over the knee axis and thus the greater their contaction the greater the load they transmit through the lateral condyle and thus aggravating the valgus loading.

In conclusion valgus knee deformity in rheumatoid disease is the result of a dynamic situation with transfer of the resultant to the lateral aspect of the joint. If the dynamic conditions are not taken into account in knee reconstruction then simple insertion of an artificial joint without proper regard for the muscle vectors is doomed to fail.

There are thus three essential steps in correction of fixed valgus deformity:

1) Deformity must be fully corrected by adequate soft tissue release.
2) Normal tibial rotatory alignment in relation to the femur must be achieved to ensure that the quadriceps apparatus has no valgus effect.
3) The dynamic situation, i.e. increased tension of the ilio-tibial tract, should be rectified.

Operative Approach for Fixed Valgus Deformity
A medial parapatellar incision is made as usual. Having inserted the trial femoral prosthesis careful note is made with the feeler gauges as to what extent the femoral component stands clear of the femoral condyles. Particular care is made at the stage of drilling the central hole in the tibia with the jig to ensure that any rotatory deformity is corrected otherwise the hole may lie well off centre. Any lateral subluxation remaining in the flexed position is also corrected.

In patients with lesser degrees of fixed deformity the capsular attachment to the upper tibia can be released through the main incision and the ilio-tibial band released by a small oblique incision on the lateral aspect of the knee with a direct approach to the ilio-tibial tract. Through the same approach a subcutaneous tenotomy of the lateral retinaculum can be performed using Helals modified Smillie knife.
If, however, a severe fixed deformity is present then the only satisfactory method of releasing the soft tissues is an extensive direct approach to the lateral aspect of the joint. Rather than using a separate skin incision, the skin and subcutaneous tissues are elevated from the medial aspect thus exposing the lateral retinacular expansion, the ilio-tibial tract and the ligamentum patella to its insertion. This approach has inherent dangers in patients with poor skin and great care should be exercised in handling the tissues.

The ilio-tibial tract and entire retinaculum up to the muscle belly of the vastus lateralis must be released - otherwise continuity may still exist between the main tract and the extensor apparatus. For this reason subcutaneous tenotomy should not be relied upon in patients with gross fixed valgus deformities. At the end of the release the lateral aspect of the ligamentum patella, the lateral aspect of the patella and its superior expansion should lie perfectly free of all attachments and the synovial membrane should be freely visible, Fig. 150.

With internal rotation of the tibia it is now possible to swing the extensor mechanism medially and create a gap in the lateral capsule at the site of release. If full correction cannot be achieved at this stage then further release of soft tissues is necessary.
The ilio-tibial tract is attached in the lower thigh to the Intermuscular Septum which in turn gives attachment to the short head of biceps. Depending on the level at which section of the tract was undertaken some continuity may still exist between the deep fibrous attachments of the tract and the biceps femoris.

Further relaxation of the ilio-tibial tract may be achieved by additionally releasing its attachment to the upper tibia as well as the attachment of the tibial insertion of the short head of the biceps which lies between the facet for the fibula and the attachment of the ilio-tibial tract. If necessary, section of the collateral ligament is undertaken but this is rarely necessary. It can be easily sectioned at its femoral attachment without endangering the lateral popliteal nerve. If correction to the neutral position is only obtained on stressing the knee then release is inadequate and further release must be undertaken so that the knee can be slightly over corrected in a varus direction.

At the present time no exact parameters can be given as to how much soft tissue release should be done in individual cases. In the past the error has been to release inadequately the structures on the lateral aspect. Slight overcorrection of the deformity prior to cementing the components should be the aim. It is not the aim to end up, following cementing of the components, with overcorrection and the exact neutral position is aimed for in all cases. The lateral capsule is left wide open and the medial capsule closed in a routine fashion - if necessary with some reefing or overlap if the medial tissues are loose, Fig. 151.
In patients with gross rotation it is perhaps better to slightly overcorrect the rotational deformity as it is easy to undercorrect it. The knee is again held in the flexed position following cementing until the cement is firm and the assistant maintains the limb in forced internal rotation. It is surprising even in loose knees how much torque must be exerted to the tibia to correct external rotation deformity.

Fixed Flexion
Regardless of the degree of fixed flexion no pre-operative wedging is performed. If the fixed flexion is secondary to or accompanied by hip arthropathy then the hips are dealt with and the patients nursed on a split mattress. Severe fixed deformities of the knee frequently rapidly diminish following hip correction and in some instances knee replacements have been deferred because of the marked improvement in knee function with increasing extension.

If severe fixed flexion of the knee is not associated with hip arthropathy and it is felt that conservative and medical management will increase the range of knee extension then such patients are given a short course of physical therapy under the management of the rheumatologist. If improvement does occur then subsequent arthroplasty is facilitated.

In patients with bilateral fixed flexion of more than 20° both knees are operated with an interval of 2 - 3 weeks between, otherwise the operated knee will assume the position of the unoperated knee. As a temporary measure a raise on the heel and sole of the shoe of the unoperated limb of approximately 1" has been tried to increase the effective length of this limb but without any noticeable success.

A considerable amount of fixed flexion can be corrected at the time of surgery once the block of bone is removed from the lower femur as impingement of the intercondydar eminence is a significant cause of flexion deformity.
The tibial component is sunk deeper into the tibia than normal so that maximum extension can be achieved. This frequently still leaves a residual fixed flexion deformity of 15° - 30°. In most cases this will virtually disappear over the course of the first two weeks post-operatively. Normally no attempt is made to free the posterior capsule as the stability of the joint in extension is largely dependent on this structure and the collateral ligaments. If fixed flexion deformity persists after the first 1 - 2 weeks, Smillie's method of reversed sling Russel type traction is used Fig. 152. This should only be used if the wound condition is satisfactory and it is used intermittently.

If adequate bone resection is performed at the time of arthroplasty to fully correct fixed flexion deformity of more than 30° then -

a) The collateral ligaments are left ineffective.

b) Poor muscular control of the limb persists and the deacceleration of the limb is poorly controlled - as in an external prosthesis. This poor control of changes in angular velocity of the limb could predispose to abnormally high stresses at the prosthetic bone interface.

It has been shown by Perry that the last 20° of knee extension requires an increase of quadriceps force of 40%. This weakness of quadriceps function may account for occasional persisting flexion deformity. Follow-up of the initial forty arthroplasties undertaken showed an average residual flexion deformity of 9°.
In general, patients with predominant knee arthropathy who were able to walk with an early return of swing phase flexion-extension were able to "walk out" remaining degrees of knee flexion within the first three months following surgery. The management of patients with polyarthritis and severe knee flexion requires further investigation and clarification.

Knee Fixed in Extension

It was initially hoped that following arthroplasty gradual elongation of the quadriceps mechanism would occur and that gradually increasing range of knee flexion would be achieved with time. It is now realised, however, that the amount of knee flexion following arthroplasty does not increase beyond the range achieved at surgery, unlike fixed flexion deformity where gradual improvement occurs for many months following surgery. With the patella dislocated laterally the range of knee flexion is usually full but when the patella is reduced the degree of flexion is frequently limited. This is probably the result of progressive quadriceps fibrosis as a result of inactivity and disuse and is most noticeable in knees fixed in extension prior to arthroplasty.

Following cementing of the prosthesis the patella is reduced and the range of knee flexion tested. If this is inadequate quadricepsplasty is proceeded with at the same time Z plasty or V-Y of the intermediate part of the quadriceps tendon is performed.
As the original incision was carried vertically into the vastus medialis muscle the attachment of this muscle is still apparent on the medial aspect of the tendon and following Z plasty continuity between the two parts of the tendon is achieved by separation of the fibres of the vastus medialis. End to end suture of the Z is then performed, Fig. 153. Usually the lateral expansion and vastus lateralis allow adequate flexion and do not require sectioning.

Due to direct continuity through the vastus medialis gentle extension can be commenced as usual but the general mobilisation is delayed for two to three weeks. This procedure has only been performed on two patients to date and should be undertaken with caution. It has the great disadvantage that it prevents early knee mobilisation.

An alternative approach to this problem is to sink the femoral component deeply into the lower femur so that although the length of the quadriceps is not changed the overall result is one of relative lengthening. This problem still requires further clarification.
Associated Hip and Foot Disease

Associated hip deformities and the resultant forces has largely been dealt with already. In summary - knee function cannot be dissociated from the function of the other joints in the lower limb and it should be considered as one link in the chain. To consider knee function as a separate entity one is bound to meet the considerable disappointment and perhaps failure. As a general principle if hip arthropathy is associated with knee arthropathy then the hip arthroplasty should be performed prior to knee surgery. It is important for 4 reasons:

a) Active knee flexion - extension depends largely on free hip function.

b) Knee alignment following arthroplasty is critical and cannot be normally positioned for weight transmission in the presence of hip disability.

Many patient complain predominantly of pain in the knee rather than hip and the temptation to undertake knee replacement initially should be resisted.

In a number of patients the pain is largely referred from the hip, Fig. 154, and following hip replacement and realignment the knee symptoms frequently improve and the performance of knee arthroplasty can be deferred. This is particularly noticeable if an adduction contracture is present at the hip with the knee thrown into resultant valgus position.

Fig. 154
During hip arthroplasty an unnecessary force may be applied to the knee of an anaesthetised patient and could result in possible damage to the knee fixation. If hip arthropathy subsequently develops in a patient who had a previous knee arthroplasty then great care should be exercised on the anaesthetised patient to avoid damage to the knee region.

If knee arthropathy is associated with hip arthropathy of the opposite side then as shortening in the region of the hip occurs the opposite knee assumes a flexed attitude. This posture places a greater load on the quadriceps mechanism of the diseased knee and thus increases the resultant force through the knee joint. There is also a tendency for the flexion deformity of the knee to become fixed and it is remarkable to note the improvement in fixed flexion of such a knee following hip arthroplasty and lengthening of the opposite limb.

Foot Deformities

This is a more difficult problem than hip disease. Valgus subtaloid deformity is frequently relatively asymptomatic and can be managed well by footwear. But it does place an abnormal load on the knee joint and a valgus deformity can shift the resultant force through the knee joint to the lateral side. If severe valgus exists the possibility of a triple arthrodesis or a Grice type graft in the sinus tarsi should be considered. It is reasonable to defer the decision of foot surgery until the foot position can be fully assessed following either hip or knee arthroplasties as again considerable improvement can be obtained in the foot if a severe valgus knee deformity has been corrected.

Smillie states that a valgus knee position in rheumatoid arthritis is secondary to peroneal muscle spasm and a resultant valgus foot. This undoubtedly shifts the resultant force laterally but is probably rarely the only factor involved in valgus overload of the knee.
Part II

Clinical Results

One hundred and twenty three patients were operated between 1971 and 1976. In thirty four instances bilateral surgery was undertaken. Thus the results of one hundred and fifty seven knee implants were reviewed. Apart from very early design modifications minimal changes in the prosthesis were made as there was a deliberate policy of minimising change so that a uniform group of patients could be studied extensively. This detailed review was undertaken in June and July 1977. As a result of detailed observation and analysis of this group the current range of prostheses have evolved.

One hundred and eleven operations were performed in females; forty six were in males. This gives a female to male ratio of 2:4:1. The youngest patient was thirty three years; the oldest seventy six years. The average age at time of surgery was 59.7 years. In patients operated on for osteoarthritis the average age at time of surgery was 68.4 years.

There was one pre-operative death. Eight patients during the follow up period died from causes unrelated to arthroplasty (one patient had bilateral arthroplasty). Eleven patients failed to return for review (two cases of bilateral arthroplasty). One had emigrated. Two were considered too ill to attend and the remaining eight were unavailable. Thus one hundred and thirty one arthroplasties were reviewed. Follow up varied from a minimum of one year to a maximum of five years and seven months. The average follow up was 33.8 months.

In terms of post-operative morbidity a major contribution is made by the pre-operative health of the patient. An exceptionally high percentage of patients in this series, i.e. 81% were suffering from advanced rheumatoid arthritis with extensive involvement of other joints and frequent manifestations of the rheumatoid disease process in heart, lung and other collagen tissues. The average duration of the presence of the disease was 15.5 years; the average duration of involvement of the knee undergoing arthroplasty was 9.1 years.
Secondary effects of prolonged invalidism were sometimes prominent. Many were or had been on steroid therapy. The indications for surgery in the remaining cases are summarised in table 2.

<table>
<thead>
<tr>
<th>Underlying Condition</th>
<th>127</th>
<th>81.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.A.</td>
<td>27</td>
<td>17.8%</td>
</tr>
<tr>
<td>O.A. Primary</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Secondary</td>
<td>1</td>
<td>1.2%</td>
</tr>
<tr>
<td>(Post Trauma)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gout</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Oochronysos</td>
<td>157</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.

The important role of the knee in locomotion and gait pattern has already been stressed elsewhere. It is only one of the joints involved in the complex mechanism. Disorders of the joints of the ipsilateral lower limb and of the contralateral knee will greatly influence the efficient role of the arthroplasty. As is to be expected in a series with such a high incidence of patients suffering from rheumatoid arthritis, multiple joint involvement is common place.

This is emphasised by the number of bilateral knee arthroplasties (34 patients) and by the number who have had replacement arthroplasty of the ipsilateral hip (25 patients), Table 3. Four patients in the series have had both hips and both knees replaced. Four patients have had a surgically stiffened knee and there is one ankylosis.

Table 3
Clinical Outcome
The clinical parameters of a successful outcome to arthroplasty are:
a) The patient is pleased.
b) There is relief of pain.
c) The patient is able to sit and arise from a chair with ease.
d) The patient is able to ascend and descend stairs.
e) The gait pattern approaches normal.

The patient must be able to perform these functions for prolonged periods and in his own environment.

Patient Satisfaction
Of the one hundred and thirty five arthroplasties available at this follow up, ninety five per cent gave the patients satisfaction. In eighty four per cent of cases the patients were enthusiastic while in eleven per cent they were satisfied. Table summarises the patients attitude to each arthroplasty.

<table>
<thead>
<tr>
<th>Patient Satisfaction</th>
<th>110</th>
<th>14</th>
<th>4</th>
<th>3</th>
<th>131</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enthusiastic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Satisfied</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non Committal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Disappointed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>83.9%</td>
<td>10.6%</td>
<td>3.0%</td>
<td>2.3%</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.

Three patients expressed disappointment with the result of surgery. One knee in particular showed lucent lines surrounding both components of the prosthesis. There was no evidence of loosening. All three disappointed results are associated with pain. In one case the pain was almost certainly due to severe ipsilateral hip disease.
Relief of pain

Pain is the major indication for surgery in the majority of patients. 81% of arthroplasties in this series had complete relief of pain. A further 16% had mild pain which the patient did not regard as of consequence as it did not interfere with activities and seldom needed individual medication, table 5. This group is of interest to us and we shall return to it later.

<table>
<thead>
<tr>
<th>Pain Description</th>
<th>Pre-Operative</th>
<th>Post-Operative</th>
</tr>
</thead>
<tbody>
<tr>
<td>None or occasional twinges (not requiring analgesics) (A)</td>
<td>7 5.3%</td>
<td>106 80.9%</td>
</tr>
<tr>
<td>Mild pain not interfering with activities (B)</td>
<td>18 13.7%</td>
<td>21 16%</td>
</tr>
<tr>
<td>Significant pain causing reduced activities (C)</td>
<td>77 58.8%</td>
<td>3 2.3%</td>
</tr>
<tr>
<td>Severe persistent pain (D)</td>
<td>29 22.1%</td>
<td>3 2.3%</td>
</tr>
</tbody>
</table>

Table 5

In four arthroplasties (3%) the pain was of a significant degree, Table 6. Three of these patients have already been outlined above. The fourth case also had advanced rheumatoid disease of the ipsilateral hip. The design of this arthroplasty did not incorporate a patellar component. At the time of surgery no synovectomy is performed. It is possible that mild pain could persist after arthroplasty from either of these omissions.
There have been a number of cases in this series who have experienced a click at certain degrees of movement. It is felt in the retropatellar area and usually lessens with time. As well as retropatellar joint problems it could be associated with possible malalignment of the patella or of the femoral component in the femur.

One patient had patellectomy performed as a secondary procedure for obvious impingement of the patella on the prosthesis. This patient had Still's disease with a particularly small femur.

Where patellar symptoms have occurred they have improved with time, particularly over the first two years. The possibility that chronic pain arises from structures other than the articular surface must also be considered. A palpable effusion was present in nine arthroplasties and some thickening of the synovium was present in thirteen instances. None of these complained of pain and there seems little indication for synovectomy. Crepitus was present in sixty one knees, (46.5%) of the overall series. It was mild in forty three, moderate in twenty four, and severe in four arthroplasties. It showed no correlation with the pain. When the osteoarthritic knees were assessed separately there was some crepitus in ten of twenty two available for review. It was mild in six and moderate in four instances.

Lateral osteophytes seem to be the major cause of crepitus and there is no indication for secondary surgery.

Ability to Use a Chair

One of the major impediments of the arthrodesed knee is the incapacity it causes the patient when they wish to sit or get out of a chair. As well as causing considerable inconvenience by projecting forwards, the actual mode of sitting has often to be changed with resultant stress on the spine. Further, the patients with rheumatoid disease often find that disease in their hands prevents the hands sustaining the forces created by the momentum of the body swing to get an arthrodesed limb under the centre of gravity.
The critical test in this respect is to ask the patient to arise from a chair. For this series a dining room type chair 45 cms. (18 inches) high was used. There were seven patients with a total of twelve arthroplasties who were unable to perform this task. All had severe R.A.

Walking
Two patients were unable to walk unaided. Both had advanced rheumatoid arthritis. Five patients can only walk about indoors. All five have had bilateral knee arthroplasties. Two in addition have had bilateral hip arthroplasties and a further case had a unilateral hip arthroplasty, Table 7.

<table>
<thead>
<tr>
<th>Ability to Walk</th>
<th>Pre-Operative</th>
<th>Post-Operative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unlimited for most day to day activities.</td>
<td>0</td>
<td>73</td>
</tr>
<tr>
<td>Mild limitation 1/4 - 1/2 mile</td>
<td>33</td>
<td>34</td>
</tr>
<tr>
<td>Marked limitation 50 - 100 yds.</td>
<td>49</td>
<td>11</td>
</tr>
<tr>
<td>Indoors only</td>
<td>39</td>
<td>10</td>
</tr>
<tr>
<td>Unable to walk</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 7.

These five patients were confined to wheel chairs before embarking on their programme of reconstructive surgery to the lower limbs. In one case the patient was confined to a wheelchair existence for five years prior to surgery. Further surgery was planned for six of the above seven patients - one bilateral hip arthroplasty, three unilateral hip arthroplasties and two reconstructions of feet and ankles. The grading that these patients achieve in tabulation for walking in no way reflects the major satisfaction they have achieved and the success that they consider their knee surgery.
The Pre- and Post-operative use of walking aids is summarised in Table 8.

Pre-operatively five patients walked with a swing phase. Post-operatively, of one hundred and twenty eight arthroplasties studied in use, one hundred and fifteen (90.6%) had a normal free swing type gait. This demonstrated conclusively the return of an effective mechanical function to the knee joint. Eleven knees showed some restriction in movement and two patients walked with a stiff knee type gait. One of these patients required hip replacement on the ipsilateral side. The remaining patient has already been referred to. She complains of pain and shows lucent areas between the bone and cement.

<table>
<thead>
<tr>
<th>Walking Aids</th>
<th>Pre-Operative</th>
<th>Post-Operative</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>24</td>
<td>69</td>
</tr>
<tr>
<td>Stick outside</td>
<td>30</td>
<td>34</td>
</tr>
<tr>
<td>Stick always</td>
<td>34</td>
<td>11</td>
</tr>
<tr>
<td>Two sticks, crutches or frame</td>
<td>31</td>
<td>14</td>
</tr>
<tr>
<td>Unable to walk</td>
<td>12</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 8.

When questioned directly, 83% of arthroplasties stated that the operated knee in no way hampered their activities. In ten arthroplasties (7.8%) it was the main impairment to mobility, Table 9.
Degree of impairment to walking offered post-operatively by affected knee

<table>
<thead>
<tr>
<th>Degree of Impairment</th>
<th>Count</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scarcely at all</td>
<td>108</td>
<td>83.0%</td>
</tr>
<tr>
<td>Partially</td>
<td>12</td>
<td>9.2%</td>
</tr>
<tr>
<td>Mainly</td>
<td>5</td>
<td>3.9%</td>
</tr>
<tr>
<td>Entirely</td>
<td>5</td>
<td>3.9%</td>
</tr>
</tbody>
</table>

Climb Stairs

Table 9.

Because of the polyarticular nature of their joint disease many rheumatoid patients find the stairs difficult to manage and frequently change their lifestyle accordingly, Table 10.

Method of Climbing Stairs

<table>
<thead>
<tr>
<th>Method of Climbing Stairs</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>One step at a time</td>
<td>37</td>
</tr>
<tr>
<td>Using banister</td>
<td>35</td>
</tr>
<tr>
<td>Unable or by bizarre method</td>
<td>22</td>
</tr>
</tbody>
</table>

Table 10

Here more than anywhere else the role of polyarticular disease was manifest. Only twenty five patients have a normal ability to use the stairs. This, however, includes eleven patients with bilateral arthroplasties.

In a further seventy two arthroplasties the impairment is slight. Thirty seven arthroplasties have to go one step at a time and thirty five have to use the banister. No patient unable to negotiate the stairs or able to do so only by a bizarre method, e.g. come down backwards, did so because of their knee arthroplasty. All did so because of polyarticular disease.
Movement

Movement is the essential asset of arthroplasty over arthrodesis. Pre-operative flexion averaged 98.8% and at follow up was 98.9%. The average flexion at time of discharge was 82.5% and most patients were not discharged until active flexion of 85° - 90° was obtained.

The loss of extension pre-operatively averaged 21.7% and post-operatively averaged 7.7%. The loss of extension at discharge averaged 12.6%, Fig. 155.

Thus the overall increase in range was from 77° pre-operatively to 90.9° post-operatively.

From the above it will be observed that this increase in range was achieved by diminution in the fixed flexion deformities. The actual range of movement available passively in the rheumatoid knee before surgery is often quite good. In this series, six knees had less than 15°, four knees had between 15° - 30°, twenty five knees between 30°-60°, forty nine knees between 60°-90° and forty seven knees in excess of 90° movement.
The frequent losses in patients with a good pre-operative arc somewhat counterbalances the gain in the knees with a poor pre-operative range so that the average gain appears to be minimal.

There were eight arthroplasties (6%) in the series with an arc of movement of less than 50°. Four of the eight knees showed gain over the preoperative state in excess of 26° minimum. Ideally not only must the arc of movement be satisfactory but the two points of functional activity must be reached. Thus fixed flexion should not limit extension to below 10° as extension to this point is essential for normal gait, while flexion should not be limited before 100° to 110° as this amount of flexion is essential for use in sitting and climbing stairs.

Extension
Correction of Fixed Flexion (limitation to extension), Fig.156, shows a graphic representation of the restoration of extension. No effort was made to completely correct extension at operation. No attempt was made to release the posterior capsular structures. Control of hyperextension is largely dependent on the posterior structures and collateral ligaments - particularly following removal of the cruciate ligaments. To minimise the stress transmitted to the prosthesis, soft tissue control of extension should persist. At the time of surgery it was common to leave patients with up to 30 to 40° flexion at the end of the procedure due to tightness of posterior structures. This gradually disappeared as a result of active exercises and walking with an active swing phase.

The interdependence of knee function on the state of the opposite knee and hip deformity became obvious and in most instance failure to regain full extension was due to flexion deformities of either the opposite knee or hips.
Cases with mild to minimal fixed flexion showed an initial deterioration so that they often left hospital with slightly increased amounts of fixed flexion. Thereafter all patients show a definite gradual improvement. This improvement continues over a long time. The single essential to this continued improvement is a free swing gait.

Extension

<table>
<thead>
<tr>
<th>Pre-operative</th>
<th>Post-operative</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>2</td>
</tr>
<tr>
<td>80</td>
<td>1</td>
</tr>
<tr>
<td>70</td>
<td>2</td>
</tr>
<tr>
<td>60</td>
<td>3</td>
</tr>
<tr>
<td>50</td>
<td>6</td>
</tr>
<tr>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>0°</td>
<td>41</td>
</tr>
</tbody>
</table>

Fig. 156

Flexion

Restoration of flexion parallels that for extension but graphically no change is noted other than in patients with very limited flexion. The same three features (a) dramatic improvement in the bad cases, (b) some initial deterioration in the good and (c) gradual improvement over a prolonged period are seen; Fig. 157. Thirty five knees (27%) have less than $90^\circ$ of flexion. Seven arthroplasties have less than 70% of flexion, Fig. 158.

<table>
<thead>
<tr>
<th>Flexion</th>
<th>Pre-op</th>
<th>Post-op</th>
</tr>
</thead>
<tbody>
<tr>
<td>140°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>130°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>110°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90°</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>80°</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>70°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60°</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>50°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30°</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20°</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 157

Post-op analysis of knee flexion.

Fig. 158
Recovery of Muscle Function

Despite long continued impairment of use, the problem of disuse atrophy and the constant risk of steroid myopathy in so many of these patients, very few show any impairment of muscle function. Two knees show lift lag in the quadricep. Case 65 has an arc of from $0^\circ$ to $97^\circ$ with a lift lag of $19^\circ$. She is confined to a wheel chair with rheumatoid disease of her hips and spine. Case 81 has $23^\circ$ of lift lag.

Correction of Alignment

Correction of alignment is important on two counts. Without correction the mechanical integrity of the prosthesis may not be achieved and less than perfect function may result. Uncorrected alignment also creates abnormal stresses within the prosthesis which predispose to failure. The use of intramedullary stems alone will not guarantee full correction of the deformity, particulary when the linkage of the prosthesis, as in this design, will allow side to side movement, (in this case $4^\circ$ is possible) in the fully extended position. If the muscle vectors are inadequately realigned the drift into either varus or vaglus could occur with time due to unequal weight transmission by one or other side of the prosthesis.

Valgus strain on the knee from either hip arthropathy with adduction or valgus deformity of the foot and ankle has proved a problem in the past. With experience this is now fully appreciated and more radical approaches to these problems are now adopted: Any associated hip disorder is corrected before knee arthroplasty.
The lack of ideal ankle arthroplasty forces us to adopt a more cautionary approach to the ankle and foot problem. Our current approach is to carefully follow these patients and at signs of progressive valgus deformity at the heel to undertake corrective realignment surgery, usually with subtalar arthrodesis. Another evolving concept in the course of this clinical trial is the realisation of the importance of adequate release of the soft tissues on the lateral aspect of the knee to achieve good correction at the time of surgery.

Of the one hundred and thirty one arthroplasties reviewed, ninety two had normal alignment as judged clinically and radiologically. Twelve had persistent fixed flexion deformity which makes assessment of vertical alignment very difficult. As far as could be judged they did not have valgus or varus deformity. One knee with a previous stress fracture of the fibula and marked bowing of the tibia had apparent valgus deformity clinically. She also had some fixed flexion. Of seventy two knees with pre-operative angular deformity, fifty one (70.5%) had correction to + 5° from normal and sixty nine (95.8%) had correction to + 10° from normal. Seven knees had incomplete correction of a pre-operative varus deformity and eighteen knees had incomplete correction of valgus deformity.

Correction of Varus Deformity
Accurate clinical measurement of persistent varus deformity was difficult. Consequently more reliance is placed on the accuracy of measurement made on weight bearing x-rays. To ensure full weight bearing the patient stands on the operated limb only. Twenty patients in this series has significant pre-operative varus deformity, Fig. 160.
Seven patients had incomplete correction on clinical examination. Two knees were difficult to assess. One patient had a previous fracture of the tibia and the persistent deformity is at the site of the fracture. The alignment of the prosthesis was satisfactory. One patient had an osteotomy of the femur in childhood for genu valgum and this resulted in an abnormal varus angulation just above the level of the tip of the femoral component. There were thus five instances of persistent varus deformity. They varied from 6° to 0° (neutral position). All five occurred in the first part of the series. At that point it was not fully appreciated that full correction of varus deformity could always be obtained at arthroplasty by release of the capsular attachments to the upper tibia and if necessary release of the medial collateral ligament.

Correction of Valgus Deformity
Fifty two knees had a valgus deformity of greater than 8° on pre-operative assessment. 8° of valgus is taken as the normal alignment of the tibia relative to the femur. Post-operatively, eighteen cases had persistence of valgus deformity. Fig.161 (patients) with post-operative residual valgus compared to their pre-operative state.

Fig. 161
In thirteen instances the deformity was less than $10^\circ$ beyond the normal. In four cases (7%) it was greater than $10^\circ$. The latter four included two cases we know to have mechanical deficiency of the prosthesis. The remaining two patients with valgus deformity in excess of $10^\circ$ had inadequate correction at surgery. One patient had a persistent valgus deformity of $22^\circ$. At the time of surgery inadequate mobilisation of the patellar attachment on the lateral side was performed and it subsequently resubluxated. This created an abnormal muscle vector.

One patient had severe rheumatoid arthritis in the knee with a previous patellectomy. At the time of arthroplasty, fracture of the lateral condyle occurred. Malalignment of the tibial component is present and this accounts for the valgus deformity. In five of the thirteen instances where the valgus deformity is less the $10^\circ$ it is associated with gross valgus deformity in the ankle/tibial region. Progression of this latter deformity may lead to accentuation of the deforming force at the knee. This is of primary concern. One of these patients has now had corrective subtaloid arthrodesis. In two other instances there is apparent shortening of the contralateral limb because of fixed flexion deformity at the hip and consequently a valgus strain on the knee. Patients whose post-operative valgus angle is greater than $8^\circ$ are summarised on Table 11.
<table>
<thead>
<tr>
<th>Valgus Angle (X-Ray Measurement)</th>
<th>Case No.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>9°</td>
<td>54</td>
<td>Judged as minimal valgus drift clinically</td>
</tr>
<tr>
<td>10°</td>
<td>37</td>
<td>Valgus strain of knee from gross valgus foot</td>
</tr>
<tr>
<td>12°</td>
<td>45</td>
<td>Valgus strain of knee from gross valgus foot</td>
</tr>
<tr>
<td>12°</td>
<td>128</td>
<td>Valgus strain of knee from gross valgus foot</td>
</tr>
<tr>
<td>14°</td>
<td>150</td>
<td>Valgus strain of knee from gross valgus foot</td>
</tr>
<tr>
<td>14°</td>
<td>6</td>
<td>Severe valgus deformity of feet.</td>
</tr>
<tr>
<td>14°</td>
<td>55</td>
<td>Valgus strain on knee from arthritic hip and short leg opposite side</td>
</tr>
<tr>
<td>16°</td>
<td>69</td>
<td>1 1/2&quot;short opposite side and arthrodesis of hip</td>
</tr>
<tr>
<td>16°</td>
<td>87</td>
<td>Revision loose McKee arthroplasty of ipsilateral hip to Girdlestone arthroplasty</td>
</tr>
<tr>
<td>17°</td>
<td>117</td>
<td>Gross valgus ankle and foot - recently corrected</td>
</tr>
<tr>
<td>18°</td>
<td>46</td>
<td>Patella not adequately reduced and subluxed</td>
</tr>
<tr>
<td>18°</td>
<td>116</td>
<td>Fracture of lateral condyle with loss of correction with prosthesis</td>
</tr>
<tr>
<td>20°</td>
<td>102</td>
<td>Fracture of tibial stud</td>
</tr>
<tr>
<td>21°</td>
<td>96</td>
<td>Fracture of tibial stud</td>
</tr>
<tr>
<td>22°</td>
<td>72</td>
<td>Fracture of tibial stud</td>
</tr>
<tr>
<td>34°</td>
<td>53</td>
<td>Fracture of tibial stud</td>
</tr>
<tr>
<td>38°</td>
<td>64</td>
<td>Fracture of tibial stud</td>
</tr>
</tbody>
</table>

Table 11.
Patellar Problems - Fig. 162.

In rheumatoid arthritis this has not proven a problem of any significance other than malalignment problems as previously discussed.

<table>
<thead>
<tr>
<th>Crepitus</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nil</td>
<td>3</td>
</tr>
<tr>
<td>Moderate</td>
<td>11</td>
</tr>
<tr>
<td>Severe</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>15</td>
</tr>
</tbody>
</table>

Fig. 162

No attempt was made to perform a patellectomy at the time of arthroplasty but if the patella was severely deformed then suitable trimming of the margins, etc. was performed as detailed previously.

In osteoarthritis despite marked crepitus in this joint at follow up in a number of cases, no major disability due to the patello-femoral articulation occurred. At this stage an impression was obtained that symptoms present in the patello-femoral joint tend to improve over the first twelve months so that early patellectomy is inadvisable.

Patellectomy was performed in one patient in this series as a secondary procedure. This was in a patient with Still's disease in which the standard prosthesis was unduly prominent anteriorly with patellar impingement.
Results of Arthroplasty in Osteoarthritis

As the results of arthroplasty in series reported in the past have frequently shown poorer results in O.A., a summary of the results in this condition was desirable, Tables 12, 13, 14. Twenty three cases with O.A. reviewed: (28.7 months average follow up)

Pain:
None or occasional twinges 18
Mild pain not interfering with activities 5 (one of which had girdlestone operation for ipsilateral infected hip prosthesis)

Table 12

There was no patient with significant pain or severe persistent pain. Three patients had mild patellar pain. In no case did it interfere significantly with function.

Patients Assessment
Enthusiastic 21
Satisfied 1
Disappointed 1 (medico-legal case)

Table 13

Function
1 mile or more 14
1/4 - 1/2 mile 8
50 - 100 yards 1

Table 14
Of the 9 patients in the latter groups:
Four had marked involvement of the contralateral knee; one patient had girdlestone operation of hip; two elderly patients, seventy four and seventy two years, considered 1/2 mile their normal limit; 1 medico-legal case outstanding; one failure of tibial stud.

The average pre-operative flexion was 98.5° and post-operative flexion was 97.7°. The average pre-operative extension was 13.0° and average post-operative extension was 3.1°.

The Pre and Post-operative complications and mechanical failure in this group are included in the overall view of the current series and are not considered separately.

The number of reoperations in this early series were as follows, Table 15, and again will be considered in detail in chapter IV.

<table>
<thead>
<tr>
<th>Reoperations</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Loose plastic tibial components</td>
<td>4</td>
</tr>
<tr>
<td>Realignment and replacement of prosthesis</td>
<td>1</td>
</tr>
<tr>
<td>Patelllectomy</td>
<td>1</td>
</tr>
<tr>
<td>Arthrodesis (for infection)</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 15

Four hundred and sixty two knee arthroplasties have been personally performed between November 1971 and August 1982. The male - female ratio was 2:4:1. The youngest patient was 14 years old, the oldest 83 years. Average age at the time of surgery was 60.7 yrs.

**Underlying Condition**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>R.A.</td>
<td>310</td>
</tr>
<tr>
<td>O.A.</td>
<td>137</td>
</tr>
<tr>
<td>Gout</td>
<td>1</td>
</tr>
<tr>
<td>Oochomysos</td>
<td>1</td>
</tr>
<tr>
<td>Stills disease</td>
<td>12</td>
</tr>
<tr>
<td>Lues</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>462</td>
</tr>
</tbody>
</table>

Table 16

Sixty one patients have had arthroplasty of the ipsilateral hip. Nineteen patients in this series have had both hip and knees replaced (quadruple arthroplasties) and will be considered separately as they are a particularly interesting group.
Complications and Hazards of Surgery - (462 cases)

**Per-operative complications**

1) Crackling of femoral condyles  
2) Malalignment of tibial component.  
3) Peroneal nerve paresis  
4) Collapse under anaesthesia

**Post-operative complications**

Specific to arthroplasty  
Fat embolism and respiratory problems  
Wound problems.

Systemic complications

- Urinary retention  
- Intestinal ileus  
- Deep venous thrombosis  
- Pulmonary embolism  
- Pressure sores
Per-Operative Complications

Cracking of Femoral Condyle

This has occurred on 27 occasions due to faulty technique. In four instances the crack was of major significance. Screw fixation was used in two cases, Fig.163. In one of the remaining cases there was significant fracture of the lateral condyle and this was associated with rotation of the femoral component during setting of the cement, Fig. 164 A & B.
This patient has subsequently suffered a fracture of the shaft of the femur above the prosthesis. The knee arthroplasty continues to function satisfactorily but there is clinical valgus deformity.

If a crack does develop during the trial reduction then during cementing the two femoral condyles are held together with finger pressure until the cement sets and it thus acts as an internal fixation. The most likely point of splitting the condyle is anteriorly and this risk can be diminished by carefully rounding the anterior edge with a small gouge rather than leaving a sharp margin. The femoral prosthesis exerts most force on the condyles at approximately 30° to 50° and when the knee is extended beyond 30° the tension on the condyles usually disappears.

The major problem associated with fracture of the condyles is the resultant loss of alignment. Central seating of the tibial component is important. Malalignment of this seating, Fig. 165, places the plastic stud under stress.

Four of our tibial components are seated eccentrically in this way. This eccentric seating of the tibial component is most likely to occur with severe disease accompanied by subluxation of the tibia. The problem is siting the initial drill hole in the tibia. So far failure has not occurred in any of the four but the possibility is of concern. On one occasion cracking of the tibial condyles occurred with no significant loss of alignment.
Peroneal Nerve Paresis
The proximity of major blood vessels and nerves to the bony structures of the knee joint puts these structures at particular risk. This is a well recognised hazard of knee surgery. There has been no damage to the popliteal artery or its continuation in any patient of the series. Six patients developed weakness of the extensors and two patients had mild transient hypoæsthæsia on the dorsum of the foot. In three patients secondary decompression of the peroneal nerve was performed. All patients have had a satisfactory outcome with virtually full recovery.

If severe degrees of fixed valgus deformity are present, then decompression of the lateral popliteal nerve should be performed at the time of arthroplasty. Simple sectioning of the fibrous tunnel where the nerve winds about the fibula has since been found to virtually eliminate the risk of nerve compression when correcting fixed deformities.

Collapse under anaesthesia
A current major cause for concern is the toxic systemic effect of released monomer from the acrylic cement. Other potential causes of sudden hypotension and or cardiac arrest should not be overlooked and include, fat embolus, pulmonary embolus, myocardial infarction and steroid depletion. We have had one per-operative death in this series and a further serious collapse - the patient subsequently dying 83 days later.

Case I. A sixty seven year old female presented with a long history of rheumatoid arthritis. Three years prior to admission she had a short episode of congestive cardiac failure secondary to a myocardial infarct. On admission for knee surgery she had moderate hypertension and auricular fibrillation. Operation including insertion of cement, was uneventful. When the tourniquet was released the patient suddenly went into cardiac arrest from which, despite intensive resuscitation, she did not recover.
A bolus effect of monomer on release of the tourniquet was the major clinical impression of the cause of death. Another possibility was fat embolisation. The past history meant that myocardial infarct could not be excluded. Autopsy failed to reveal any obvious cause for the arrest. Naturally, causes related directly to arthroplasty are the most likely. As a routine the tourniquet has been deflated prior to closure so that good haemostasis can be achieved. This is particularly important when early mobilisation is required.

Case II. - A second patient with severe polycythaemia rubra vera and peripheral vascular disease suffered severe operative hypotension and failure of adequate cardiac output. She responded to resuscitation and made an excellent early recovery. She died suddenly 83 days post-operatively after achieving full mobility. The cause of death was not firmly established as post mortem was not performed. Either cardiac failure or a massive cerebral infarct was the most likely cause of death.

A high concentration of monomer may enter the circulation on release of the tourniquet or the effect of cement may be indirect as a release of other metabolites, i.e. fat. Other authors have reported cardiac arrest following the use of bone cement for arthroplasty and the cardiovascular effects of methylmethacrylate cement have been widely reported, and the cardiovascular effects of methylmethacrylate cement have been widely reported, and the cardiovascular effects of methylmethacrylate cement have been widely reported, and the cardiovascular effects of methylmethacrylate cement have been widely reported, and the cardiovascular effects of methylmethacrylate cement have been widely reported, and the cardiovascular effects of methylmethacrylate cement have been widely reported, and the cardiovascular effects of methylmethacrylate cement have been widely reported, 80, 81, 82, 83, 84, 85, and the cardiovascular effects of methylmethacrylate cement have been widely reported, 86 - 106 incl.

Experimental work by Dowling on Monomer Toxicity in Knee Arthroplasty and by Hurson into the use of plugs in the medullary canals have greatly helped our understanding of this problem. Both these investigations were performed under my supervision and formed the subjects for M.Ch. thesis at University College, Dublin.

It is of interest to note that in the present series five patients were operated upon without tourniquet. One of these exhibited a severe fall in B.P. during cementing. Hypotension either during insertion of cement or on release of the tourniquet has not been a significant feature in patients operated upon with a tourniquet.
In an effort to minimise the dangers of further such arrests the following precautions are taken:

1) The medullary canals are sucked clear of as much marrow as possible prior to insertion of cement.
2) Suction drainage tubes are introduced into the medullary canals during cementing.
3) Use of plastic plugs in the medullary canals.
4) The cement is introduced into the canals as late as possible to minimise the monomer release to the canal and its contents.
5) A good interval, at least 10 - 15 minutes, is allowed to elapse between setting of cement and release of the tourniquet.
6) Table is tilted head down to counteract hypotension.
7) 50 M.Eq. Sodium Bicarbonate is given prior to release of tourniquet to counteract acidosis due to accumulation of metabolites in the limb.
8) Blood infusion running so that any loss due to bleeding can be readily replaced.
9) Surgery contraindicated in patients with severe cardiac disease.

Other Post-Operative Deaths

Three further post-operative deaths occurred at 3, 4 and 20 post-operative days. One was due to pulmonary embolism, one to cardiac causes, and the remaining death probably due to fat embolism but unconfirmed at autopsy. The incidence of per and post-operative death in this series was 1.1%.

Post-Operative Complications

Fat Embolism and Respiratory Problems
A particular clinical problem is the patient seen immediately post surgery or in the early recovery phase who presents with one or all of the following: slowness in recovery from anaesthesia; mild confusion; minimal disorientation.
The accompanying clinical signs are mild hypotension, tachycardia, tachypnoea, and on one occasion in this series, transient hemiparesis.

Amongst the aetiological factors to be considered when confronted with this syndrome are:

a) Negative balance in the correction of hypovolaemia.
b) Cerebrovascular ischaemia.
c) Sequelae of per-operative hypotension.
d) Fat embolus
e) Myocardial insufficiency.
f) Hypoxia
g) Analgesic overdose.
h) Steroid deficiency.
i) Allergic response.

Frequently a combination of some of these factors is involved. Senility is frequently present and confuses the picture. The myocardial insufficiency is as liable to be due to rheumatoid disease of the myocardium as it is to arteriosclerosis or conduction defects. Respiratory insufficiency can range from steroid myopathy, rheumatoid lung, to chronic airway disease or mild fluid overload.

Of the total four hundred and sixty two operations this clinical problem or part of it was seen on thirty five occasions (7.6%).
The probable causative factors were as outlined in table 17.

**Post-Operative Complications**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat embolism</td>
<td>8</td>
</tr>
<tr>
<td>Basal atelectasis/infection</td>
<td>10</td>
</tr>
<tr>
<td>Myocardial insufficiency</td>
<td>7</td>
</tr>
<tr>
<td>Analgesic overdose</td>
<td>1</td>
</tr>
<tr>
<td>Cerebral ischaemia</td>
<td>2</td>
</tr>
<tr>
<td>Allergic reaction (blood)</td>
<td>2</td>
</tr>
<tr>
<td>Confusion without cause</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 17
A satisfactory outcome in Fat Embolism is related to early diagnosis and early treatment and as this complication is known to occur following reaming of the medullary canals observation for early signs should be adopted as a routine.

If fat embolism is suspected PO$^2$ estimations are of paramount importance as the PO$^2$ level is frequently found to be much lower than suspected clinically. All patients responded dramatically to large doses of steroids - 0.5 g. Hydrocortisone 1 V. 2 to 4 hourly for 24 hours and one patient was placed on positive pressure ventilation due to a diminished PO$^2$.

Fat Embolism
There were two classical case of fat embolus in the series one of which proved fatal on the third post-operative day but as recorded above was unconfirmed at autopsy. The second patient had the classical pecticheal rash and transient hemiparesis. Recovery was complete. One other case was definite without the rash. There were eight other highly probable cases.

Respiratory Insufficiency
Primary chest problems were seen on eight occasions. In one patient basal atelectasis was associated with gastro-intestinal distension and in another with urinary retention. While streptococcus veridans was the dominant organism isolated, two patients had staphylococcus aureus grown from their sputum. The chest problem was somewhat confused in a further three patients. One had an attack of asthma for which she had had extensive investigation and treatment in the past, one had slight overloading of fluid and one had airway obstruction due to laryngeal spasm.

Myocardial Insufficiency
The very first patient in the series developed chest pain and ischaemic changes in E.C.G. shortly after surgery. Four other patients had atrial fibrillation or ischaemic changes. None of these cases proved serious.
Analgesic Overdose
The quantity of analgesia needed post-operatively is sometimes difficult to estimate. Certain patients with extensive rheumatoid arthritis have low pain thresholds. This is particularly true in those patients who have had lax control over the amount of steroids they use. These same patients are often of small stature and lightweight so that the standard dosage of narcotics may produce signs of overdosage. Overdosage in one case was produced by 100 mgs. of pethidine. Prior to knee arthroplasty she had had hip arthroplasty and at the time of knee surgery her medication included steroids, Imuran, Ibuprofen and Paracetamol.

Cerebral Ischaemia
Confusion from transient cerebral ischaemia was seen in seven patients. There were no permanent sequelae. One of these patients was initially suspected of having a fat embolus syndrome, subsequently disproved.

Allergic Response
All patients in this series had low molecular weight dextran as a preventive measure for deep venous thrombosis. This frequently raises the pulse rate by ten to fifteen beats per minute and the temperature by one degree Fahrenheit. Two patients developed a pyrexia tachycardia and mild hypotension while receiving a blood transfusion. Rapid return to normal was achieved by curtailing the blood transfusion and administering steroids.

Blood Loss
The average per-operative blood loss is between 150 mls and 250mls. The insignificance of this must not produce a sense of security as the sudden flow of blood into the limb when the tourniquet is released may produce far greater degrees of systemic hypotension. Subsequent to theatre, suction drainage of the wound produces a blood loss up to 500 mls over the following thirty six hours. On one occasion the tourniquet collapsed at the start of surgery and was not reapplied because of the risk of desterilisation. Per-operative blood loss in this case was estimated at 1400 mls.
Wound Problems

The possible contamination of deep layers by superficial infection is of primary concern. Because of the relatively superficial siting of the prosthesis absolute care is taken with wound closure. Equally even the most minute area of erythema of serous discharge in the wound is carefully monitored. Nearly all ultimately proved insignificant. In twelve cases was there a positive growth on the culture plates.

One wound broke down at nine days post-operation. Prior to arthroplasty this patient had previously had a patellectomy and the overlying skin was atrophic. Repeated wound and blood cultures were sterile. Following antibiotic irrigation, resuture was performed. Healing was satisfactory. This case has now been followed for over seven years without evidence of deep infection. During that interval she has had bilateral hip arthroplasties.

Following extensive undermining of the skin to free contracted lateral structures in the case of fixed valgus deformity in patients, patchy necrosis of the lateral skin edge occurred. All healed by secondary intention. There has been 4 failures in the series because of deep infection. Two of these patients have had secondary arthrodesis and will be considered separately.

Previous surgery has not presented problems with the exception of skin breakdown at the time of arthroplasty in a patient who had previously had a patellectomy. Thirty patients had previous surgery. Almost all patients had had previous aspiration and or injection. Previous surgery did not increase the risk of deep infection.
Systemic Hazards of Surgery

In company with all major forms of surgery knee arthroplasty is no exception to the systemic hazards that patients encounter. Our experience with these problems is summarised in table 18.

<table>
<thead>
<tr>
<th>Systemic Hazards of Surgery</th>
<th>Table 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urinary retention</td>
<td>4</td>
</tr>
<tr>
<td>Intestinal Ileus</td>
<td>1</td>
</tr>
<tr>
<td>Deep venous thrombosis</td>
<td>11</td>
</tr>
<tr>
<td>Pulmonary embolism</td>
<td></td>
</tr>
<tr>
<td>major</td>
<td>2</td>
</tr>
<tr>
<td>minor</td>
<td>6</td>
</tr>
<tr>
<td>Pressure sores</td>
<td>5</td>
</tr>
</tbody>
</table>

There were two major embolisms and six cases were minor episodes.

Both the steroid and rheumatoid skin are notoriously frail and it is of concern that despite every effort we have had five pressure sores. One of these was minimal. The other four cases occurred at the heel and protracted discharge of the patient.
Late Analysis

Mechanical Problems:

A. Detachment of tibial plastic from holder.
B. Tibial stud failure.
C. Loosening of tibial component.
D. Realignment and increasing deformity
E. Failure of femoral component
F. Patellectomy (secondary)
G. Reabsorption of condyles
H. Osteophyte formation
I. Wear
A - Detachment of Tibial Plastic from Holder:

This occurred in seven cases of the early design where vertical shear pins were used. The plastic is now available already mounted and in the event of wear occurring the complete tibial prosthesis is replaced.

With the redesigned plastic mounting it has been impossible to dislodge the plastic in any instance from the holder in destructive testing and in each test specimen the intramedullary stem broke rather than dislodgement of the plastic at a force of approximately 5 kN.

In the possible event of wear the tibial components are now cast so that they are freely interchangeable in the same cement bed. Five of these cases have been satisfactorily revised with the current design of tibial prosthesis, (introduced January 1974).

<table>
<thead>
<tr>
<th>No. in series</th>
<th>Age at time of arthroplasty</th>
<th>Initial Deformity</th>
<th>Date of arthroplasty</th>
<th>Mts. to revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>54</td>
<td>49°flexion</td>
<td>24.8.72</td>
<td>108 mts.</td>
</tr>
<tr>
<td>25</td>
<td>59</td>
<td>20°valgus</td>
<td>29.3.73</td>
<td>41 mts.</td>
</tr>
<tr>
<td>32</td>
<td>65</td>
<td>40°valgus</td>
<td>14.6.73</td>
<td>7 mts.</td>
</tr>
<tr>
<td>36</td>
<td>61</td>
<td>15°valgus</td>
<td>19.7.73</td>
<td>not yet revised</td>
</tr>
<tr>
<td>37</td>
<td>61</td>
<td>35°flexion</td>
<td>19.7.73</td>
<td>awaiting revision</td>
</tr>
<tr>
<td>39</td>
<td>74</td>
<td>28°varus</td>
<td>2.8.73</td>
<td>28 mts.</td>
</tr>
<tr>
<td>49</td>
<td>65</td>
<td>25°varus</td>
<td>30.11.73</td>
<td>37 mts.</td>
</tr>
</tbody>
</table>

Table 19.
Case No. 39  Detachment of tibial plastic

Examples

![Operative photograph showing loose plastic](image1)

**Fig. 167** Operative photograph showing loose plastic

**Fig. 166** A post-op. 1973  
**Fig. 167** B 1975 loose plastic  
**Fig. 168** C 1975 revision of plastic

**Fig. 168** Tibial HDP specimen removed
Further examples of detachment of tibial plastic

Case no. 37

Fig. 169 1973

Fig. 170 Plastic removed from patient no. 49
To date five patients have presented with stud failure. It is of interest that four of these five patients noticed gradual rather than sudden giving way of the knee. All patients had gross pre-operative deformity and three of the five had valgus deviation. Three of these patients have been reoperated but in the remaining two patients the position is adequately controlled by a caliper.

Fracture of the tibial plastic has been the single greatest design problem with this prosthesis and with the introduction of the Endoskel version with metal reinforcement this problem will hopefully be solved.

**Tibial Stud Failure**

<table>
<thead>
<tr>
<th>No. in series</th>
<th>Age at time of arthroplasty</th>
<th>Initial deformity</th>
<th>Collateral ligament</th>
<th>Mts. to failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>53</td>
<td>65</td>
<td>40° valgus</td>
<td>Rupture Medial</td>
<td>7 mts</td>
</tr>
<tr>
<td>64</td>
<td>74</td>
<td>46° valgus</td>
<td>Rupture Medial</td>
<td>24 mts</td>
</tr>
<tr>
<td>96</td>
<td>66</td>
<td>26° valgus</td>
<td>Ligs. intact</td>
<td>64 mts</td>
</tr>
<tr>
<td>146</td>
<td>65</td>
<td>19° varus</td>
<td>Ligs. intact</td>
<td>44 mts</td>
</tr>
<tr>
<td>155</td>
<td>67</td>
<td>12° varus</td>
<td>Ligs. intact</td>
<td>52 mts</td>
</tr>
</tbody>
</table>

Nos. 53 and 64 not as yet revised but controlled in calipers.
Case no. 53: Arthroplasty performed: Date 14.6.73.
Pre-operatively the knee showed gross valgus instability with lateral displacement of the patella and adherence of the patella to the tissues on the lateral aspect, Fig. 171. Following arthroplasty the patella was left in a laterally displaced position, Fig. 172, and in complete valgus correction.

Some six months later the patient returned with recurrence of her deformity, Fig. 173.
At this stage it was appreciated that the anchorage of the tibial plastic in the holder was inadequate. Design modifications were thus made to the current type of retaining plates and a new component inserted. The original femoral component was used as was the existing bed of cement for both components, this again resulting in the same post-operative degree of valgus as previously. The patella was not disturbed as up to this stage the importance of accurate quadriceps alignment was not appreciated.

After an elapse of a further seven months the patient returned and said that her knee "gradually gave way". Radiology suggested a fracture of the stud, Fig. 175
This knee has not been re-explored as the patient can get about very satisfactorily with the aid of a caliper to control the valgus force on her leg. From constant use of the caliper the knee has partly stabilised and the patient can now fully weight bear without the caliper. Despite the fracture of the UHMWPE stud she is satisfied with the result.

Analysis of her problem drew attention for the first time to the importance of adequate correction not only of valgus deformity and lateral displacement of the patella but also to the importance of correction of external rotation of her leg.

Fig. 176

As previously detailed inadequate correction of external rotation allows both the quadriceps mechanism as well as the iliotibial tract to exert a direct valgus effect on the knee.
Case No. 64:
This seventy four year old female had osteoarthritis of both knees, the left being worse than the right. She had major unicompartmental collapse of the lateral compartment of the left knee, Fig. 177. There was rupture of the medial collateral ligament and a valgus deformity of 46° on stress film, Fig. 178.

Fig. 177 1974 supine film.

Fig. 178 1974 weight bearing
Post-operative x-rays showed persisting valgus deformity, Fig. 179, and failure to reduce the patella. At twenty four months post-operation the valgus deformity occurred. Check films show fracture of the H.D.P. stud, Fig. 180.

Fig. 179 1975

Fig. 180 1976

This patient is also controlled in a walking caliper, is pain free, can walk 1/4 - 1/2 a mile using a stick. Although technically a complete failure the patient is satisfied with the result.

Both these patients had complete rupture of the medial collateral ligament and both had laterally dislocated patellae which were uncorrected at the time of surgery. It is felt that total absence of either collateral ligament is a contraindication to the standard prosthesis and total reliance for stability should not be placed on the stud. The revision type prosthesis is now advocated for this problem. Fortunately, even in patients with grossly unstable knees, it is unusual to have rupture of the collateral ligaments and thus the use of the standard prosthesis is rarely contraindicated.
Case No. in series 96.
This patient had a windswept knee type deformity with gross valgus deviation of the knee, Fig. 181. Arthroplasty was performed on 23.1.75, Fig. 182. Some five years later the patient noticed a gradual recurrence of valgus deformity. Gross valgus occurred over a short period prior to Jan.'81, Fig. 183,184, and revision arthroplasty with a broad condyle prosthesis was performed on 11.2.82, Fig.185. A patellectomy was performed at the same time to correct the marked lateral displacement of the patella.

Fig. 181 1975

Fig. 182 1975

Fig. 183 1980
Fig. 184 1982

Fig. 185 1982
Post Revision
Case No. in series 146:
Previous osteotomies of both knees were performed in childhood for genu valgum deformities. The collateral ligaments were clinically intact. Arthroplasty was performed on 26.3.76 with a patellectomy performed at the time. Varus deviation appeared to gradually reoccur from Nov.'79. Revision arthroplasty was performed on 25.6.81, Fig. 187 A & B.
Case No in series 155:
This patient noticed gradual giving way of her knee some four years after her arthroplasty which was performed for gross destructive osteoarthritis, Fig. 188 A,B,C & D. Revision surgery confirmed failure of the plastic stud. Her joint was replaced with the broad conoyle prosthesis and she made an uneventful recovery, Fig. 190.

Fig. 188 A  1976

Fig. B. 1976 post arthroplasty  Fig.C 1977 gradual deviation
Fig. 189 1982 Revision of broken stud

Fig. 190 1982 Post Revision.
C - Loosening of Tibial Component

No. in series 29

Only one patient has been revised for loosening of either femoral or tibial component.

Initial arthroplasty 24.5.73 - Age 62 years: Fig.191 A

This patient on follow up was one of two patients in the series who showed significant reabsorption of bone in the lower femoral region. Nine years following arthroplasty it became apparent that there was loosening of the tibial component, Fig. 191 B & C. This was revised and recemented on 30.4.82, Fig. 191 D.

Fig. 191 A 1973

Fig. 191 B 1980

Fig. 191 C 1982 Pre Revision

Fig. 191 D 1982 Post Revision
D - Realignment and Increasing Deformity (2 cases)

No. in series 10: Age 71 years.

Increase in Valgus Deformity

Her initial arthroplasty was performed in 1972 in the early stages of the trial, Fig. 192 A & B. At this stage the locating tract of the femoral prosthesis was removed to prevent a distraction force on the femoral component. In this patient the importance of realignment of the extensor apparatus was not fully appreciated at this time. Lateral dislocation of the patella in association with the valgus deformity allowed gradual recurrence of valgus deviation to occur over a four-year period. Both the femoral and tibial components remained firmly implanted and the prosthesis was changed to a current model with realignment of the prosthesis: Date 1.4.77.

Fig. 192 A 1972

B. 1972
C 1977

D. 1977 Post Revision
No. in series 284, Fig. 193 A, B, C, D.

This patient age 74 years at the time of initial arthroplasty had 10° varus deformity pre-operatively, Fig. 193 A. Six months following arthroplasty a gradual drift into valgus was noticed, fig. 193 C and revision was finally performed 2 years later.

Significant wear of the medial aspect of the stud was found and a revision type prosthesis was used, Fig. 193 D.
Case No. 247: E - Failure of Femoral Component

One patient had failure of the femoral component. Initial arthroplasty performed 9.11.78. Four years later the patient's knee gave way suddenly and at revision arthroplasty fatigue failure of the medial condylar bearing was discovered. This was successfully revised on 12.8.82 using a revision type prosthesis.

Fig. 194  A Pre-Op.  B. Post Op.

C Pre Revision  D. Post Revision
Fig. 195  Broken Prosthesis
F - Patellectomy

Seven secondary patellectomies have been performed since 1971. This small incidence (1.5%) is not a true indication of the incidence of patello-femoral problems. The majority of patients at review have detectable patello-femoral crepitus but in only a small number of cases are these symptoms of sufficient magnitude to interfere with knee function. Surprisingly some patients who have had a surgical patellectomy still have mild crepitus from synovial reaction over osteophytes.

Case I. No. in series 58.
Initial arthroplasty 4.4.74 for Stills disease, Fig. 196 A. A small femoral component was not available at this time as this was the first patient with Stills disease in the series. The femoral component could not be incorporated in the femur during surgery and was sent for trimming of the anterior surface while the patient was undergoing surgery. The prosthesis subsequent proved prominent and the patella was painful with limited knee extension, Fig. 196 B & C.
Secondary patellectomy performed on 29.7.76.
Fig. 197 A Modified small prosthesis (A) subsequently B inserted in Right Knee compared to Left Knee (B) prosthesis

Fig. 198 Bilateral Hip Arthroplasties in same patient.
Case 2. No. in series 41
Left knee arthroplasty 16.8.73. Femoral condyle split at the time of initial arthroplasty and a fragment of bone approximately 2 cms. in diameter was removed from the patellar surface. The patient subsequently complained of increasing difficulty with knee flexion and at surgery on 24/5/80 the patella was jammed between the condylar surfaces.
Case 3. No. in series 16, Fig. 201 A, B, & C.


Patient complained some 8 years later of instability particularly on stairs. Gradual wear of the patella was observed and patellectomy was performed on 5.11.81 for a worn denuded patella.
Case 4. No. in series 6, Fig. 202 A, B, C, & D.
Initial arthroplasty 24.8.72.
Revision procedure for loose plastic performed on 26.9.81 and a thin shell of patella was removed at the time of revision surgery.
Case 5. No. in series 262, Fig. 203 A, B, C, & D.

Left knee arthroplasty on 22.2.79 for psoriatic arthritis. Patient both pre- and post-operatively was stiff and slow mobilising. A left patellectomy was performed on 9.4.81.

Fig. 203  A.  1979  

B.  1979

C.  1981  View in flexion

D.  1981  View in extension
Case 6. No. in series 252, Fig. 204a,B,C,D.
A right knee arthroplasty was performed for a fixed varus deformity. An extensive medial release was performed and clinically and radiologically overcorrection was achieved. The patella subluxed laterally and appeared to aggravate the valgus position and an early patellectomy was performed on 31.5.79.

![Fig. 204 A 1978 Pre Op](image1)

![B](image2)

![C 1979](image3)

D  Skyline view showing dislocated patella
Case 7. No. in series 274, Fig. 205 A, B, & C.
Right knee arthroplasty performed on 15.3.79.
Post-operatively the patient walked with a stiff knee gait and complained of retropatellar pain on knee flexion. On 4.3.82 a secondary patellectomy and removal of lateral joint osteophytes was performed. There appeared to be some weight transmission through these lateral osteophytes and these may well have been the source of discomfort rather than the patella itself.

Fig. 205 A 1979

B. 1979

C. 1982
Cement at tip of components
Every effort is made to insert sufficient acrylic cement into the medullary cavities to completely encase the prosthetic components. In a small percentage of cases the cement did not reach the tip of the femoral component. It was far less often absent from around the tip of the tibial component. This failure to reach the tip, though it is not recommended to practise it, does not appear to produce any detrimental effect. One patient showed a fracture of the cement at the tip of the femoral component.

G - Reabsorption
Since the prosthesis replaces the articular surface, there was concern lest it should by transferring the knee forces to itself and away from the subarticular bone, lead to absorption of the condyle. This would make arthrodesis very difficult if it later became necessary, case no. 23, Fig. 206 ABCDE. This form of absorption has been seen in two patients, in one patient bilaterally. This patient in addition developed gross destructive changes in both hips, Fig. 206.

The reason we see it so infrequently is that contrary to our original expectations the collateral ligaments play an active part in the stability and function of the prosthesis. It is this involvement which maintains the integrity of the condylar bone.

Fig. 206 X-Ray of hips showing gross destruction in patient
Fig. 206 B  Patient 23 1973

C 1973 Post op.

D. 1974

E 1977
Case No. 29 - Reabsorption of Condyles, Fig. 207 A - D

Fig. 207 A 1973

Fig. 207 B 1974

Fig. 207 C 1980

Fig. 207 D 1982
H - Osteophyte Formation
Case No. 143, Fig. 208 A - G.

Age 61 years, with an excellent early return of function following arthroplasty on 11.3.76, returned with increasing discomfort 5 years later and a feeling of "catching" in her knee. At revision operation 6 years following initial arthroplasty, osteophytes had grown over the lateral femoral condyle of the prosthesis and covered the metallic surface. A new prosthesis was reinserted with removal of osteophytes.
I - Wear

Case No. 216:
One further patient awaits replacement of his arthroplasty because of wear, Fig. 209 A - D. Initial arthroplasty performed 3.2.78. Patient returned with gradual recurrence of varus deformity. He has suffered either stud failure or wear of the stud permitting recurrence of the varus deformity. In addition some periosteal reaction is noticed in the femoral region, Fig. 210 A & B.
Fig. 210 A 1978 Some periosteal reaction noted in early post operative period

B. 1981 Note increase in periosteal reaction over 3 years
Lucency about prosthesis, Fig. 211 A & B.

Lucent lines surrounding the cement of both components was present in two patients, one of these being a patient with bilateral arthroplasties, where lucent lines were present on both sides. Two of these three arthroplasties are in patients who complain of pain and they are being closely followed for long term loosening or infection. A further two patients had a lucent line, one involving the femoral side and the second virtually complete on the tibial side. In a number of patients a patchy area of demarcation between the bone and cement is present at some area of the interface. This is most commonly at the tip of the tibial component. In the majority of instances this was present on the 3 monthly x-ray and there is nothing to suggest that it is in any way associated with late loosening or reabsorption. Follow up of up to 10 years has shown no progression of this latter finding.
Long Term Observations

8 ll year review

A) Wear of Femoro-Tibial articulation
B) Lucent lines
C) Subsidence of component
D) Osteophytic overgrowth
E) Patellar changes

Sixty four patients had the implant inserted over 8 years by summer 1982. In 18 patients bilateral arthroplasties were performed. Twenty three patients with a total of 29 knee arthroplasties performed for a minimum period of 8 years were reviewed. The longest surviving patient with an arthroplasty is now 10 years 9 months.

Patients who had revision procedures for loose plastics, mechanical failures, etc., were eliminated so that long term observations in this early group only apply to primary procedures. One patient was found to have a loose plastic component with moderate knee instability and is awaiting revision surgery, (see table 19) All other patients continue to function satisfactorily.
A) Wear - At the present time our methods of measuring wear is rather crude and wear of 1 - 1.5 mm. as in hip sockets is not possible with anything like the same degree of accuracy. Two patients showed evidence of measurable wear (over 2mm.), Fig. 212 & 213. The majority as in hip arthroplasty showed no evidence of significant change in the femoro-tibial articulation despite considerable activity in a number of patients for over eight years. Two further patients showed evidence of increased medial compartment weight transmission with minimal wear of this compartment (less than 2 mm.)
B) **Lucent Lines**

No lucencies about either the femoral or tibial components were observed other than partial lucencies at the stem tips with no progression over the review period as previously mentioned.

C) **Subsidence of components**

No measurable alteration in either the femoral or tibial component was observed, Fig. 214 & 215

Examples I & II.

Fig. 214  
Case no. 2 1982

Fig. 215  1982
Case no. 34 9 yr. follow up

1982  10 yr. 9 mths. follow up
D) Osteophytic overgrowth, Fig. 216 A & B

Apart from the patient previously mentioned who had a revision performed for osteophytic overgrowth (and is excluded from this follow up because only mths. from reoperation), six patients showed evidence of new bone formation on the femoral condylar surface. In five instances this involved the medial and in one instance the lateral condylar surface. In two of these cases there appeared to be weight transmission through this bony surface due to the presence of sclerosis. It is to be noted that at the time of insertion of the components minimal bony resection was performed. For some years past more radical removal of the lower femoral surface is performed to minimise this possibility.

Case No.

Fig. 216 A & B
E) Patellar Changes

Two patients showed evidence of marked patellar wear, Fig. 217 A & B. (One had recent patellectomy and is previously discussed) A further five patients showed moderate wear changes, Fig. 218 A & B. All patients with wear changes evident in the patella had moderate crepitus.

Fig. 217 A  Case no. 59 Severe patellar wear
1974 - 1982

Fig. 218 A  Case no. 74 Moderate patellar wear
1974 - 1982
Associated Long Term Problems

1) Fracture of femoral shaft

2) Fracture of femoral neck

3) Salvage procedures - Arthrodesis

(A) Fracture of the femoral shaft above the prosthesis.

This complication has occurred in four patients in the total series of 462 cases (0.9%). In all cases some degree of trauma was associated with the fracture but it is particularly interesting to note that two fractures occurred in patients who had revision arthroplasties. In both cases the femoral cortex was perforated by the power reamer as was evidenced by the escape of cement at this point. Conservative measures are unsatisfactory for the management of this complication.

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Trauma</th>
<th>Mts. since (original or revision) arthroplasty</th>
<th>Initial arth.</th>
<th>Mts. from arth. to fracture</th>
<th>Open reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>47</td>
<td>Simple fall</td>
<td>27.11.73</td>
<td></td>
<td>86 mts.</td>
<td>Yes</td>
</tr>
<tr>
<td>72</td>
<td>Fall at home</td>
<td>30.5.74</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>146</td>
<td>Stumble</td>
<td>Revision 2 mts. from revision 25.6.81</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>284</td>
<td>Stumble</td>
<td>Revision 37 mts. 11.5.79</td>
<td></td>
<td></td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 21
Case no. 284

Fig. 219 A  Post Revision

B  Following fracture

Case no. 47

Fig. 220 A

Post fracture 27.11.73

B  Internal fixation
Case no. 146

Fig. 221 A  Aug. 1981.

Post internal fixation
Spontaneous Fractures of the Femoral Neck following Knee Replacement.

No previous report of this complication was documented in the literature. Seven cases have occurred in this series (incidence 1.4%)

Discussion

Having searched the literature no detailed descriptions of stress fractures of the femoral neck after total replacement of the knee could be found. The pathomechanics of a stress fracture in a particular bone are not always clear and are often due to a number of aetiological factors, including osteoporosis due to disuse, steroid medication and the disease process in rheumatoid arthritis. Restoring a painless range of movement to a knee after replacement increases the patient's mobility. This increases the muscular tension and the loading on the hip in which stresses and bone strength have been previously reduced. Without adequate protection the hip may yield under the increasing load. This is illustrated in this series by the fact that all fractures occurred on the same side in unilateral replacements of the knee and in the most symptomatic side when bilateral replacements were undertaken.

Increased activity without sufficient protection of the weakened bone is probably the cause of these fractures. In all these patients pain was considerably reduced permitting increased activity; this increased activity was particularly significant and dramatic in two, both having been bedridden before arthroplasty. All but one patient graduated to using only one stick intermittently after arthroplasty, thereby giving little protection to the hip in the early stages. These fractures occur in patients who are light in weight and not just in obese patients.
As the incidence of this complication is low and as it can occur at a considerable time after arthroplasty, it is doubtful if graduated weight-bearing would result in a significant reduction in its incidence. However, patients with gross osteoporosis would probably benefit by graduated exercises and physiotherapy for the first six months after arthroplasty to minimise the risk of fatigue fracture of the femoral neck.

Clinical Material
Six patients had suffered from rheumatoid arthritis for an average of 15 years before arthroplasty of the knee: all had been receiving varying amounts of steroids for up to four years. One patient had osteoarthritis. The average age of the seven patients was 70 years. All the fractures occurred in the same leg as the replacement in unilateral arthroplasties and on the most symptomatic side in those patients with bilateral replacement. Two patients had sustained stress fractures of one or both tibiae before arthroplasty. The early symptom in all but one patient was severe pain in the hip of sudden onset on activity. Any patient sustaining a fall or who had a history of direct trauma to the hip was excluded. The radiological appearance of the hip before arthroplasty of the knee was essentially normal in all but two of the patients with rheumatoid arthritis. One patient had narrowing of the joint space and the other had moderate destruction of the head of the femur. Generalised or local osteoporosis was present in all cases.

The time of fracture after arthroplasty and weight of the patients

<table>
<thead>
<tr>
<th>Case</th>
<th>Time of fracture (months)</th>
<th>Weight (kilograms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>72</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>70</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>51</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>48</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>62</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>45</td>
</tr>
</tbody>
</table>

Table 22
The average interval between arthroplasty of the knee and stress fracture of the femoral neck was eight months with a range of 3 to 16 months. The average weight of the patient was 58 kilograms.

Table 22 outlines the patients' weight and the interval between arthroplasty of the knee and fracture of the hip.

Illustrative Case Reports

Case 1: A 66 year old man with a six year history of rheumatoid arthritis had both knees replaced. Before operation he had pain at rest and could only walk for 100 to 200 yards. He was receiving five mgs. of prednisolone a day for 14 months before arthroplasty. The success of his arthroplasty was demonstrated by the fact that he had no pain and could walk a normal distance for a man of his age and degree of rheumatoid arthritis. Four months after replacement of his knee he sustained a transverse undisplaces stress fracture of the neck of his left femur while walking, Fig. 222 A & B.

However, displacement of the fracture could not be prevented even with bed rest and traction and he eventually had a Charnley low-friction arthroplasty.
Case 2: A 70 year old woman with a 20 year history of rheumatoid arthritis was referred for assessment. She had stress fractures of the uppermost third of both tibiae with angulation simulating a windswept deformity, Fig. 223.

She had been bedridden for three months before admission to hospital and had received 7.5 mgs. of prednisolone a day for three years. Her operative treatment initially consisted of total replacement of the left knee. Three months later the valgus deformity of her right tibia was corrected by osteotomy and intramedullary nailing. After six months the tibial nail was removed and active mobilisation encouraged. Sixteen months after full mobilisation she sustained a completely displaced transverse fracture of the neck of her left femur. She also developed an early stress fracture of her right hip.

While this patient did not return to complete independent mobilisation, she had a significant decrease in her pain and a substantial increase in her mobility, having improved from total immobilisation before arthroplasty to being able to walk up to three quarters of a mile with the aid of sticks. The interval between arthroplasty and fracture in this case was longer than in Case but it can be explained by the complexity of problems and the slow but gradual return to activity.
Case 3: A 53 year old woman with osteoarthritis of her left knee had excruciating pain for 12 months and had placed minimal weight on the knee for 10 months before arthroplasty. She underwent routine mobilisation after the operation and six months later she sustained a marginally displaced transverse fracture of the neck of the femur which required internal fixation. Initial radiographs of her hips were normal. She had evidence of generalised osteoporosis that was presumably due to prolonged immobility.

Cases 4, 5 & 6: These patients had straightforward unilateral arthroplasties of the knee and had sustained fracture of the femur at three, seven and 15 months respectively after operation.

Case 7: A 70 year old woman with a 20 year history of rheumatoid arthritis presented with a stress fracture of the proximal end of her left tibia. She had been bedridden for six months before admission to hospital. Eight years previously she had had an Austin moore prosthesis inserted in her right hip. Initially she had her fractured tibia realigned and fixed internally with an intramedullary nail. She later underwent a total arthroplasty of the right knee. Six months after admission when her fractured tibia had united, she had a total replacement of the left knee. Approximately four months later, she developed a stress fracture of the neck of the left femur while walking very satisfactorily with the help of just one stick.

Results
All patients showed a significant improvement in mobility and reduction in pain after arthroplasty of the knee. They were also less dependent on the use of supports after operation. The compulsory use of support was not advised but most patients used one stick for at least three months after arthroplasty. Adequate correction of angular deformities was obtained in all patients. One patient case who had a severe fixed valgus and flexion deformity which could not be measured radiologically before operation, had complete restoration of normal alignment of the knee. One other patient with a stress fracture of the proximal tibia had a varus deformity of the knee which was also corrected. All seven patients had a Charnley type arthroplasty performed for the fracture. All had a successful result.
Salvage Procedures: Arthrodesis:

Two patients had arthrodesis performed for infection.

Case No. 12: This sixty year old female presented with a history of generalised arthritis diagnosed as sero-negative rheumatoid arthritis. Her main problem was with her right knee. A possible cystic area below the lateral tibial plateau was confirmed by tomography, Fig. 224 A & C. Initially suspected as being a Brodie's abscess this diagnosis was revised by a consensus of opinion in favour of a rheumatoid cyst. The ESR was fifty five. The patient was being treated with steroids. Arthroplasty was performed, Fig. 224 B. Cultures taken from the joint and from the medullary cavity of the tibia were sterile. There was no microscopic evidence of infection. On the ninth post-operative day a serous discharge from part of the wound grew coagulase positive staphylococcus aureus. A short course of ampicillin was prescribed and the wound healed rapidly.

At seventy five days post insertion, suspicion of infection was present and confirmed at the end of the third post-operative month. Arthrodesis was performed without difficulty or complication four months after the arthroplasty, Fig. 224 D & E Charnley clamps were used at this time - 1972.

Case no. 140 - age 46 years. This patient had an old tuberculosis of his knee which had resulted in a virtual amkylosis and clinically was quiescent. Arthroplasty was performed on 13/2/76, Fig. 225 A. The post operative result was never satisfactory as the patient continued to complain of pain. Close follow up showed no evidence of loosening but by April 1979 a very small endosteal cavity became apparent, Fig. 225 B, and was thought to be a reactivation of his old tuberculosis.
Case No. 12 Fig. 224 A - E.
Case 140 - Fig. 225

A

B

C

D
The prosthesis was subsequently removed on 10/5/79 and the use of the Hoffman apparatus allowed early mobilisation on crutches. Fig. 225 C. 226. 227.

A sound arthrodesis was achieved by three months, Fig. 225 D. The patient still complains of discomfort despite the arthrodesis.
One major advantage of an intercondylar prosthesis is the ease of arthrodesis if indicated as a salvage procedure. Following removal of the prosthesis approximately 15 cms. of cancellous bone is available for arthrodesis. By confining the cement to the intramedullary region, the bone end available for fusion has not undergone necrosis due to the presence of an infected mass of bone cement and healthy bleeding cancellous bone is exposed once the surface cortex has been removed.

Removal of Implant
If for any reason removal of the implant is necessitated then the joint is approached in the routine manner. A small fine osteotome is inserted anterior to the femoral component and the retaining groove of cement is split. The femoral prosthesis can then be readily removed by a sharp tap on the femoral extractor. The tibial component can then be removed by application of the tibial introducer - extractor or alternatively it can be removed by introducing a pointed instrument through the thin anterior cortex of the tibia and giving it a sharp tap.

To remove the cement as in a case of chronic osteitis a gutter is cut on the subcutaneous aspect of the tibia and on the anterior aspect of the femur and the cement removed in its entirety. Arthrodesis can then be performed between the buttresses on the medial and lateral aspects of the gap from which the prosthesis was removed.

Late Infection
Apart from the 2 patients already detailed who had an arthrodesis performed, two further patients have evidence of late infection.
Case 306: Arthroplasty performed 13/9/79. Seven months later this patient presented with a large mass in her right breast and supporting glands in the auxilla. The outer quadrant of the breast subsequently broke down from a massive abscess and this required extensive surgical drainage and management. Three months later she presented with a large fluctuant swelling in the suprapatellar pouch and she has drained intermittently since that time. No evidence of infection is as yet apparent radiologically, Fig. 228 A & B.

Fig. 228 A

Fig. 228 B
Case no. 165: Initial knee arthroplasty performed 23.9.76. Patient admitted to hospital 5 years later with acute respiratory infection. She was hospitalised for three weeks and on the day prior to discharge noticed swelling of her left knee. Her knee was subsequently drained three weeks later and it has discharged intermittently since then with a growth with pneumococcus. Again, no radiological changes are apparent, Fig.229 A & B. Both these cases suggest a haematogenous spread of infection.
Quadruple Arthroplasty

Introduction
The acceptance of individual total hip replacement and total knee replacement as a rehabilitative measure in irreparably destroyed joints is undisputed. When the arthritis becomes diffuse, involving many joints, the question of multiple joint replacement arises. There have been many reported series of bilateral total hip and total knee replacements but comparatively few on the combined procedures, 109, 110, 111, 112. This may be reflected by the fact that patients with advanced rheumatoid arthritis are regarded as poor surgical risk because of their associated systemic and medical problems. To perform surgery in these situations a definite policy on procedure must be adopted.

Although the goals of surgery are relief of pain and improvement of function, correction of the deformities in polyarthropathy are equally important if adequate function is to be restored and implant failure avoided. In this study the treatment policy adopted is presented and attempts to define the indications, contraindications and complications in quadruple arthroplasty.

The Approach
Patients with advanced rheumatoid arthritis commonly present with combined knee flexion and hip flexion deformities, adduction contractures of the hip and valgus and lateral rotation deformities of the knee.
In severely debilitated patients the policy has been to replace one joint at a time. The schedule of surgery in polyarthritis must then be such that the proximal deformities are corrected initially. This is based on the following observations. In normal standing the weight bearing forces pass from the central of the femoral head through the centre of the knee to the centre of the ankle. This alignment produces a zero mechanical angle at the knee. If structural deformity from any cause results in these three points no longer falling in a straight line, then abnormal bending moments are produced and the lower limb is no longer loaded like a straight column. The resultant change in the mechanical angle leads to increased loading on either the medial or the lateral compartment of the knee.

Conditions around the hip such as adduction contracture, shortening due either to destruction of the head, subluxation and protrusion acetabuli result in the transfer of forces to the lateral compartment of the knee producing a valgus deformity. Furthermore if there is an existing valgus deformity of the knee, as invariably there is in rheumatoid arthritis, the problem is compounded and late failure of the prosthesis is possible.

In the lower limbs if hip arthropathy is associated with knee arthropathy then hip arthroplasty should be undertaken prior to knee arthroplasty for the following reasons.

a) Active knee flexion and extension depend largely on free hip function.

b) Proper knee alignment cannot be obtained in the presence of hip disability. In unilateral hip and knee arthritis frequently patients complain of pain in the knee rather than the hip. This is usually referred and following replacement and realignment of the hip, the knee symptoms invariably subside and occasionally arthroplasty can be deferred indefinitely.

c) During hip arthroplasty unnecessary force may be applied to the knee of an anaesthetised patient resulting in irreparable damage to the knee fixation.
d) If knee arthropathy is associated with hip arthropathy of the opposite side than as shortening in the hip occurs the opposite knee assumes a flexed attitude. This may become fixed and to prevent it, lengthening of the opposite limb by hip arthroplasty is necessary. Severe flexion deformities of the knee frequently diminish following hip correction.

**Indication and Clinical Material**

Severe restriction of daily activities as a consequence of pain, deformity and joint destruction were the main indications for multiple joint replacements. All patients were assessed at a combined Rheumatology/Orthopaedic Conference to determine their suitability. The proposed surgical procedures and rehabilitative effort involved post-operatively were discussed with each patient. It was imperative that patients with severe disability contracted to have all four joints replaced.

All patients had involvement of the upper extremities to varying degrees. Severe rheumatoid involvement of the upper limbs was not considered a contraindication. Special attention was paid to the clinical and radiological assessment of the cervical spine where significant subluxation was regarded as a relative contraindication. The aetiology of upper limb weakness due to neurological or arthritic causes or both may be difficult to differentiate in severe rheumatoid arthritis.

All patients were on steroid medication and the necessary adjustments of this and other drugs were made pre-operatively. Careful assessment of associated medical problems was undertaken before each procedure. Severe medical problems that made the risk of survival too great were considered absolute contraindications.

Nineteen patients whose average age was 53.8 years (mean 27 - 67 years) were studied. The duration of the disease varied from 6 to 30 years with an average of 17 years. The follow up ranged from 6 months to 7 years with a mean of 29.4 months. Charnley hip prosthesis were used for the hip replacement in all cases.
One patient had Still's disease and the remainder had rheumatoid arthritis. Not all patients presented initially with all four major joints destroyed. Some presented after varying periods of time with progression of the disease in the unoperated hip or knee. The approach and rehabilitation followed the principles already outlined. Two groups of patients are identified. The first group consisted of patients with gross deformity and had all four major joints replaced on the same admission. In this group of five patients the interval between hip arthroplasty ranged from 1 - 4 weeks depending on the medical status of the patient. The knee arthroplasties were done after an average interval of six weeks (range 2 - 12 weeks). Overall, in this group the total average time to completion of quadruple arthroplasties was 13 weeks (6 - 28 weeks).

In a second group of 14 patients the procedures were staged over a period of time and with separate admissions. The sequence of operations was dictated by the patient's disability and deformity and by the improved functional result having had one or two joints replace.

Overall 11 patients had both hips replaced before proceeding to knee arthroplasty. Three patients had both knees replaced before hip arthroplasty was undertaken. This may appear contradictory to the outlined principles but on initial assessment their hips were normal. As a measure of the severity of the deformities and disability all but four patients had two or more joints replaced during one single admission.

A further indication of the severity of their handicap and loss of independence was that pre-operatively eight patients were either bedridden or confined to a wheelchair for periods ranging from 6 months to 16 years. A further two patients were unable to rise from a chair without assistance. A total of 14 patients were unable to climb stairs even employing the most bizarre methods.
Results
Each individual hip and knee arthroplasty was assessed using the numerical classification of Merle D'Aubigne and postel for the former and the British Orthopaedic Association Research Subcommittee Criteria for the latter. The comparative pre-operative and post-operative status of the patient is presented in table 23.

<table>
<thead>
<tr>
<th>No.</th>
<th>Duration of disease</th>
<th>Pre-op status</th>
<th>Follow-up</th>
<th>Post-op status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11yrs.</td>
<td>Bedridden X 6/12</td>
<td>18mts.</td>
<td>Mobile without supports</td>
</tr>
<tr>
<td>2</td>
<td>15yrs.</td>
<td>Less than 50 yds. with two sticks</td>
<td>6mts.</td>
<td>Walks 1/2 mile with one stick</td>
</tr>
<tr>
<td>3</td>
<td>13yrs.</td>
<td>Mobile only indoors with two sticks</td>
<td>57mts.</td>
<td>Unlimited walking without sticks</td>
</tr>
<tr>
<td>4</td>
<td>19yrs.</td>
<td>Bedridden X 2 yrs.</td>
<td>24mts.</td>
<td>Walks 1/4-1/2 mile with crutches, needs assistance getting out of chair</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Confined-wheelchair was mobile using 2 tripods for 3 yrs. after quadruple arth.</td>
</tr>
<tr>
<td>5</td>
<td>30yrs.</td>
<td>50 - 100 yards with 2 sticks</td>
<td>24mts.</td>
<td>Confined to wheelchair</td>
</tr>
<tr>
<td>6</td>
<td>30yrs.</td>
<td>Bedridden X 15 yrs.</td>
<td>64mts.</td>
<td>Unlimited walking with one stick</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Can walk 50 yds. with two sticks</td>
</tr>
<tr>
<td>7</td>
<td>14yrs.</td>
<td>Bedridden X 6 yrs.</td>
<td>42mts.</td>
<td>Unlimited walking without supports</td>
</tr>
<tr>
<td>8</td>
<td>12yrs.</td>
<td>A few steps indoors</td>
<td>10mts.</td>
<td>Unlimited walking without supports</td>
</tr>
<tr>
<td>9</td>
<td>25yrs.</td>
<td>A few steps with crutches</td>
<td>72mts.</td>
<td>Unlimited walking without supports</td>
</tr>
<tr>
<td>10</td>
<td>12yrs.</td>
<td>Bedridden for 30mts.</td>
<td>14mts.</td>
<td>Unlimited walking without supports</td>
</tr>
<tr>
<td>11</td>
<td>25yrs.</td>
<td>Bedridden for 16yrs.</td>
<td>11mts.</td>
<td>Unlimited walking without supports</td>
</tr>
<tr>
<td>12</td>
<td>20yrs.</td>
<td>A few steps with two crutches</td>
<td>22mts.</td>
<td>Unlimited walking without supports</td>
</tr>
<tr>
<td>13</td>
<td>18yrs.</td>
<td>Indoors with two crutches</td>
<td>6mts.</td>
<td>Unlimited walking with one stick</td>
</tr>
<tr>
<td>14</td>
<td>25yrs.</td>
<td>Indoors with two crutches</td>
<td>6mts.</td>
<td>Unlimited walking without supports</td>
</tr>
<tr>
<td>15</td>
<td>10yrs.</td>
<td>Wheelchair life for 3 months</td>
<td>14mts.</td>
<td>Unlimited walking without supports</td>
</tr>
<tr>
<td>16</td>
<td>11yrs.</td>
<td>Less than 50 yards with 2 sticks</td>
<td>7mts.</td>
<td>Walks more than 100yds - 2 sticks</td>
</tr>
<tr>
<td>17</td>
<td>7yrs.</td>
<td>Wheelchair life</td>
<td>9mts.</td>
<td>Walks up to 1/2 mile with 1 stick</td>
</tr>
<tr>
<td>18</td>
<td>23yrs.</td>
<td>A few steps indoors with a stick</td>
<td>51mts.</td>
<td>Walks up to 100yds with one stick</td>
</tr>
<tr>
<td>19</td>
<td>12yrs.</td>
<td>Wheelchair life for 10 mts.</td>
<td>55mts.</td>
<td>Walks more than 1ml. without sticks</td>
</tr>
</tbody>
</table>

Table 23
Hips

One of the primary goals of surgery is to relieve pain. Pre-operatively all but five patients had either Grade 1, 2 or 3 pain (classification of D'Aubigne and Postel) and were thus very disabled. Post-operatively all but one had complete relief of pain. The average pre-operative hip flexion was 61.5° whereas post-operatively all 19 patients had a composite range of movement of less than 160°, whereas on review only one patient was thus restricted. Twelve of 13 patients with fixed flexion deformities had complete restoration of normal alignment post-operatively. The one patient whose flexion deformity was not corrected had been confined to a wheelchair from the onset because of continuing progression of the systemic disease.

Fig. 231
Quadruple
Arthroplasty
Knees
Pre-operatively 16 patients had persistent pain. At review nine patients had complete relief of pain. Eight patients had mild pain, mainly retro-patellar which did not interfere with their daily activities and rarely required medication. Two further patients with persistent patello-femoral pain had unilateral patellectomy performed since arthroplasty without compromise to the final result. The average knee flexion before and after operation was similar at 85°. Flexion contractures ranged from 10° to 52° pre-operatively with an average of 25°. Follow-up flexion deformity ranged from 0° to 42° with an average of 14°. Decrease in the flexion contracture was noted in 16 patients, remained unaltered in two and increased in one. Overall a total increase in the arc of flexion was recorded in 16 cases, mainly due to a decrease in the flexion contracture. Deterioration in the total range of flexion occurred in a 49 year old woman with severe rheumatoid arthritis for 25 years. Correction of 42° flexion deformity was not obtained at surgery and at review six years later she can mobilise with the help of two sticks, having lost 20° of flexion in the interim period. An overall improvement on the pre-operative alignment was noted in all cases.

Patient Response and Overall Function

With the exception of two cases all were exceptionally satisfied with their hip and knee arthroplasty. Two patients, although they had a considerable relief of pain, were disappointed because of being confined to a wheelchair and therefore not independent. Although the relief of pain fulfilled the primary goal of treatment, their continuing disability classified them as failures. One patient with Still's disease was mobile for three years using two tripods as supports following quadruple arthroplasty but developed progressive cervical myelopathy with weakness of all extremities. Neurosurgical intervention was considered unwise. The second patient with quadraparesis from suxluxation of C4 and C5 had gross destruction of all joints of the upper limbs typical of the mutilans variety.
Walking distance was increased for all 17 patients that were mobile. Dramatic improvement was recorded in eight out of ten patients that were bedridden or wheelchair bound prior to surgical intervention. Six of the eight no longer need any form of support and can walk in excess of one mile. One of the remaining two uses one stick and the other uses two crutches. The support required for walking decreased for all patients. Nine patients no longer require any supports, six require one stick and the remaining two require two crutches or two sticks. The latter two although requiring assistance in rising out of a chair now enjoy a better quality of life with restoration of their independence.

Miscellaneous activities such as independently rising from a chair and climbing stairs were improved for all mobile patients except two. Both of these had extensive arthritic changes and weakness in their upper limbs and were unable to propel themselves sufficiently far enough forward to get their lower extremity under their centre of gravity. The combination of extensive arthritic changes and decreased motion in their lower limbs also prevented them from climbing stairs.
Current Status of the Disease
At review eight patients continued to have symptomatically active rheumatoid disease predominantly of the upper limbs. Activities of daily living were restricted in two of these patients because of their total dependence on supports, the decreased range of motion in the lower limbs and the extensive destruction of the joints of the upper limbs. The final result in the remaining six patients was not compromised because they had a normal range of motion in the lower limbs and consequently were not totally dependent on supports. Correction of the deformities in the lower limbs with improved function undoubtedly reduces the need for any form of support. In the early stages of the rehabilitation programme upper limb involvement may delay the expected progress but with the many varieties of walking aids available this problem may be overcome.

Further surgical procedures of the foot and ankle were undertaken in two patients while a further two patients required unilateral excision of the radial head.

Complications
Prevention of progressive knee contracture proved a problem in four patients, all of whom had their hips replaced initially. Smillie traction and casting did little in the way to decrease the deformity. Surgery was the ultimate solution. In the early part of this series two anterior dislocations of the hip occurred in patients with severe hip and knee flexion deformities. This problem has now been overcome by the use of the split mattress. The remaining complications, including an oblique fracture of the femur between both prosthesis sustained after a fall four years after completion of quadruple arthroplasties.
Discussion

Replacing four joints in a severely disabled patient demands careful planning and assessment. Restoring a patient with polyarthropathy to a functional status requires several operative procedures. Johnson (1975)\textsuperscript{109} reporting on 11 patients with bilateral hip and knee arthroplasty suggested that the hips be replaced before the knees. He did not outline the specific reasons. Arafiles (1979)\textsuperscript{110} with a smaller number of patients approved of this schedule. To correctly stage these procedures and to get the maximum functional result, malalignment must be corrected together with leg length equalisation. Thus if knee replacement is undertaken in the presence of hip arthropathy with deformity the muscle vectors will not be correctly aligned and unequal weight transmission will result on one or other side of the prosthesis. Correction of a flexion deformity of a knee will not be obtained in the presence of contralateral limb inequality due to hip arthropathy. Restoring the limb length following hip replacement invariably leads to an improvement of the knee contracture.

Another factor to be considered is that the energy requirements in moving the lower limbs are reduced if free hip movement is restored prior to replacing the knees, a factor not to be overlooked in debilitated patients. If knee arthroplasty is undertaken before hip arthroplasty there is always the inherent danger of damaging the knee fixation. For these reasons the preferred schedule of reconstruction is to operate on the hips before the knees and on the more diseased joints first.

Replacing two joints under one anaesthetic is a radical procedure. It has several advantages such as, reduction in hospital stay and hence a reduction in cost and it minimises the number of surgical procedures under anaesthesia. The increased incidence of pulmonary embolism, wound problems, and ectopic bone formation reported by Gradilis (1979)\textsuperscript{113}, Bracy (1981)\textsuperscript{114} and Ritter (1980)\textsuperscript{115} respectively make this an unattractive procedure.
Head (1977) reporting on eight patients with ipsilateral hip and knee replacement under one anaesthetic, five of whom had four joints replaced, considered the shorter rehabilitation of significant value in increasing patient motivation to attain functional status. The merits of this procedure are not disputed but the prolonged operative time and the vast quantities of whole blood replacement, in one case up to 21 units, makes this an unacceptable procedure.

The functional status was improved for all except two patients as measured by their ability to walk with less assistance, an increase in distance and by the increase in their ability to perform daily activities. Reduction in pain was uniform. Severe rheumatoid arthritis of both hips and both knees and prolonged immobilisation as seen in ten of the patients are not contraindications to a successful outcome.

Factors that seem to determine the success of quadruple arthroplasty are primarily the neurological status of the patient and to a lesser extent the destruction of the joints in the upper limbs. Non-treatable neurological lesions can not be compensated for but with upper extremity involvement suitable walking aids may be provided for each individual situation. In this series patients with normal function of the lower limbs were not dependent on supports, suggesting that proper lower limb reconstruction is a critical factor. Conversely a less than optimum result in the lower limbs increases the dependence on supports and the overall functional result was severely compromised where gross upper limb deformities were present. It would appear that cervical myelopathy is a definite contraindication.

The individual results of the operative procedures were similar to those reported previously for single arthroplasty of the hip and knee. Casual use of supports is often necessary because of alteration in proprioception following multiple joint replacements.
The early and late complications are higher than in other reported series. Two patients with anterior dislocations had flexion contractures of both hips and knees. That they dislocated anteriorly indicates their lack of control of lateral rotation under these circumstances. A split mattress enhances the stability of the hip but may lead to increase contracture of the knee. Our dislocation rate of two cases is higher than those reported by Khan (1980) Colville (1978), Ring (1974) and Bekenbough and Ilstrup (1978). No further trouble occurred following relocation and the eventual functional result was not impaired.

Too often patients are allowed to slide gradually into a situation where there or four joints need to be replaced before they can take the first step. Replacing four joints in a row places a considerable burden on the surgeon, nursing staff and patients. If the problems can be tackled as they arise, it is far easier for the patient and for the doctor, and superior in the end results. Perhaps one of the most significant factors when considering multiple procedures is patient motivation, an element very difficult to assess. The rehabilitative effort involved is very extensive particularly when four joints are replaced in rapid succession and it is mandatory that each patient be prepared for the effort that is required post-operatively.

Summary

An approach to the rehabilitation of polyarthropathy is presented designed to obtain the optimum function, to prevent mechanical complications and to correct deformities following joint replacement. The preferred schedule of treatment is to replace the hips before replacing the knees. Nineteen patients who had quadruple arthroplasty are presented with a mean follow-up of 27.3 months. The overall function was improved in all but two patients. Severe rheumatoid disease and prolonged immobilisation were not contraindications to a successful outcome. Factors that determine a successful outcome are either the presence or the development of myelopathy combined with gross upper limb deformity.
Comparative Results with other Semistabilised Prostheses

Three other designs of semistabilised prostheses have been in clinical use prior to 1974 with results documented in the literature and a comparison between the published clinical results and the results of the comparable early five year series of the currently described prosthesis (Sheehan type) are summarised.

Fig. 232

The Gschwend (GSB) prosthesis, Fig. 232

Gschwend, GSB (Gschwend, Scheier and Bahler). The GSB prosthesis is polycentric in type. The connection between the femoral and the tibial component is effected by a central bridge, in which there is a slightly curved slot running from below (anterior) to above (posterior). The slot serves as a guide for the non-loading axis of the femoral component. Rotation proper is absent but there is some clearance between the components, allowing slight anteroposterior movement.
In addition, the femoral component can - in analogy to a normal knee joint - be lifted off the tibial component in maximum flexion without disturbing the functional relationship between the two components. The amount of bone resected is small and the bearing surface of the prosthesis on the bone is very wide.

Attenborough\textsuperscript{122,123}, Fig. 233. The femoral component of the Attenborough prosthesis consists of a shell for the two femoral condyles attached to a tapered intramedullary stem. A stabilising link exists between the two components. Because of the possibility that stress is transmitted to the other component by this linkage, tapered intramedullary stems are provided. Attenborough feels that it is best to have interchangeable prostheses fitting either knee and for this reason the stem length is restricted.

At the base of the stem is a hollow into which is fitted a ball on the end of a rounded stem. This ball is free to rotate and its stem runs in a gap between the posterior parts of the femoral condyles. This gap is only just greater than the stem's diameter at the front, but widens at the back. There is a radius of 40 mm. on the normal weight-bearing surface of the prosthesis and a smaller radius of 25 mm. posteriorly and anteriorly. These last two curves are long enough at the back to allow for flexion of the knee through about 120° and at the front they are long enough to allow the patella to articulate with the femoral prosthesis and not with the femoral condyles. The tibial component has a tapered, hollowed intramedullary stem into which the rounded linking stem of the femoral component fits. It has a tibial plateau shaped with the same radius as the larger radius of the femoral condyle (4 mm.)

Thus in extension the two components fit exactly, but as soon as 20° of flexion is reached the smaller curve of the posterior parts of the femoral condyles comes into apposition with the tibial plateau and some backward and forward movement of each femoral condyle is possible, allowing rotation.
At the same time, in this position the linking stem of the femoral component is in a wider gap between the condyles of the femur and is thus able to move sideways, allowing some lateral mobility, which increases with flexion and decreases to nothing in full extension.

The movement of this joint is polycentric because of the different curves of the femoral condyles, and the length of the linking stems projecting below the level of the femoral condyles must therefore vary according to the position of the joint, as the centre of the ball cannot lie at the axis of both radii. Thus there is a longer projection in extension than in flexion. This makes the stem move up and down within the tibial component. There is a hole drilled from just above the weightbearing surface of each side of the tibial plateau to the bottom of the central hole containing the rounded stem. The stem has one flattened surface. Synovial fluid can run into the bottom of the central hole when the knee is flexed more than a few degrees and on extension the stem acts as a piston, driving the fluid up again and out through the two small lateral holes close to the main weight bearing area.
This design has since been altered so that the metal sphere now articulates in a high-density polyethylene (HDP) socket. This simplifies the technique of insertion and also removes the metal-to-metal articulation that previously existed. A patellar surface has also been added. No clinical results with this modified prosthesis are yet available.

Spherocentric\textsuperscript{124,125,126}, Fig. 234.
The spherocentric prosthesis is an intrinsically stable, nonhinged device with three metal-on-ultra-high-molecular-weight polyethylene (UHMWP) bearing surfaces, a ball and socket joint located within the femoral component, and two runner and track joints between the femoral and tibial condyles. The ball and socket joint is composed of a central sphere on top of a column rising from the tibial component. In the articulated prosthesis this sphere is contained within a polyethylene socket. This in turn is fixed within the femoral component by its flat outer posterior surface, which abuts against a reciprocal flat surface within the cavity of the femoral component and by flanges on the femoral component which prevent distal displacement.
The ball and socket joint formed by this socket and sphere permits triaxial rotation, but translation (dislocation) is not possible in any direction. The centre of the sphere lies above the joint surfaces and well posterior to the long axis of the femur, thus approximating the location of the average flexion axis of the normal knee. The location, dimensions, and contour of the metal femoral runners and their mated tibial polyethylene tracks serve to guide and control flexion, varus - valgus movement, and torsion, and to increase the total bearing surface of the joint. The contours of the femoral condylar surfaces of the prosthesis in the sagittal plane include an anterior part with a larger radius of curvature, which is not concentric with the surface of the sphere, and a posterior part with a smaller radius of curvature, which is concentric with the surface of the sphere.

As the knee approaches full extension, the anterior surfaces of the femoral condylar runners with their larger radius of curvature bear increasingly on the plastic tibial tracks, thereby unloading the top of the sphere and forcing the underside of the sphere against the surrounding plastic socket. The central pillar is thus placed in tension. Hyperextension is arrested by gradual deceleration due to the cam effect with no rigid extension stop. Impact loading at the end of extension should therefore be minimised and at full extension the prosthesis is fixed and completely stable in all directions except flexion.

As the prosthesis flexes from its fully extended position, the femoral condylar surfaces slowly lift off of the plastic tibial tracks, gradually transferring all the load to the dome of the sphere, thereby permitting triaxial rotation of increasing amplitude as the condylar runners lift further and further off the tibial tracks. At maximum flexion (120°) the prosthesis permits up to 30° of tibial rotation and up to 5° of varus-valgus motion.
All articulating surfaces are metal on plastic. There is no metal-to-metal contact in any position. All plastic (and thus potentially deformable) components (including the press-fit tibial tracks) are supported by metal and are readily replaceable should this be desirable because of wear.

This prosthesis, although consisting of arcs of two different radii, is not truly polycentric, as most of the load is transmitted from the central sphere to its plastic socket. It is only towards full extension that the load is transmitted to the outer condylar surfaces. Thus in normal function, movement is largely uni-axial in a coronal plane.

Intramedullary Fixation
All four of these devices use intramedullary fixation. It is totally impractical to consider a semistabilised prosthesis depending on surface fixation; if there is any stability in the prosthesis itself - other than the stability produced by compressive loading - then intramedullary stems become mandatory to achieve adequate fixation.

In soft osteoporotic bone such as is frequently encountered in R.A., the ideal method for both fixation and alignment is the use of intramedullary stems. In patients with normal bone density, intramedullary fixation still has the advantage that it greatly facilitates the insertion and accurate alignment. In addition, the degree of destruction or collapse of the condyles does not influence the final stability of the joint. On the other hand, fatigue failure of femoral hip stems is now becoming a major problem, so that an appreciation of the importance of adequate stem design has been growing for some years. Thus sharp angles form points of stress concentration which predispose to failure of the stem through fatigue and also cause failure of the acrylic cement with crack propagation starting at these sharp points. The latter phenomenon, if it occurs, causes loosening of the stem in its cement bed. This imposes high loads on certain areas of the stem, and this in turn predisposes to stem failure due to fatigue.
Stem Length
The ideal stem length is still unknown. The stem should be long enough to give adequate cement fixation and alignment. On the other hand, it should be short enough to allow cement to be introduced at its tip and to permit removal of the implant and of its accompanying cement if infection ensues. An additional consideration in decisions concerning femoral stem length is that in the long term it will be of interest to see whether the short stems of the Attenborough and Spherocentric prostheses will be elongated by their designers or whether the long stems of the GSB and Sheean prostheses will be shortened.

Patello-Femoral Joint
None of the prostheses in this group has a specifically designed surface for the patella, but all allow the patella to come into contact with the anterior surface of the femoral prosthesis during flexion. The articular surface of the patella is trimmed of osteophytes in all cases.

Clinical Results
It is impossible to compare the results obtained with the different prostheses directly and to draw conclusions. Consequently the current results obtained with each type in the hands of the designer will be summarised and some of the particular problems will be analysed.

The principle factor preventing a direct comparison of the results is the wide variation in the pathological conditions requiring replacement in the different series. Most of the patients in these four series had moderately or severely damaged knees but table 24 summaries the aetiological conditions in each series. The assessment of function following knee arthroplasty is a complicated procedure. Pain, function and movement have all been differently graded by different designers. The greatest discrepancy is found in the method of recording function. Thus, no attempt at a comparison of this parameter will now be made. A comparison of pre and post-operative pain and movement is made in tables 25 and 26, however.
Duration of follow-up and aetiology in the four series:

<table>
<thead>
<tr>
<th></th>
<th>Number in series</th>
<th>Maximum follow-up months</th>
<th>Aetiology(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>OA</td>
</tr>
<tr>
<td>Sheehan</td>
<td>131</td>
<td>67</td>
<td>19</td>
</tr>
<tr>
<td>GSB</td>
<td>117</td>
<td>45</td>
<td>56</td>
</tr>
<tr>
<td>Attenborough</td>
<td>166</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Spherocentric</td>
<td>25</td>
<td>23</td>
<td>26</td>
</tr>
</tbody>
</table>

Table 24

The incidence of moderate or severe pain in the four series:

<table>
<thead>
<tr>
<th></th>
<th>Moderate to severe pain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before operation</td>
</tr>
<tr>
<td>Sheehan</td>
<td>81%</td>
</tr>
<tr>
<td>GSB</td>
<td>95%</td>
</tr>
<tr>
<td>Attenborough</td>
<td>Majority</td>
</tr>
<tr>
<td>Spherocentric</td>
<td>Grading not applicable</td>
</tr>
</tbody>
</table>

Table 25

The average arc of movement in the four series:

<table>
<thead>
<tr>
<th></th>
<th>Before operation</th>
<th>After operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheehan</td>
<td>77</td>
<td>91</td>
</tr>
<tr>
<td>GSB</td>
<td>66</td>
<td>108</td>
</tr>
<tr>
<td>Attenborough</td>
<td>Not recorded</td>
<td>80°+ (in over 80%)</td>
</tr>
<tr>
<td>Spherocentric</td>
<td>74°</td>
<td>92°</td>
</tr>
</tbody>
</table>

Table 26

Re-operations for patello-femoral symptoms in the four series:

<table>
<thead>
<tr>
<th>Prosthesis used</th>
<th>No. of re-operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheehan</td>
<td>1</td>
</tr>
<tr>
<td>GSB</td>
<td>-</td>
</tr>
<tr>
<td>Attenborough</td>
<td>10</td>
</tr>
<tr>
<td>Spherocentric</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 27
Patello-Femoral Symptoms
Re-operation for patello-femoral symptoms has been necessary to a greater or lesser extent with all designs, table 27. Attenborough (1973, 1974) has had a high incidence of symptoms (necessitating secondary surgery in ten patients) and he now routinely resurfaces the patella with a HDP surface. The patellar symptoms in his series increased with time and accounted for a falling off in the number of good results at 2 years as against the 1 year follow-up.

Gschwend (1974) and Gschwend et al (1973) state that patellar pain is not an infrequent finding and that it is attributable less to the destructive changes in the articular surface of the patella than to an uncorrected subluxation. He hopes to be able to dispense with artificial replacement of the patella in the majority of patients.

In the Spherocentric series, approximately 15% of patients have mild to moderate patello-femoral symptoms in the initial post-operative period. However, these symptoms have resolved spontaneously within the first 6-9 post-operative months and only one patient has so far required revision surgery.

In my own series the incidence of patients with retro-patellar symptoms was 13%. One patient required patellectomy but in none of the remaining cases were symptoms severe enough to interfere to any significant extent with function. Where patellar symptoms have occurred, they have improved with time in the majority of patients and an early decision with regard to the need for secondary surgery is not encouraged.

Further Remarks on Individual Series, Tables 28 - 34.
The grading for function pre- and post-operatively is based solely upon the ability to walk (Sheehan, 1978).

### Ability to walk after Sheehan arthroplasty

<table>
<thead>
<tr>
<th>Before operation</th>
<th>After operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unable</td>
<td>10</td>
</tr>
<tr>
<td>Indoors only</td>
<td>33</td>
</tr>
<tr>
<td>100-200 yards</td>
<td>49</td>
</tr>
<tr>
<td>440-880 yards</td>
<td>33</td>
</tr>
<tr>
<td>Normal</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 28

### Ability to walk after GSB arthroplasty

<table>
<thead>
<tr>
<th>No. of patients</th>
<th>Up to 100 m</th>
<th>1 km</th>
<th>1 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Patients with RA (48)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unilateral</td>
<td>35</td>
<td>6</td>
<td>19</td>
</tr>
<tr>
<td>Bilateral</td>
<td>13</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>b) Patients with OA (45)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unilateral</td>
<td>32</td>
<td>1</td>
<td>11</td>
</tr>
<tr>
<td>Bilateral</td>
<td>13</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 29

### Pain after spherocentric arthroplasty

#### Grading

0. None
1. Minimum: does not limit activity
2. Mild: occasionally limits activity
3. Moderate: often limits many activities
4. Severe: constant, disabling and intolerable

#### Results (average grade)

<table>
<thead>
<tr>
<th>Before operation</th>
<th>3.76</th>
</tr>
</thead>
<tbody>
<tr>
<td>After operation</td>
<td>0.56</td>
</tr>
</tbody>
</table>

Table 30
Function after spherocentric arthroplasty

Grading
0. Non-walker: in chair or bed all the time
1. Severe restriction: walks only short distance with support, needs help to stand.
2. Moderate restriction: definitely limited as to distance walked and terrain walked on. Uses cane, crutches, brace or walker most of the time.
3. Mild restriction: somewhat limited as to distance walked and terrain walked on; seldom uses cane or crutches.

Results (average grade)

<table>
<thead>
<tr>
<th>Before operation</th>
<th>After operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.36</td>
<td>2.98</td>
</tr>
</tbody>
</table>

Table 31

Mechanical complications

<table>
<thead>
<tr>
<th>Prosthesis</th>
<th>Nature of complication</th>
<th>No affected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheehan</td>
<td>Detachment of tibial plastic in original design</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Failure of tibial stud</td>
<td>2</td>
</tr>
<tr>
<td>GSB</td>
<td>Failure of tibial component in original design</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Loosening: certain possible</td>
<td>1</td>
</tr>
<tr>
<td>Attenborough</td>
<td>Failure of tibial plastic</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Loose tibial component</td>
<td>1</td>
</tr>
<tr>
<td>Spherocentric</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 32
Mortality

<table>
<thead>
<tr>
<th>Prosthesis</th>
<th>Operative</th>
<th>Post-operative</th>
<th>Fat embolism</th>
<th>Pulmonary embolism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheehan</td>
<td>1</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>GSB</td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Attenborough</td>
<td></td>
<td></td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Spherocentric</td>
<td></td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 33

Successful arthrodesis for infection

<table>
<thead>
<tr>
<th>Prosthesis</th>
<th>No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sheehan</td>
<td>1</td>
</tr>
<tr>
<td>GSB</td>
<td>3</td>
</tr>
<tr>
<td>Attenborough</td>
<td>4</td>
</tr>
<tr>
<td>Spherocentric</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 34

Gschwend

Gschwend graded function separately for patients with RA and with OA and distinguished between unilateral and bilateral replacements. Prosthetic failure occurred in one case of an earlier design in which the connecting bridge between the femur and the tibia was thinner than in the current model. It has not occurred with the current design.

Loosening occurred in one case where a hinge joint had previously been implanted. In a further two cases a radiolucent line of 4 mm is present suggesting loosening. Gschwend feels that radiolucent lines of up to 2 or 3 mm round the stem of the prosthesis have no importance as long as they are not found around the articular part of the prosthesis itself, i.e. at the cement cancellous bone interface. Three knees became infected: all had successful arthrodeses with 16-18 hole AO plates.
Attenborough

No detailed breakdown of pre- and post-operative function is available for the Attenborough prosthesis. However, pre-operatively 20% of the patients were unable to walk and a further 38% could only walk indoors while 12% could walk between a quarter of and half a mile. Post-operatively over 70% could walk a quarter of a mile and in 30% - 40% of cases activities were essentially unlimited. Four patients underwent removal of the prosthesis and arthrodesis of the knee for infection. Three patients now have sound arthrodeses and one has a fibrous ankylosis.

In two patients the tibial component has loosened due to a large amount of residual cement in the back of the knee, causing a sudden block to flexion. In one of these the tibial component broke at the lower end of the stabilising rod. One further patient who was left with a $10^\circ$ varus deformity had a similar type of fracture of the tibial component.

Ten patients have had secondary operations for patello-femoral pain. In these cases a HDP prosthesis has been implanted on the articular surface of the patella. This is now a routine feature of the Attenborough procedure at the initial operation.

Spherocentric

Only average pre- and post-operative figures for pain and function have been quoted for the spherocentric prosthesis, so that no direct comparison with other prostheses is possible. The total experience at the University of Michigan at the time of comparison was 140 cases (personal communication 1978). No mechanical failures have been reported. There have been two re-operations for infection; in both these cases the implant was removed and an arthrodesis attempted. One is a recent case and still undergoing treatment. In the second infected case the infection has been controlled but fusion has not occurred. A further patient with recurrent haemarthrosis has had a synovectomy and patello-femoral replacement with the Bechtol prosthesis.
Summary

This brief review of the design considerations and early clinical results of semi-stabilised prostheses is an attempt to summarise the present state of the art. Results to date indicated a high percentage of satisfactory results. Patellar problems still require further investigation and clarification. With the exception of the Attenborough prosthesis, the reoperation rate for these residual symptoms has been minimal, and the overall impression is that they improve with the passage of time. Time alone will prove whether the current phase of replacing the patellar surface with a convex button will give as good a long-term result as a hemi-arthroplasty of the patella or, if troublesome symptoms persist, a patellectomy.

The ideal design and length for an intramedullary stem is still uncertain. The incidence of stress fractures of the lower femur associated with short stems will be of particular interest in the future.
Conclusion

Knee Arthroplasty has proved a much more complex problem than hip arthroplasty. A much improved understanding of the muscle vectors about the knee, soft-tissue release procedures, and patellar alignment, as well as the correction of associated foot and hip deformities, augurs for a greater success rate with knee prostheses in the future. The magnitude of the work presented in this thesis is impossible to describe but a small measure of this undertaking can be appreciated when one realises that over one thousand hours alone were spent inserting this series of arthroplasties. The hours on design, patient assessment, material investigation and other facets of this work are incalculable.

Many more years of close observation, collaborative clinical trials, and extensive mechanical analyses are required before the best characteristics of each individual prosthesis are proven. Every designer of a knee implant at present agrees that a great deal remains unknown and unsolved. The clarification and ultimate solution of these remaining problems provide the challenge for the future.
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Final Prototype - Femoral Component

Section on A-A
ENDOSKEL TIBIA (METAL)

ENDOSKEL TIBIA COMPLETE
R (RADIUS)
AT POSITION A = 2.5 (SHOWN)
" " B = 1.5

X (ANGLE)
AT POSITION A = 40 (SHOWN)
" " B = 20

ANTERIOR FLANGE FEMORAL COMPONENT
DETAILS OF FORM AT POSITION 'A'
STANDARD BROAD CONDYLE