Henry Ford Hospital Medical Journal

Volume 19 | Number 1 Article 2

3-1971

A Replacement Prosthesis For the Hip: A Preliminary Report

H. M. Frost

E. R. Guise

Henry Ford Hosp. Med. Journal
Vol. 19, No. 1, 1971

A Replacement Prosthesis For the Hip

A Preliminary Report

H. M. Frost, M.D.* and E. R. Guise, M.D.*

Because of theoretical as well as practical difficulty in the total hip endoprostheses available to orthopaedic surgeons at the present time, an anlysis of the present and potential difficulties reveals that substitution of a roller-bearing for the present slider-bearing prosthesis and the establishment of a larger end-bearing surface on the acetabular side would be of benefit. Thus, the Ring prosthesis was re-designed to satisfy these hopes. A modification of the Ring's approach gives complete acetabular exposure and control of the prosthetic insertion. This is a preliminary report describing the design modifications of a prosthesis, presently under investigation, and illustrated by a typical case.

In the late 1940s, orthopaedic surgeons around the world received enthusiastically the invention of the hip endoprosthesis. They subsequently developed several styles of femoral head and head-neck interposition endoprostheses. Some of these proved serviceable and reliable in actual use but severe hip joint problems still exist for which present surgical solutions remain inadequate. For example, while a cup arthroplasty produces good mobility and pain relief in many cooperative and vigorous patients, it is a poor choice for the elderly patient because of the prolonged bedrest, major nature of the surgery and the physical and mental vigor required to achieve good results. This is particularly true if the patient is in precarious medical condition possibly with muscular weakness, impaired coordination, poor memory, and emotional instability.

One recent response to this challenge to our therapeutic ingenuity has been the so-called total hip replacement prosthesis. In this procedure, besides replacing the head and neck of the femur, the acetabulum is replaced by an artificial socket which produces a mechanically secure hip requiring minimum postoperative mechanical protection and after-care. It provides good mobility, good durability, and little or no pain.

Two major routes have been taken in attempting to achieve this. In the first, typified by John Charnley's work,[1-5] a metal ball sits in a plastic socket, which is anchored to the pelvic

*Department of Orthopaedic Surgery.

bone by a second self-curing plastic, in the region of the natural acetabulum. The intent is to obtain and retain secure mechanical fixation of the socket to bone. Of course, one assumes both chemical and biological inertness on the part of the plastics and the metal employed.

In the second route a separate metal socket is fitted to the metal ball of the femoral prosthesis. Inserted into the pelvis through the natural acetabulum, the socket does not depend upon any interposed plastic for its anchorage to bone.[6] Ring's total hip prosthesis[7] is the archtype of this design approach.

We undertook to modify Ring's prosthetic socket because of several reservations arising from previous experience with implanting a plastic compound intended to carry essentially normal body weight plus muscular loads for a decade or more, and because of the wear associated with any sliding bearing composed of nonviable bearing materials. This preliminary report describes some of the engineering benefits (one of potentially major importance) which we believe the modified design provides.

Since we continue to improve the device, it has not yet reached a stable design, and so we emphasize that this indeed constitutes a preliminary report. But, we believe the design principles involved in the modified device have considerable potential value to others engaged in similar efforts.

In modifying the Ring we drew heavily upon experience accumulated over the past generation or more with various forms of arthroplasty, hoping that if we make errors, at least they might be new ones.

Finally, we describe a relatively simple modification of the surgical approach which makes insertion of the prosthesis little more difficult than the endoprosthetic replacement, eg, a Moore prosthesis, of the femoral head and neck alone for a typical transcervical fracture.

Objectives in Design

1) Problems: To us, previous endoprosthetic bearing designs presented three major problems in actual use:

(a) Most of them provided essentially a *sliding bearing surface* in the artificial joint (Fig 1). That is, the relative motions of the two bearing surfaces resemble those that engineers call a "journal." With this sliding and with use of artificial bearing materials, wear becomes inevitable and service life has been limited. While certainly not an insurmountable problem in principle, it seems undesirable to us to insert such a device in a patient who may make vigorous use of the resulting artificial hip for more than 10 years.

(b) By various means, most currently available acetabular replacement devices anchor the artificial socket securely to the bone of the superimposed pelvis. Frequently past experience has shown that artificial load-carrying devices inserted into and/or onto the skeleton were loosened and lay in a bed lined with fibrous tissue from which a thin layer of synovial-like fluid partially separated them. We would anticipate, therefore, that even the plastic bed of the Charnley-designed artificial socket in time would loosen from its attachments to the pelvic bone and we would expect the socket of the standard Ring prosthesis to loosen too, much more rapidly than the Charnley. (We're not implying that harm to the patient would automatically follow.)

(c) Some devices have employed geometric configurations at the interface between device and bone which unduly concentrate mechanical forces on small regions of live tissue, leading to breakage and/or migration of the device and/or its bony bed.

Objectives of Modification

These and other problems (not discussed in this preliminary report) led to the following criteria for a design modification.

(a) *Socket Rotation:* Since the artificial hip socket will often loosen, some way should be found to benefit from this. Of several possibilities we considered, we chose to let the modified socket rotate freely around its longitudinal axis (Fig 1B). Therefore, we eliminated the threads on the stem of Ring's original design but retained its circular configuration around its longitudinal axis at all levels. As a result, the modified socket can spin freely without obstruction around that axis.

Furthermore, it is inserted in a reamed recess with a *deliberately loose fit* to provide space for producing a fibrocartilaginous lining ultimately separating the metal from the bone. This followed practical experience with cup arthroplasties, in which loose fits between the cup and the opposing socket and head permitted fragile granulation tissue to grow out of the underlying bone. Via subsequent metaplasia, that tissue then transforms into the much tougher fibrocartilage needed to provide an adequate bearing surface for carrying loads.

This requires a postoperative regime which protects the bone-metal interface from large mechanical loads for many weeks, as in the case of cup arthroplasties.

(b) *Geometry of the Load-transfer Interface:* The bone-metal interface of the original Ring socket represents a wedge driven up into the ilium by the mechanical loads of body weight and muscle pull when the patient walks. These loads probably achieve typical values of 300-500 lbs total force. Simple trigonometric analysis of Ring's original socket design shows that a wedge-like effect arises which generates a lateral bursting force against the bony cortex embedding the socket. This force exceeds *by a factor of approximately two* the total axial load. Such a large bursting component could make the socket gradually work loose in all planes and migrate proximally into the pelvis, as load-carrying trabeculae in contact with it gradually crumbled from progressive fatigue failures. And indeed that problem has arisen with such designs, particularly if much osteoporosis exists in the bony pelvis.

We reshaped the bone-metal interface of the socket to produce a series of end bearing surfaces, each of which transfers axial load in a direction perpendicular to the underlying trabecular bone (Fig 2).

Trigonometric analysis of the modified socket now shows that less than 15% of the axial load value exists as a lateral bursting pressure (partly because of the compliance and architecture of the underlying trabecular bone). Most of the axial load transfers per-

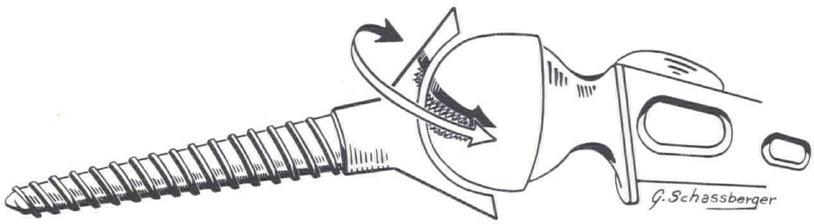

Figure 1A

Sliding bearing showing motion about one axis producing wear in a single weight-bearing area when acetabular portion is firmly anchored in bone.

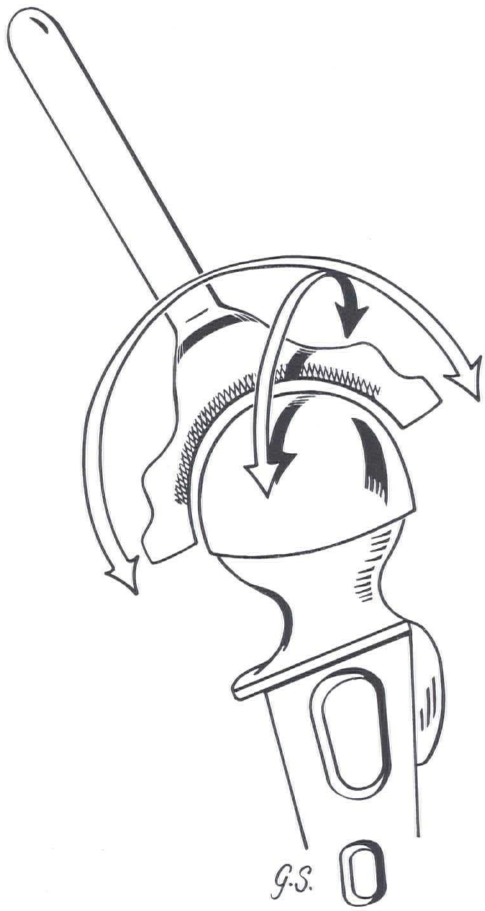

Figure 1B

Rotation of acetabular portion translating sliding-bearing action into roller-bearing action with wider distribution of potential wearing of prosthetic surfaces.

A Replacement Prosthesis

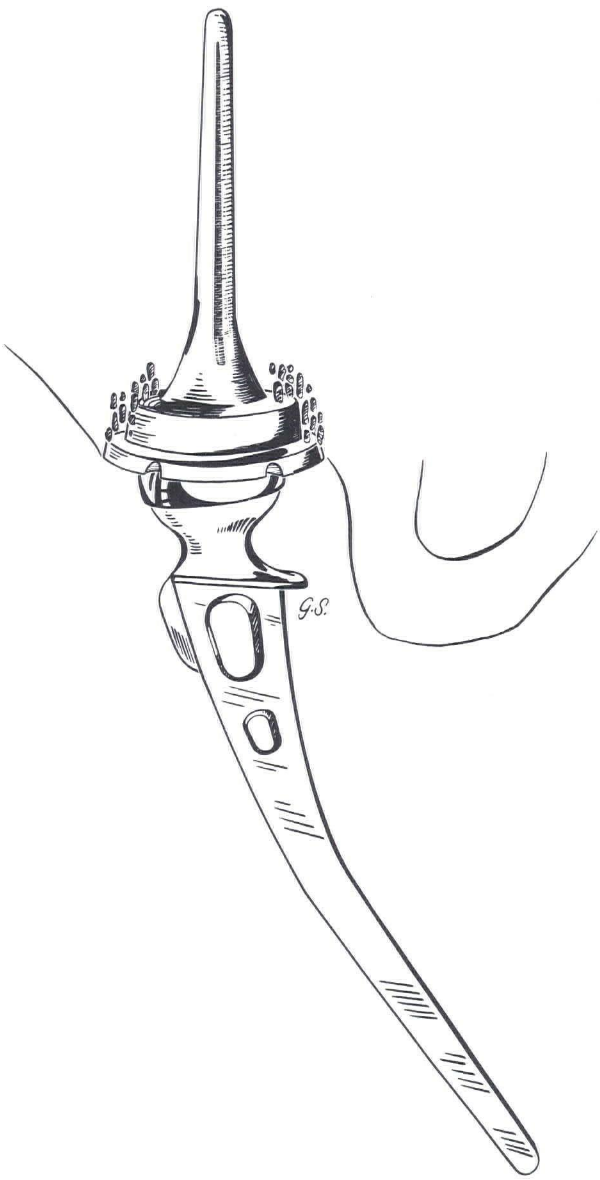

Figure 2

Modified acetabular Ring prosthesis. The authors use a special reamer which creates two steps of flat weight bearing surface in the acetabular bone to support the prosthesis.

pendicularly to the underlying trabecular bone and in a direction parallel to the longitudinal axis of the redesigned socket.

(c) *Total Area of the Bone-metal Interface:* Because the hip carries large mechanical loads and many patients undergoing such an operation have considerable osteoporosis of the bony pelvis, we felt that the total cross-section area of the load carrying bone-metal interface of the original Ring socket could be increased. We enlarged its diameter by one centimeter, obtaining thereby more than a 25% increase in total axial load carrying cross-section area. Since the much smaller Smith-Petersen cups rarely migrate proximally through the pelvis in actual service, we believe the modified socket should prove at least as satisfactory.

(d) *The Roller Bearing Principle:* Metal sliding on metal in artificial bearings in the living body has proven a problem with other designs in the past. Wear produced innumerable fine particles of bearing metal which react chemically and adversely with the joint tissues. Also, an excessive rate of wear of such bearings has occurred (Fig 1A). Our modification, allowing the socket to spin around its longitudinal axis, converted the typical walking motion between the head and the socket sections of the prosthesis from a pure sliding to a *primarily rolling motion.* We believe this could be an extremely important development in future designs of joint endoprostheses, since substituting a rolling for a sliding motion markedly reduces wear (Fig 1B), lubrication problems and friction. It thereby prolongs the service life of the resulting bearing. For example, the roller bearings in electric motors or automobile wheels serve with little maintenance through the useful life of the machine.

(e) This brings us to a more speculative although equally intriguing matter. If the radius of curvature of the ball is *slightly* less than that of the socket in which it fits, a small wedge of fluid lubricant will exist peripherally to any region of actual metal-to-metal contact. Given this configuration, one finds that the ball *always tends to roll forward onto a fluid wedge.* Given suitable geometry, including the angle of the wedge, and suitable lubricant viscosity and bearing dimensions, it should be possible to achieve a nearly perfect hydrodynamic lubrication and separation of any sliding regions of metal-to-metal motion by such means. Such sliding still occurs to some extent in the present design because some "wiping" action occurs peripheral to the region of actual contact. If this principle could be realized in a practical device, the service life of such bearings might increase by tenfold or more. This would leave as a major residual potential design problem only the possibility of mechanical fatigue of the bearing surface material itself due to repetitive loading and deloading cycles.

We recognize that fairly expensive modifications in the manufacturing process would be necessary, but they would be justified if the potential benefits could be obtained.

We are currently designing new tools for the operation which should reduce operative time to a minimum and make minimum demands upon technical skill to achieve success.

We anticipate further modifications, since it is unlikely that all possible problems and objections to the present construction and instruments have been answered or even identified. We hope to report progress along those lines in greater detail later.

Operative Technique

One difficulty in technique associated with inserting an acetabular prosthesis arises in gaining *easy* access to the acetabulum. The work needed on the acetabulum makes it very difficult to approach adequately with the patient in the strict supine position. We currently use a technique with the patient in the lateral decubitus position, and a modified "Moore Southern Approach," resulting in fixed acetabular-pelvic angles such as provided by Ring's guide.

With the patient in that position and the affected hip superior and flexed 60°, we prepare the leg, hip, and pelvis from the waist to the knee, then drape it free, as described by Ring. Sealed drapes are applied around the groin and buttock and adhesive polyethylene is attached to the buttock and thigh area.

Ring's approach is used (Fig 3A), except that we also divide the femoral attachment of the gluteus maximus to expose fully the subgluteal area and visualize clearly the sciatic nerve. The pyriformis attachment can be preserved by inserting a Cobra retractor between its tendon and the superior capsule of the hip joint, as Ring describes. The inferior and superior gomellae, obturator internus, and the quadratus femoris are then detached from the posterior aspect of the trochanter and upper femoral shaft. This exposes the posterior, inferior and superior capsule, which is then totally excised. After division of the ligamentum teres, the femoral head is dislocated into the wound and the neck divided, leaving 3/8 to 1/2 inch of the calcar above the already exposed lesser trochanter. This can be trimmed to fit the prosthetic femoral device later, also as Ring describes. After excision of the femoral head and by internally rotating the thigh, the remainder of the hip capsule is exposed and excised. Then the extremity is flexed 20° and a Cobra retractor is placed between the anterior brim of the pelvis and the direct head of the rectus femoris (Fig 3B). The Ring guide is positioned and the guide wire is directed towards the posterior iliac spine with a finger in the sciatic notch, as described by Dr. Ring.

The hole for the shaft of the new prosthesis is produced with a cannulated drill along the previously inserted Steinman pin. The new multistep reamer is inserted into the drill hole and the socket is reamed. All fragments are irrigated from the wound and the step cut prosthesis is tapped into position.

A sponge is placed over this prosthesis while the femoral shaft is turned into adduction, 100° flexion, and internal rotation. The trochanter and femoral neck are prepared in the usual way with a Moore osteotome and broach to receive the head-neck part of the total hip prosthesis. Approximately 10° of anteversion is provided in the seating of the femoral portion of the prosthesis as it is inserted into the shaft. Any posteriorly protruding portion of posterior femoral wall is removed with a tiny osteotome and curette. Again, the wound is irrigated

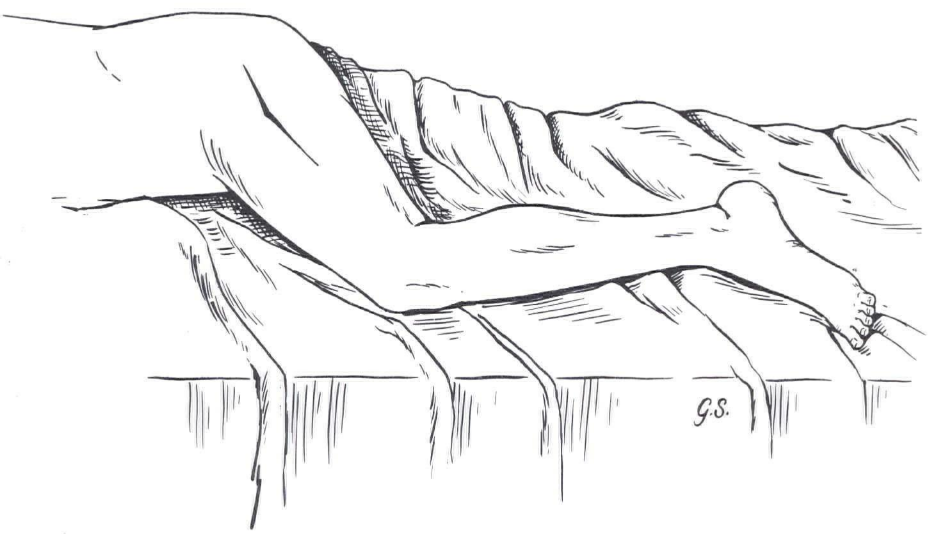

Figure 3A

Lateral decubitus position with an inferiorly extended "Southern" incision.

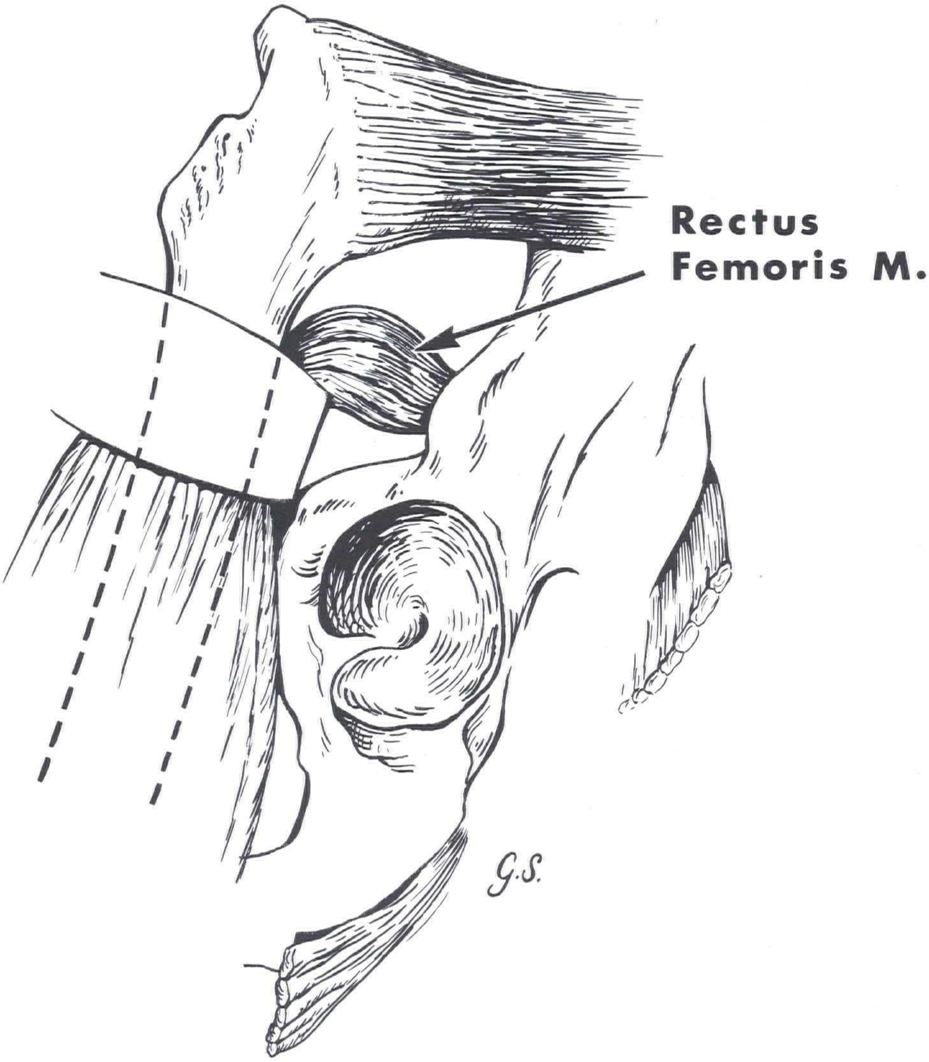

Figure 3B

Total exposure of the acetabulum affording easy access for removal of osteophytes and insertion of the acetabular reamer.

thoroughly. The sponge is removed from the acetabular portion of the prosthesis, the two sections of the prosthesis reduced and the range of motion is checked. Occasionally an adductor tenotomy may be necessary in order to obtain sufficient abduction.

Abductor lengthening via transfer of the greater trochanter is rarely necessary. If there is abductor weakness due to short abductor position, the insertion of the prosethesis would be accomplished after trochanteric osteotomy as a planned portion of the initial approach. The short rotators including the quadratus are then closed. Suction drainage is established below the closure of the gluteus maximus as well as above the fascia in the subcutaneous tissue, and removed in 48 hours. The wound should be inspected after 72 hours.

After wound closure, the patient is placed into balanced suspension in 20° of abduction. As soon as the patient can tolerate it, he is placed in a chair. Pendulum exercises in the standing position, thereby eliminating weight bearing forces, are begun on the third day. Patients may occasionally turn into external rotation in bed. This seems to be primarily because neutral or internal rotation causes pain in the buttock over the area of closure of gluteus maximus. This pain rapidly disappears over the first seven days postoperatively. Toe-touch partial weight bearing begins on the fifth to seventh postoperative day and the patient usually progresses to discharge from the hospital on the tenth to fourteenth hospital day—depending on age, initial abnormality and his ability to manage crutches. Partial weight bearing with crutches should be maintained for 12 weeks. We then allow walking with one crutch, and progress to a cane after 16 to 20 weeks.

Case Report

The prosthetic insertion and results are illustrated by the following typical case: Nine years prior to admission, this 60-year-old male fell and suffered a severe contusion of the left hip, with no demonstrable fracture. With rest he obtained pain relief for approximately two years and then began to have pain on all weight bearing. This gradually increased in severity so that he was placed on total disability one year prior to operation.

On examination there was no flexion contracture; flexion was 80°, rotation 10° external, 0° internal, abduction 20°, adduction 15°, with pain at the extremes of motion.

X-rays revealed degenerative changes in the femoral head and acetabulum with progressive cystic formation over a one-year period of observation, thus suggesting acute cartilogenous necrosis as the basis of this disease (Fig 4A).

On 11-25-70 operation was performed (see Fig 4B) and the patient was placed in exercise slings for five days. He was then placed in a chair and begun on ambulation with crutches. He was discharged on the 13th postoperative day walking independently upon crutches with a well healed wound. One month after surgery flexion was 90°, abduction was 60°, adduction was 30°, internal rotation was 10° and external rotation was 60°. There was no flexion contracture. Seven weeks after surgery the patient began walking with full weight bearing on a now painless hip. He was considering a part time job.

Summary

Ring's acetabular prosthesis has been modified as follows:

(a) The total area of the bone-metal interface which transfers mechanical load from metal to bone in the total hip replacement socket has been increased, thereby lowering unit loads on the bone-metal interface.

(b) The geometry of the load-

A Replacement Prosthesis

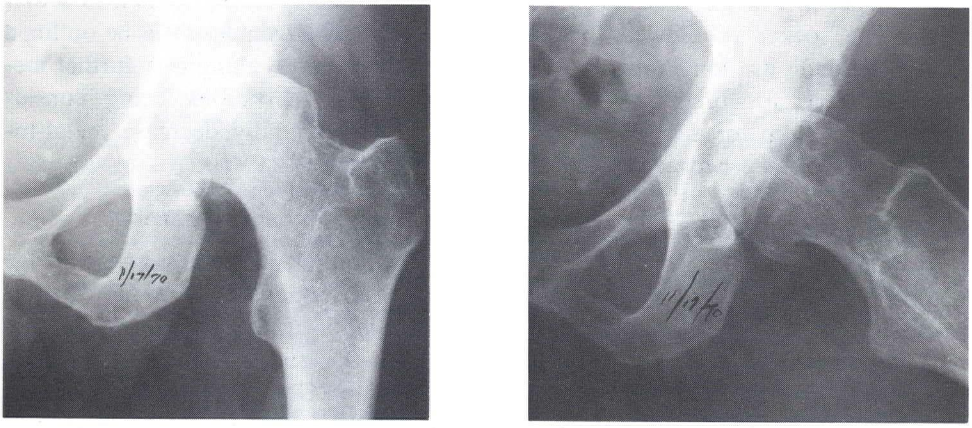

Figure 4A

Pre-operative x-rays of right and left hips.

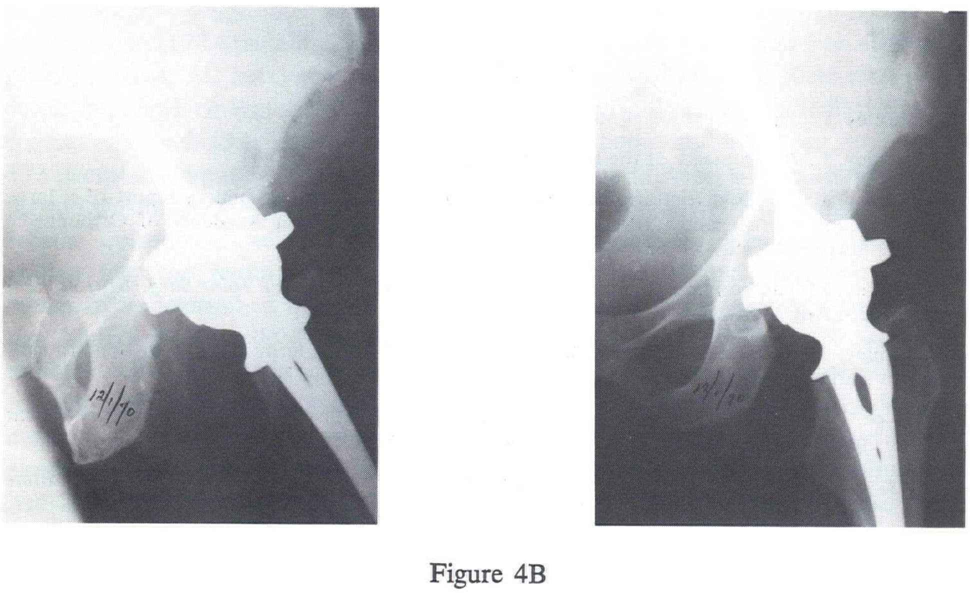

Figure 4B

After total hip replacement.

transfer interface between bone and metal has been redesigned to greatly reduce its lateral bursting effect on the bony socket in which it sits.

(c) The socket is allowed to spin freely around its longitudinal axis, choosing tools for preparing its bed which leave room for a layer of fibrocartilage to develop between it and the bone (Fig 2).

(d) Essentially the sliding motion of a moveable ball in a fixed socket is changed to the *rolling* motion of a moveable ball in a moveable socket (Fig 1B).

We stress that this is an initial report of a prosthetic replacement. The prosthesis is all metal, relatively easy to insert via a slightly modified standard approach and incorporates some mechanical advantages not seen in previous published reports. It increases the cross sectional area of load transfer to bone, and *converts a sliding action to a primarily roller bearing action.* Further mechanical advantages will be outlined in a later report, along with further mechanical modifications being considered to potentially decrease metal-to-metal wear.

Acknowledgment

The authors gratefully acknowledge the contributions of the Howmedica Corporation in the design and production of the prosthesis, and the contributions of Grace L. Schassberger for illustrations in this article. We also wish to express our admiration to our operating room nurse, Miss Dixie Bechtol, for her ability to withstand the authors' vicissitudes.

REFERENCES

1. Charnley, J.: The lubrication of animal joints, *New Scientist* 6, 1959.
2. Charnley, J.: Arthroplasty of the hip, *Lancet* 1:1129-32, 27 May 1961.
3. Charnley, J.: The low friction principle in arthroplasty of the hip joint: a report of a large scope clinical study, (President's guest speaker) American Academy of Orthopaedic Surgery Meeting, 1963.
4. Charnley, J.: The bonding of prostheses to bone by cement, *J Bone Joint Surg (Brit)* 46:518-29, Aug 1964.
5. Charnley, J.; Follacci, F. M.; and Hammond, B. T.: The long term reaction of bone to self-curing acrylic cement, *J Bone Joint Surg (Brit)* 50:822-9, Nov 1968.
6. McKee, G. K., and Watson-Farrar, J.: Replacement of arthritic hips by the McKee-Farrar prosthesis, *J Bone Joint Surg (Brit)* 48:245-59, May 1966.
7. Ring, P. A.: Complete replacement arthoplasty of the hip by the Ring prosthesis, *J Bone Joint Surg (Brit)* 50:720-31, Nov 1968.