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New Ideas in the Design and Function of the Austin Moore Prosthesis

A Non-Spherical More Normally Shaped Head

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Before discussing any new ideas in the re-design of the Austin Moore prosthesis, particularly ideas of providing it with a non-spherical more normally shaped head component, a review of past ideas on which we lean so heavily is very much in order.

A large amount of early credit must go to Smith-Peterson,[1] who in 1923 performed the first mold arthroplasty. The molds were made of glass, and they broke too often. In 1925 Viscaloid, a type of celluloid, was used, but had to be abandoned because of foreign body reaction. Pyrex glass was used in 1933, but this also broke. In 1937, Bakelite was used and finally, in 1938, Vitallium.

In 1940, Moore and Bohlman[2] used a custom-made Vitallium hip and proximal femoral shaft replacement prosthesis on a 46-year-old patient who had had a hip fracture, pin fixation, bone grafting, and finally a resection of a giant cell tumor, including the proximal portion of the femur. The patient survived two and one-half years, dying of heart failure. During that time he had had good use of the prosthesis.

In 1946 Professor Robert Judet of France and his brother, Jean,[3] began using a short stem head replacement made from the acrylic methyl, polymethacrylate. That same year, Loomis[4] used a proximal femoral replacement in a 43-year-old patient who had sustained a shot gun injury. Four years later it was reported that the patient still had excellent use of the prosthesis.

In 1947 McBride[5] used a "door knob" prosthesis with a substantial screw-type fixation into the shaft of the femur. The head portion was a sphere except for a flattened area which was said to prevent pressure on the tender cotyloid notch area and to also create a cushioning pocket to relieve friction. This particular prosthesis is of special interest to me because it represents the only deliberate deviation from a perfectly spherical head that I have discovered in the literature. However, the flattened portion did not involve the weight-bearing area. That portion was spherical. McBride[6] modified the prosthesis the following year to make it substantially one solid piece, and abandoned the flattened area on the head.

In 1951 Lippman[7] began using the transfixion hip prosthesis. The head was free to rotate on a shaft.

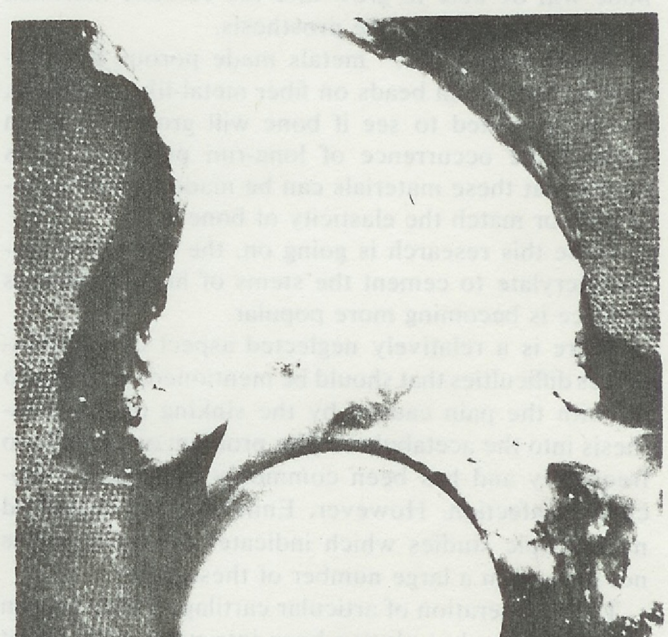

Fig. 1. *A typical fresh specimen of a femoral head with its own acetabulum. Clearly seen is the fibrillated area which occurs in all normal acetabuli just anterior to the superior aspect. Dr. Cathcart calls this area the "dome mark."*

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Extra rings could be used if the neck was short. There was lateral fixation which prevented settling of the prosthesis on the calcar, if not well seated, to begin. Poor seating would cause the calcar to atrophy, which in turn allowed the prosthesis to loosen.

In 1950, Moore[8] had designed and used an intramedullary prosthesis that was somewhat more straightened. This early model had a valgus orientation of the head. In 1951, designs similar to many being used today, began making an appearance. These had the advantage of being self-locking. They tended to settle onto the calcar even when not quite driven home at the time of insertion. It is not recommended to rely on this settling, however.

Many Stem Designs

A host of stem designs have been developed, both because of the problem of stem fixation and because of the failure of previous models. The "I" beam designs are currently popular.

Moore more recently designed the longer straight stem. The 12-inch variety is useful in the event of a proximal femoral shaft fracture, or a fracture of the femur at the tip of the shorter prosthesis. However, it also has its disadvantages. Because of its length, the discrepancy between the coefficient of elasticity of bone and the stem of the prosthesis becomes quite important. The flexible bone bends around the stiff stem, sometimes causing the prosthesis to loosen.

Currently, animal investigations are underway to test the possibility of having the stem, if not the total prosthesis, made of ceramics. The thought is that the bone will be able to grow into the ceramic material, thus helping stabilize the prosthesis.

Sintered materials,[15] metals made porous by compacting tiny metal beads on fiber metal-like materials, are being tested to see if bone will grow into them without the occurrence of long-run problems. It is hoped that these materials can be made to closely resemble or match the elasticity of bone.

While this research is going on, the use of methylmethacrylate to cement the stems of hemiprostheses in place is becoming more popular.

There is a relatively neglected aspect of hip prostheses difficulties that should be mentioned. This has to do with the pain caused by the sinking of the prosthesis into the acetabulum. The problem occurs all too frequently and has been commonly ascribed to subclinical infection. However, Enneking has described microscopic studies which indicates that infection is not present in a large number of these cases.

The regeneration of articular cartilage under certain circumstances has always been intriguing. One might thus hope that regeneration might occur even in the presence of a prosthesis, if certain physiologic principles are respected. An often given reason is revascularization of the head,[17] or a change in the pull of muscles across the joint, thereby relieving large pressures.[9]

Osteotomy procedures will also change the relationship of the two articular surfaces to each other. The changing of the worn shape of one surface in relationship to the other should be considered. I have had patients with fairly advanced degenerative arthritis go into prolonged remissions by walking for a time with their toes turned in and then for a time with their toes turned out, in a sort of bloodless osteotomy.

Walmsley's Law

Thomas Walmsley in 1928 proposed the Law of Incongruence:

- No articular surface is a surface of revolution. That is, the joints are never perfectly spherical, cylindrical, conical, etc. They are always slightly out-of-round.
- No one pair of articulating surfaces is congruent with its fellow except in one position which is characteristic for each joint.

My own investigations indicate the second part of Walmsley's Law is not necessarily so because the elasticity of articulating cartilage allows congruity with motion even though the surfaces are not surfaces of revolution.

I believe there is very good reason why animal joints are not surfaces of revolution and that the reason could well apply to hemi-joint replacement prostheses. Ideally, it seems obvious that all of the physical qualities of cartilage would best be copied in hemi-joint replacement prostheses. From the practical point of view, however, there are limitations to this idea. Materials that are porous and as elastic as cartilage are not as yet within practical reach. However, the shapes of articular cartilages might well be respected.

In the German literature, Aeby[11] in 1863 described the femoral head as not being a sphere. Thomas Walmsley[12] described the shape of the femoral head as having a difference between the greater and lesser radii of curvature of 1.7 mm. The descriptions of the shape of the femoral head in the literature just were not complete enough to serve as a basis for the design of the femoral head replacement.

To that end, I dissected 45 fresh femoral heads in 1967[13,14] at the Stanford University School of Medicine. All specimens were kept moist by speed of dissection, by keeping the head within its own acetabulum most of the time, and by continually moistening the heads with only its own synovial fluids. No specimen was allowed to dry before measurement and particularly no specimen was crenated in formalin before measurement.

I first tried to measure the radii of curvature with various instruments, but found most were useless on the soft articular surfaces. A complex optical comparator method was tried which also failed. Finally, special radius gauges were utilized, which gave reliable results.

Femoral Head Not Spherical

The constant normal gross shape of the femoral head, I found, was nowhere near that of a sphere. The typical specimen, in its superior saggital plane, had a diameter about 1/8-inch greater than its equational diameter. Converted to the metric system, the specimens averaged a difference in diameter of 2.8 mm. That is, the greater radius of curvature exceeded the lesser radius of curvature by about 1.4 mm.

To any engineer dealing with bearing surfaces this is a fantastic deviation from a sphere, even though it may not be obvious to the eye on casual inspection.

In the equatorial plane, the radius of curvature, about 15 degrees anterior to superior, was about .4 mm less than most superiorly. There was thicker cartilage anterior to superior.

Paradoxically, in the saggital plane, at right angles to the equator, and anterior to the superior saggital plane, there was slight flattening. In the saggital section, the articular cartilage on the head is always normally thicker medially. The bony head is usually rounder than the cartilage head.

It has been maintained that the deviations from a sphere are due to the dryness of the specimens. This, I found, was not so. Quite to the contrary, the drier the specimen, the rounder it proved to be. This was especially true of those crenated in formalin. Hammond and Charnley[15] bore this out when they described the femoral head as spherical, and cited measurements of 10 femoral heads to prove it. Eight of the ten had been preserved in formalin.

Out-of-Round Elastic Congruity

Joints tend to seat in a natural position easily in the hip in complete extension, and in some specimens again in a sitting position. However, it should be noted that as the hip is taken through its range of motion, without being put under pressure, there is still some slight misfit. Mild pressure, certainly no more than that present normally, will force the head into a congruous position despite the fact it is not a surface of revolution. This compliance is possible because of the elasticity of the cartilage; hence, I use the term "out-of-round elastic congruity," rather than physical incongruity.

Thus, we now have one of the parameters of the shape of joints.

- They must not be perfect surfaces of revolution.

However, they must also not be so far out-of-round as to exceed the ability of the elastic cartilage to comply and remain congruous throughout the range of motion.

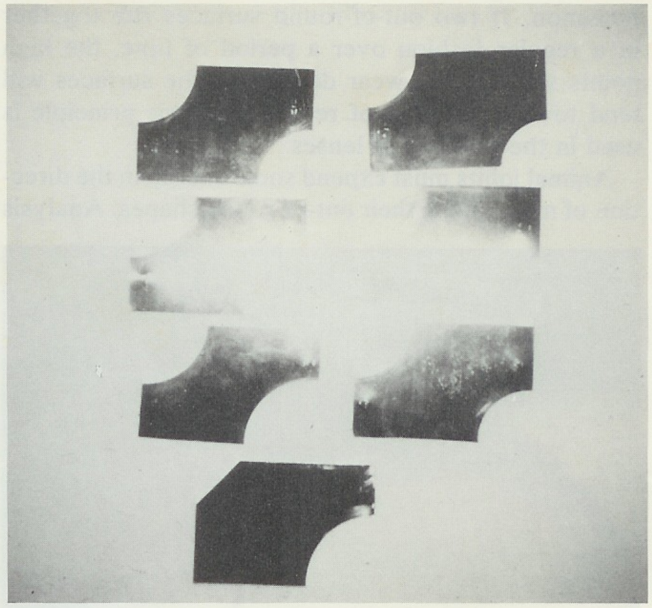


Fig. 2. *These specially designed radius gauges are used to measure and determine the shape of the femoral head. They have provided reliable data showing the head has a constant normal gross shape that is nowhere near being a sphere.*

We are not questioning whether or not the acetabulum can comply to a spherical prosthesis. On the x-ray (Fig. 9) this would result in a picture of cartilage spaces being remarkably equal in thickness despite the fact that medially most of the cartilage is on the head and laterally on the acetabulum.

A favorite theory is that articular cartilage is thickest where there is most intermittent pressure of weight bearing. This theory fits the head but not the acetabulum. This ironical thicker cartilage on the head, matching the thinner cartilage in the acetabulum and vice versa, can be explained by the analysis of the shapes of the femoral head and the acetabulum, and the resulting intermittent pressures from these out-of-round shapes.

Since articular cartilage is a porous substance through which synovial fluid (particularly the smaller molecules) flow, and since the articular cartilage in the adult human derives its nutrition solely from the synovial fluid, then the out-of-round shapes, driving synovial fluid through the porous cartilage, must be critical to the normal nutrition of cartilage. A sphere or other surface of revolution would cause relatively little flow of nutrients through articular cartilage.

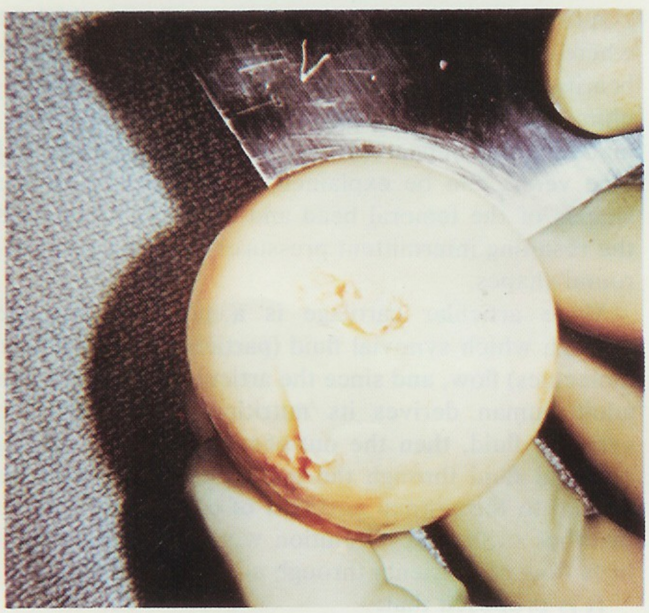
It is proposed that:

- Out-of-round shapes are absolutely necessary for the normal nutrition and function of animal joints—especially in the adult human.

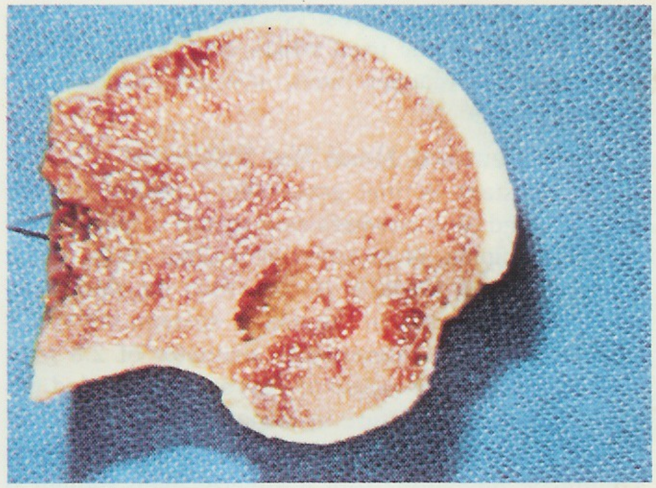
Failure of Perfect Sphere

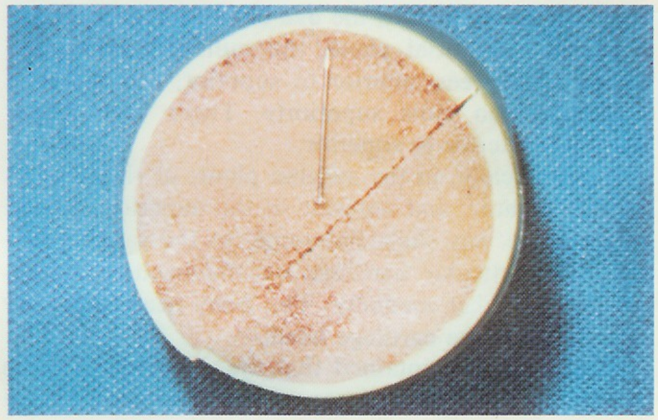
For every physiologic phenomenon in nature there is a disease connected with the failure of that phenomenon. If two out-of-round surfaces rub together in a regular fashion over a period of time, the high points will tend to wear down, and the surfaces will tend toward surfaces of revolution. This principle is used in the grinding of lenses.

Animal joints must expend some energy in the direction of maintaining their out-of-round shapes. Analysis



Figs. 3 & 4. *A typical specimen of a femoral head being measured by a radius gauge. In its superior saggital plane (top) it has a diameter of about two inches as compared to its equational diameter (bottom) of 1-7/8 inches. In the metric system the average difference in diameter of all the normal specimens was 2.8 mm, with the greater radius of curvature exceeding the lesser radius of curvature by about 1.4 mm. Though not obvious to the eye, the deviation from a sphere is obvious when measured with a radius gauge.*





Figs. 5 & 6. *In the saggital section (top), the articular cartilage on the head is normally thicker medially. Note that the bony head is rounder than the cartilage head, laying to rest the notion that the deviations from a sphere found by previous investigators was due to the drying of the specimens. In the equatorial plane (bottom), note the thicker cartilage anterior to superior. To allow the specimen to dry or to crenate the specimen in formalin causes it to be rounder than the fresh specimen.*

of this theory reveals some simple mechanical equilibriums based on function which can explain the thickness of cartilage and the shapes of the articular surfaces. Secondly, the mechanical pressures generated might serve as a control on subchondral enchondral ossification and thereby determine the shape of the bony epiphysis. The relative equality throughout a joint of the cartilage space strongly suggests such an equilibrium. Failure of such physiologic equilibrium would result in degeneration of the articular cartilage. The possibility suggests itself that some degenerative joints in their very early stages, perhaps preclinical stages, would tend toward increasing sphericity. This shape would become increasingly destructive. Alerted to this possibility, we had little trouble finding examples to illustrate this.

Because of the hardness of chrome-cobalt, prostheses made from this material were cast, rather than milled, until about five years ago. Their spheres were poor. Now, they are being milled much in the same way as the stainless steel prosthesis, with more perfect spheres. But it should be noted that the milled stainless steel prosthesis commonly had defects at its seam. What is more, the final buffing, done by hand, introduced many additional flaws in the intended sphere.

It seems most possible to me that the unpredictable results that are obtained with hip prostheses may often be related to this phenomenon. And, I wonder if, with the increasing ability to make the femoral head of the prosthesis a perfect sphere, the clinical result will not deteriorate. Perhaps it is this frustrating phenomenon of the "super sphere" that is driving modern orthopaedic surgeons to consider total hip procedures primarily for sub capital fractures.

A measuring device for the femoral head was suggested in 1969 by Davis and Frymoyer.[16] They claimed that the head of the femur was spherical. Their device had a three-point stationary tripod with a fourth movable central point. Unfortunately such a device when used to measure an imperfect sphere will average the greater and lesser radii of curvature and gave an inaccurate illusion of sphericity.

New Off-Round Prosthesis

Based on these theories, a modified nine-inch, straight-stem Moore prosthesis was designed with the head component being shaped more closely to that of a natural head. For practical purposes, the prosthesis was designed to be used in either the right or left hip. While the head is a surface of revolution about a center axis in line with the neck, it does not function as such because the hip does not rotate solely around that axis.

The modified head of the prosthesis while deviating from a sphere, is slightly less out-of-round than the normal femoral head. This compromise was decided upon because, in the intact joint, both articular surfaces comply during function. However, with the hard metal prosthesis, only the acetabular cartilage is able to comply.

Clinical application of this more normally shaped prosthesis was begun at Mills Memorial Hospital in San Mateo and at Peninsula Hospital in Burlingame, both in California, in September of 1968. Later cases were done at the Palo Alto-Stanford Hospital. A few cases have also been done at the Cleveland Clinic.

Approximately 95 of these out-of-round normally shaped prostheses have been inserted to date. The results, although not perfect in all cases, appear to be unusually good. There have been the usual medical complications in the elderly patient. Certainly none of our surgeons are considering primary total hips for sub capital fractures. During the same period two Moore prostheses, done by "hold out" surgeons in the community for sub capital fractures, have already had to be redone with total hip replacements.

The typical appearance of the acetabular cartilage following the insertion of the more normally shaped prosthesis in fracture cases can be seen in Fig. 17. The cartilage is thicker laterally than medially. Typically so far with several years of follow-up, there has been no change in the x-ray pictures.

I had intended to use the new prosthesis in only fracture cases. However, braver more senior orthopods such as Gene Bleck and Ned Froning used the prosthesis in cases of avascular necrosis and rheumatoid arthritis. These patients have done remarkably well with no further narrowing of acetabular cartilage.

Several Cases

The x-ray in Fig. 18 is that of a bilateral case by Gene Bruce. What makes it so interesting is that bilateral avascular necrosis usually does quite poorly with a Moore prosthesis. One would expect that an advanced case such as this would deteriorate early. Yet, this case and many others like it, have done exceptionally well with the new out-of-round prosthesis. The patient, a taxi driver, claims he has no pain and that his gait is totally normal. His cartilage spaces were narrow to begin with, and they have not changed at all despite considerable activity.

Another is that of a 65-year-old woman who had very early prosthesis of the left hip before her fracture. During the first postoperative year, there may have been 1 mm more sink than usual, associated with some pain. However, there has been no sinkage since. She complains only of pain with the first few steps following long rest periods.

◀ **Fig. 7.** *This acetabulum was sectioned in this plane so as to permit a view of the articulating surfaces from the inside out. Note the "dome mark," the fibrillated area which occurs anterior to the superior aspect in all normal acetabuli.*

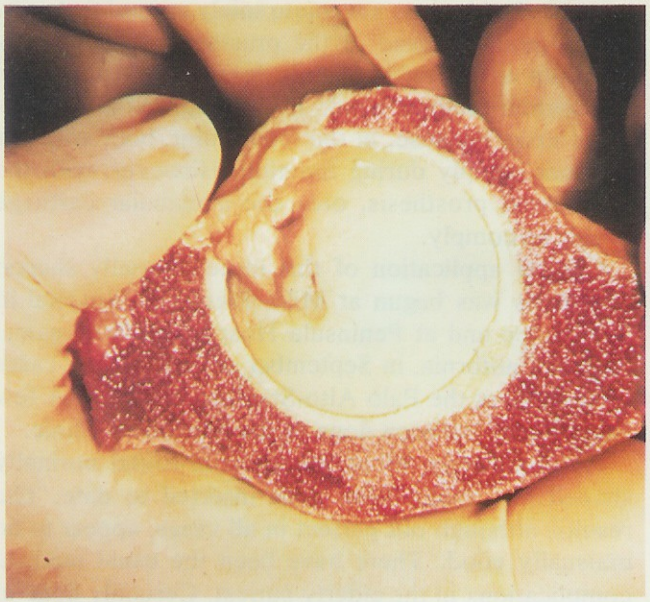


Fig. 8. *There is a slight misfit as the hip is taken through its range of motion without any pressure being applied. Mild normal pressure will force the head into a congruous position, despite the fact it is not a surface of revolution, because of the elasticity of the articular cartilage.*

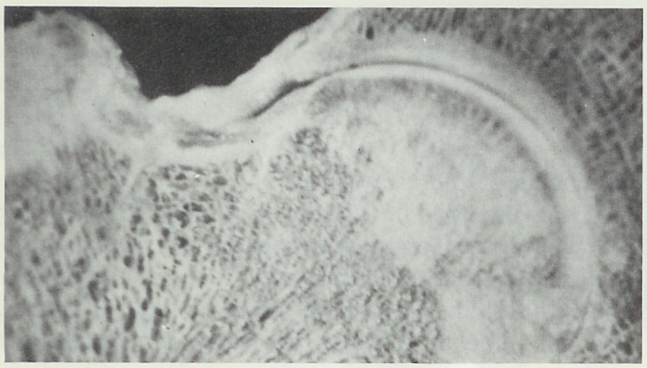
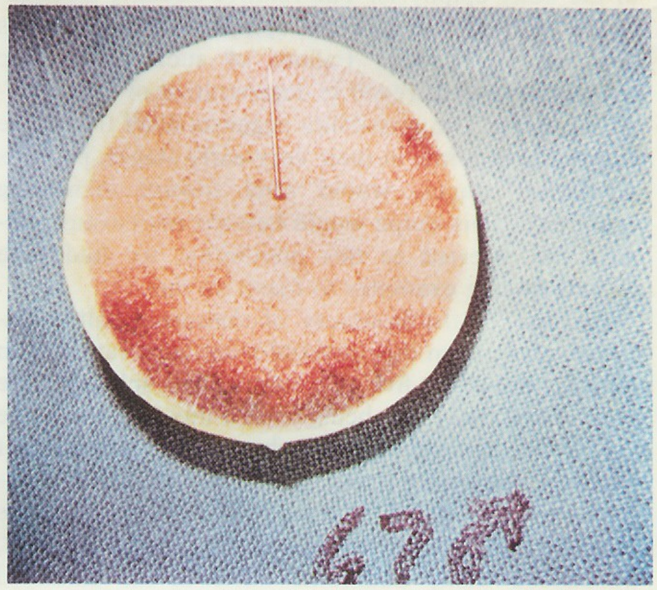
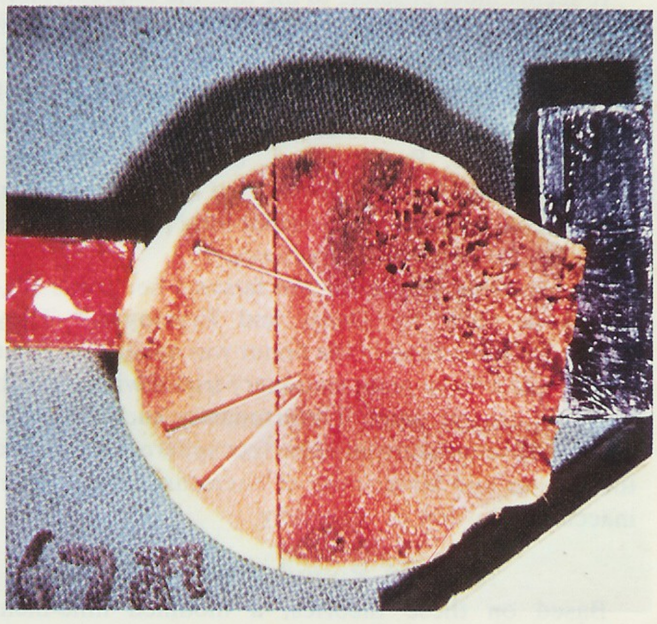


Fig. 9. *In this x-ray, cartilage spaces are remarkably equal in thickness despite the fact that medially most of the cartilage is on the head and laterally on the acetabulum. The theory that maximum weight-bearing areas would have the thickest cartilage fits only the head.*

The only case reamed is that of a 63-year-old, 240-pound man who had had a congenitally dislocated hip. He also had a degenerative knee on the same side. Because of the post-operative complication of dislocation, a reaming was done to deepen the acetabulum. A varus osteotomy was also performed on the knee.





Figs. 11 & 12. *Failure of physiologic equilibrium results in the degeneration of the articular cartilage. Some degenerative joints in their early stages tend toward increasing sphericity, thus adding to the destructive process. The articular cartilage in the equatorial section (top) is a little more equal in thickness than normal. Note high points are wearing down. The same specimen (bottom) in the saggital section.*

◀ **Fig. 10.** *Synovial fluid must flow through porous articular cartilage to nurture it. The out-of-round shapes of the articular surfaces cause a pumping of fluids through the porous matrix of the cartilage.*

Following reaming, there was a total absence of cartilage space. Six months later, a thin halo of fibrous cartilage was evident. Over a two-year period, there was no sinkage. However, the patient experienced sufficient pain to warrant a total hip replacement. It was the only one done or even threatened in this series. At surgery, a thick fibro-cartilage layer was found in the acetabulum. The stem had a minute wobble in the shaft of the femur. The insertion of cement in the femur reproduced the pain complained of previously, the pain being in the anterior thigh, not in the groin.

Figs. 13 & 14. *This femoral head specimen is from a 70-year-old woman whose right hip had been mildly painful for about 10 years and whose left had been more painful for about three. The woman had fallen, fracturing one of her hips. Using the gauge, it was found that the specimen was rounder than any normal specimen, and that, in each plane, it was also grossly spherical, thus bearing out the theory that some early degenerative joints increase in sphericity.*

Figs. 15 & 16. *Made of Vitallium, the femoral head of this prosthesis has been buffed into a smooth high brilliance, giving the illusion of being a perfect sphere. Actually, the head is not spherical at all, because of previous practical limitations on the manufacture of a spherical head. Measured by the gauge (left) it is 1-7/8 inches in diameter at the tip. Measured at the equator (right), diameter is two inches by coincidence similar to normal head. Flattening is obvious.*

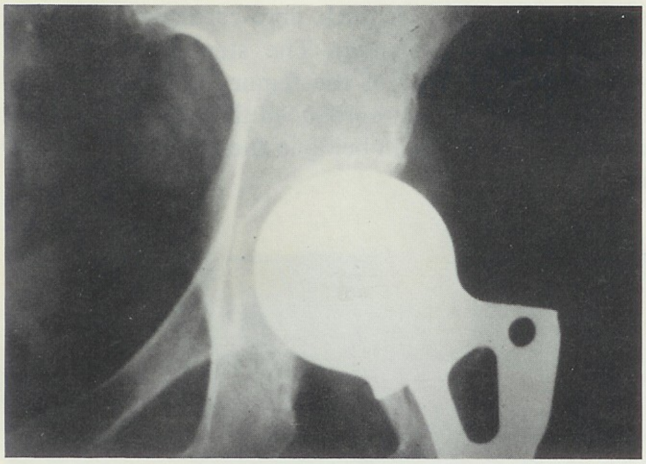


Fig. 17. *X-ray shows the typical appearance of the acetabular cartilage in a fracture case following insertion of the off-the-round, more normally shaped, prosthetic head. Note that the cartilage is thicker laterally than medially.*

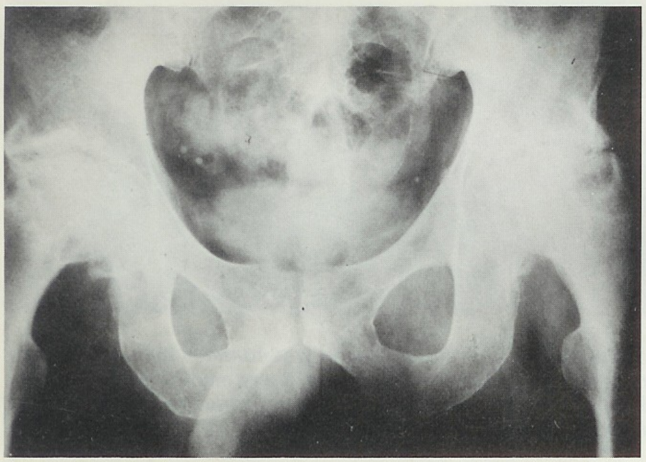


Fig. 18. *An advanced case of bilateral avascular necrosis that usually does poorly with a Moore prosthesis and which usually deteriorates early. Yet, it did exceptionally well with Dr. Cathcart's out-of-round prosthesis.*

There have been two other cases with anterior thigh pain with prolonged weight bearing. One almost perfect result had anterior thigh pain following a fall, but after six weeks on crutches, there was no more pain.

A new series is about to be started utilizing cement and a re-designed Mueller stem. The re-designed nine-inch, straight "I" beam Moore stem, with its more normally shaped femoral head replacement prosthesis, is now readily available. So is the re-designed Mueller stem. (Manufactured by De Puy as The Cathcart Orthocentric Hip Prosthesis.)

Summary

Forty-five femoral heads were dissected and found to have a typical non-spherical shape. A modified Moore prosthesis with a non-spherical normally shaped head was designed. Clinical results have been very encouraging. There has been no unexplained sinkage of the prosthesis into the acetabulum.

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