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Rev iew of the methods for determining the viability of the femoral head following femoral neck fractures

Robert R. Taylor
University of Nebraska Medical Center

A REVIEW OF THE METHODS FOR DETERMINING THE VIABILITY OF THE FEMORAL HEAD FOLLOWING FEMORAL NECK FRACTURES

ROBERT R. TAYLOR

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INTRODUCTION

A fracture of the femoral neck of the femur has often been called the "unsolved fracture". It has earned this name because of the high incidence of avascular necrosis in the head of the femur as a complication. Almost every series reported shows that avascular necrosis develops in about 20 to 30 per cent of the cases. However, in every large series that is followed long enough, the incidence approaches 40 per cent. This figure holds true no matter what type of treatment is used. Of these 20 to 40 per cent who will develop avascular necrosis, at least 50 per cent of these have enough pain and discomfort to warrant further surgical treatment.

The American Academy of Orthopedic Surgeons lists the mortality following this type of fracture at 8.5 per cent. The rate after primary orthoplasties is reported as 14.9 percent to 17.7 per cent. The rates after a secondary procedure are not available but would understandably be higher. A single primary procedure would save these patients at least six months of waiting and another 20% mortality or more if a second procedure is needed.

It has long been recognized that the mechanical problem of maintaining secure fixation is only a small part of the problem. The main problem is the status of the circulation within the femoral head.

The basic question is then how is the surgeon going to determine whether the broken hip is going to heal and

be useful or whether the necrotic femoral head collapses and results in a painful, useless hip. If the surgeon had some way of knowing the answer to this question, he could modify his operation and procedure and decrease the incidence of pain disability and future reconstructive procedures.

Surgeons have considered this basic problem for over 150 years. Unfortunately, we still do not have the answer. This paper reviews the methods various surgeons have attempted since 1949 to determine the viability of the femoral head at the time of operation for a femoral neck fracture.

RADIOACTIVE PHOSPHORUS

This method clearly illustrates the problems inherent in attempting to determine the viability of the femoral head. Tucker [12] was the first to study this method. He published articles in 1949 and 1950. Boyd, Calandruccio and Zilversmit [13,16,17] have been studying this method since 1951. Arden and Veall [8] used Tucker's procedure until 1953 and then devised their own modification. Block reported on a small series in 1962 and modified Veall's probe counter. All of the above authors obtained similar results. Each author's variation will be discussed along with his results.

Tucker was the first to report on the use of radiophosphorus in 1950. The basis of the test is that when radioactive phosphorus is given I.V. it is distributed in the bone. It is known that the trochanter has a normal blood supply following a fracture of the femoral neck. If the head of the femur is avascular, it should not emit any beta radiation from the radioactive phosphorus. Thus, a ratio is formed between the amount of beta radiation emitted from the trochanter as compared to the femoral head.

They all chose radioactive phosphorus for the following reasons: 1) It is a pure beta ray emitter. 2) It has a half life of fourteen and one-half days. 3) It is a moderate bone seeker. 4) It does not cause depression of the haemopoietic centers or injury to the cellular elements of the blood. 5) In the necessary dose it gives less than two roentgens of body irradiation.

Tucker removed a piece of bone from the head of the femur and from the greater trochanter during the nailing procedure. The fragments were then assayed for radioactive content.

The gross disadvantages of this method were as follows: 1) It was a time consuming procedure. 2) There was the risk of further impairing the blood supply and bone strength by removing a sample of bone. 3) The results were not available at the time of surgery.

However, his results were similar to those of the other authors discussed below.

Arden and Veall followed the same procedure until 1953. Since 1953 direct readings have been taken at the time of operation with a needle counter designed by Veall. The needle counter has a thin probe fifteen centimeters long with a diameter of three millimeters. The sensitive eye is located six millimeters up and is twelve millimeters long. The needle counters are fragile and last only about three to six months. A sterilizable lead connects the enclosed base of the needle counter to a clinical monitor. This apparatus automatically counts the number of beta rays picked up by the needle counter in thirty seconds. The needle counter and lead can be sterilized in hot formaldehyde vapor.

They gave 200 microcuries of P_{32} intravenously in a sterile solution of sodium phosphate. They then inserted the guide wire in the usual manner. The Harris drill was inserted along a suitable guide wire and both were then removed. The probe was then passed into the head of the femur along this channel and its position was checked by radiographs. The site was usually along the center of the

head. A reading was taken here and along the trochanteric region of the drill hole. Three readings were taken to obtain an average. After twenty cases, they found that washing out the canal with saline after each reading did not change the reading. So they discontinued the saline rinse between.

They started with one hundred cases. They dropped fifteen because of technical faults. They dropped seventeen others because of unreliable readings. Seven patients died leaving sixty-one. Of these, forty patients had displaced fractures of the neck of the femur and twenty-one had intertrochanteric fractures. The period of observation was not less than two years.

The seventeen cases that were omitted had marked discrepancies in one of the three readings so that there must have been some technical fault in the apparatus. The fifteen other cases that were omitted were for faults in the counter, false readings from the cable, faults in the clinical monitor and electrical disturbances from the main supply. All the trochanteric fractures united with ratios below two point five between the trochanter and the head.

Forty patients had femoral neck fractures. Of the twenty-eight with a normal P_{32} ratio, two developed avascular necrosis and three went on to non-union. Of these five that did not correlate, three had trouble with fixation or reduction. The other two had good reduction and fixation.

Four patients had borderline ratios with three avascular

necrosis and one non-union.

Eight had abnormal ratios. Of these one united, three developed avascular necrosis and four went to non-union.

They had an eighty-two per cent correlation between a low ratio and a good clinical result. It must not be overlooked that one united with an abnormal count and five who should have done well did not.

This figure of eighty-two per cent correlation is a bit misleading at this point. When Block's analysis of his figures is presented, it will be seen that the correlation is not this high.

Boyd, Calandruccio and Zilversmit first reported on this method in 1951. They found in their dog experiments that two microcuries of radioactive phosphorus per pound of body weight would produce a measurable amount of radioactivity in the femoral head and trochanteric region. They also found that there was a rapid rise of radioactivity in the first thirty minutes. A plateau was established after sixty minutes. The uptake after sixty minutes was small. Even if the blood supply to the head were damaged, a plateau was still reached in the head in about the same time, but the ratio was altered by the P_{32} reading in the head being diminished. Thus, they gave their patients 250 microcuries of a buffered solution of P_{32} and the counts were recorded one hour or more after intravenous injection of the solution.

They obtained their rates in vivo with a Geiger-Muller tube sensitive to beta radiation that was designed by

Robinson for localization of brain tumors. The probe is the same diameter as a Smith-Peterson nail and about nine centimeters long. A thirteen millimeter segment five millimeters up from the tip is sensitive to radiation. This tube was connected by a coaxial cable to a preamplifier and rate meter. This enabled the radioactive uptake to be measured in the operating room in the trochanteric region and head. They sterilized the probe and covered the cord with a sleeve. They did not have any wound infections.

The probe was always calibrated with a standard source. They grounded the rate meter and cautioned against using it when X-rays were being taken or when cautery was being used.

Their procedure involved inserting one guide wire into the superior weight bearing part of the head to be replaced by the probe and the other to be used for the Smith-Peterson nail. AP and lateral X-rays were then taken to determine the position of the guide wires. If the one was not in the superior weight bearing portion, it had to be reinserted since this is the critical area.

The probe then replaced the wire in the superior portion of the head. The uptake of P_{32} in the weight bearing portion of the head was then recorded and the probe withdrawn so that three centimeters of it remained in the trochanteric region. The uptake was recorded there for comparison. The trochanter to head ratio was then calculated by dividing the counts per minute in the trochanter by the counts per minute in the head. The trochanter to head ratio was thus an expression of the uptake of the head in comparison with the uptake of a segment

of bone with an unimpaired blood supply.

Before proceeding to clinical trials, they tested their method on dogs. They found that if the circulation to the femoral head was interrupted there was no uptake of P_{32} in the avascular portion by diffusion through the interstitial tissue.

They then studied normal dogs and found a normal ratio of 0.8 to 2.3. When the circulation was partially impaired the ratios rose rapidly to as high as 32.

Their patients were from the Campbell Clinic over an eight year period. They were all done at the same hospital. The patients were consecutive unless the surgeon objected at the time, or the patient's condition would not permit the extra time.

They collected data from 298 patients and reported on 130 of these that were followed for two years or more. Sixty-seven of these had impacted fractures and 231 had displaced fractures. The incidence of avascular necrosis was higher in the displaced fractures and they were analyzed separately. I am not including the results of the impacted fractures.

They had a control of fourteen patients with trochanteric fractures with ratios of 0.7 to 3.7. None of these developed avascular necrosis.

PRESENT STATUS OF PATIENTS WITH DISPLACED FRACTURES OF THE FEMORAL NECK

Avascular necrosis (7 non-union)	49
No avascular necrosis after two years or more	46
More than two years since operation but less than two year follow-up	20

Less than two years since operation	73
Died before diagnosis was established	31
Non-union	7
	231

Summary of correlation of Trochanter Head Ratio and Clinical and Result in 95 patients followed for two years or more after operation:

Range of Trochanter Head Ratio	No Avascular Necrosis	Avascular Necrosis	Total
0.4 - 2.9	26	5	31
3.0 - 5.9	13	18	31
6.0 or more	7	26	33
	46	49	95

From these charts, it is evident that a ratio of less than 3.0 or more than 6.0 is of prognostic value. Thus 64 of the above 95 ratios would have prognostic value. But those with ratios between 3.0 and 5.9 would be of no value.

By going to the ratio of 4.0, they found 43 patients below the figure but 10 went on to avascular necrosis. This is about a 75 per cent correlation with the ratio. Fifty-two patients had a ratio of 4.0 or higher. Avascular necrosis developed in thirty-nine of these and thirteen did well. This is again about a 75 per cent correlation.

They found that if the patients with ratios of less than 3.0 or greater than 6.0 were taken as correct the total error as to whether the hip should be pinned or a prosthesis inserted would be only ten per cent. However, as Block points out in his article, the ninety per cent rate of prediction is misleading.

Block also studied radioactive phosphorus and made

some interesting comparisons with his small series. He used 200 microcuries of radioactive P as orthophosphate. His technique was the same. He also did a control study on trochanteric fractures.

The six in the control series all united and had a ratio of 1.9 except for one with a ratio of 9.0 which was thrown out. They all united. They followed up the one that was way out of line and it healed normally.

They did a second control series on four control subjects in whom the femoral head was definitely avascular and necrotic. They took readings with the needle counter at the time the psoas release was performed and the avascular head removed. Veal and Vetter state these readings should be greater than 5. The readings were 5, 2, 1.7, and 6.

Results of Six Cases of Transcervical Fractures

Case Number	Ratio of Trochanter to Femoral Head	Fate of Fracture	Isotope Results
I	2.5	United	+
II	14.5	Avascular	+
III	11.3	United	-
IV	1.1	United	+
V	0.7	United but patchy necrosis	-
VI	0.5	United	+

Five cases were abandoned because of faulty function of the equipment. The problem was the fragility of the needle counter. The slight deformation which sometimes occurred on its insertation into the drill hole was sufficient to

cause either continuous arching or alternately complete lack of response of the counter.

In these 21 cases, they had to abandon five due to the faulty operation of equipment. This agrees roughly with the 40 per cent of cases Arden had to abandon due to faulty equipment. Arden had an error rate of 20 per cent. The one case here in error would be about 17 per cent. Their small control series of known avascular heads was misleading in two out of four cases. When they grouped the two small control groups together, they found they had three misleading readings out of ten known cases. Thus, this 30 per cent rate is almost equal to the error rate found in the series of patients with fractured femoral necks which was 33 per cent.

Boyd and Calandruccio reported error rates of only ± 10 per cent in 1960. However, a more careful analysis will reveal that this is a bit misleading. They investigated and followed 100 patients for two years or longer. They report that if the ratio of the trochanteric reading to the head reading is six or higher, then approximately 90 per cent of the patients will develop avascular necrosis. Similarly, if the ratio is three or less, 90 percent of the patients will have a living head. However, patients lying between three and six are unaccounted for. Block found that 40 per cent of their cases had a ratio between three and eight. If their patients were divided into classes, those with ratios above five and those with ratios below five, it is found that their error then becomes

greater than 10 per cent. This would be more in agreement with the figures of Arden and also of Block.

Thus there is fair agreement between Arden, Boyd and Calandruccio and Block. Block had a small series but it agreed with the larger series. Block believes that the method, the way it is now practiced, gives results which are too uncertain to justify its general adoption.

One of the major problems hindering this method is the fragility of the probe counter. Block designed a small scintillation counter with a flexible light guide. The new counter is stronger and should hold up better. He believes that it will give greater reproducibility than the needle counter. He is now using this new probe counter and will report on it at a later date.

Boyd and associates found that the radiation measured was from an area of 3 millimeters. This is one of the main disadvantages of their method. Bone rapidly filters out beta radiation and the probe is unsensitive to radiation more than 3 millimeters away. Therefore, it measures only a very small area. Boyd did extensive work with autoradiograms on femoral heads removed at the time of surgery. He demonstrated the segmental necrosis that often existed in these specimens. However, this is also a problem in many other methods. Any one area may not be representative of the entire head since the isotope uptake in the head may be irregular.

Another big factor that should not be overlooked is the venous damage. This point was made by Dr. Ian Macnole of Toronto, Canada. The arterial supply may not have been

significantly damaged and the head may receive radioactive phosphorus. However, if the venous drainage is obstructed, it leads to death of the bone. Perhaps someone should try combining radioactive uptake studies and phlebography of the hip.

It is known that soft tissue absorbs much more P_{32} than does bone. Many agree that it is a measure of the uptake of the soft tissue.

At present in the literature, this method has received the most studies and clinical trial. There is also a difference of opinion on the actual mechanism of absorption. Laing [24] studied the uptake of radioactive phosphorus in rabbit bones. He stated that it does not give an indication of the availability of the radiophosphorus to the bone crystals and that with time the radiophosphorus may reach the area by diffusion. Boyd disagrees with this and stated that diffusion was not a factor in his experiment. Laing found in his studies that the vascularity of the normal femur was minimal in the cortical bone of midshaft and increased markedly at both metaphysis falling significantly at both epiphyses. Therefore, areas such as the femoral head with its large area of cancellous bone may be particularly difficult to evaluate correctly. Woodhouse also throws in the following comment: "The studies may represent a difference in the physiochemical or metabolic activity of epiphyseal and metaphyseal bone. The uptake of P_{32} may be influenced by this method."

Some authors feel that contamination of the probe by blood may give a falsely high reading. But authors as Veal

did not find any difference in their results when they rinsed with saline to keep the probe clean of blood while it was recording.

Laing also noted that bone marrow will absorb more P^{32} and that this may cause some variation between two specimens.

The fact still remains that the necessary equipment to do this at the time of operation is expensive. It is going to prolong the time of the operation and make it more difficult since it requires an extra guide wire. There are many possibilities of error in technique or malfunction of equipment. Therefore, I do not believe it is applicable at the time to be used by the orthopedic surgeon doing surgery on the average clinical case.

However, since there is alot of interest in the method, the procedure may be so modified as to be applied at the clinical level in the future.

ARTERIOGRAPHY

Rook [19] and McGinnis [18] studied arteriography as a possible method of solving this problem. McGinnis started studying normal anatomy in 1949 but did not publish his work until 1958. Rook published his article in 1953. They are the only two surgeons who have studied the actual status of the arterial supply. They both demonstrated that it is an easy and safe method that is not detrimental to the elderly patient's progress. However, they both had small series and could not draw any definite conclusions or statistical evidence to support their views.

Rook made an extensive study and review of the vascular anatomy of the normal hip. From this, he made composite diagrams as a standard to compare with other arteriograms. He wanted to know whether a defective vascular pattern would heal as well as one in which the vessels appeared normal.

He injected 20 cubic centimeters of 35 per cent diodrast into the common femoral artery by direct arterial puncture just below the level of the inguinal ligament. He used a pneumatic tourniquet with a pressure of 12 pounds around the thigh. He took one film after all but 2 cubic centimeters had been injected under pressure.

This was done post-operatively so as not to interfere with the nailing procedure. The arteriogram did not cause any post-operative complications.

He studied twelve patients. Two were discarded with poor arteriograms. Two had an excellent supply and united

well. Four had a definitely inadequate supply. Of these, there was one non-union and one avascular necrosis. The others had a limited supply but proceeded to union.

His conclusions, which he feels would be supported by a larger study, are as follows: 1) If the individual shows an anatomically poor vascular pattern, the healing is likely to be poor. 2) The medial femoral circumflex was absent in patients who did poorly. 3) They were not able to demonstrate the entire vascular supply but that if certain known segments, as the medial circumflex, can be shown to be deficient, other units as the finer capsular arteries are equally disturbed or deficient.

McGinnis and associates approached the problem by comparing the vascular pattern of the fractured hip with that of the opposite normal hip. The only other investigator to compare the two hips was Mussbichler who studied a variety of normal and pathological hips. McGinnis injected dyodine and took serial X-rays. He noted that the posterior collum branch which arises from the medial circumflex was found to be consistently filled on the normal side.

He also found in their studies that the posterior collum artery was quite important to them. They found that they were primarily dependent upon visualization of the posterior collum branch and the general vascularity of the hip in making a statement regarding the status of the circulation.

Their procedure consisted on injecting 50 cubic centimeters of myokon into the femoral artery by a direct puncture.

They did not use a tourniquet and took one film after the first 15 cubic centimeters. It took five seconds to inject all the dye. They did not have any untoward reactions.

They studied twelve cases of sustained displaced intercapsular fractures of the femoral neck. All had closed reduction and internal fixation with a Smith Pederson nail.

Of the twelve cases, they were able to follow nine of them. Eight of these cases showed evidence of decreased flow to the posterior collum branch. One of these obtained union without complication. The other seven all had complications of either aseptic necrosis, non-union or both.

The only conclusion that Rook could draw from this small series was that when the circulation appears equal to or greater than the uninjured hip, the chances are better for union and a viable head.

The technic and arterial pattern have been fairly well established. McGinnis suggests that now a larger and more controlled series would be of some value. The series should be done with bilateral pre-operatively and post-operatively arteriograms with anterior, posterior and lateral views.

Hulth states that the main problem is that those vessels which are of interest, the foveal and the retinacular branches, are so small that it is not easy to distinguish them.

For the time involved in technique, I do not believe that arteriography would give as much information as the other methods. This method has not been reported on by anyone else and will probably not be considered in the future.

FEMORAL HEAD PHLEBOGRAPHY

Arteriography did not prove to be very satisfactory. In 1956, Anders Hulth [9,10] published his work on phlebography. This work was done in Sweden and was done routinely on all patients with femoral neck fractures. Dahlgren [11] did a small series in 1959. His methods and results were the same as Hulth's.

The basis for this method is that a contrast media injected into cancellous bone of the femoral head immediately fills the veins. It has been concluded from studies on normal femoral heads that femoral heads with a good vein pattern also have corresponding arteries. The veins are more friable than the arteries. If the veins are intact the arterial supply should also be intact. Since the veins are more fragile than the arteries, part of the avascular necrosis is possibly due to vein damage. They felt that this method should be more definite than arteriography because it would show more vessel damage if present. It also has the advantage over arteriography in that the small retinacular vessels can be visualized whereas they cannot with arteriography.

The stainless steel cannula that is used in this method is 10 centimeters long with an obturator that is slightly longer. One end of the cannula has threads on it and inserts into a handle for insertion and withdrawal into the femoral head.

The venographic examination is done at the time of surgery which is delayed three days following the fracture

to give the vessels time to thrombose so the contrast media will not leak out.

The fracture is then reduced and the cannula inserted into the trochanteric head under roentgenographic control. It is then hammered a calculated distance into the head. The cannula is placed at least two centimeters into the head. The cannula is nearly at right angles to the lateral surface of the femur. It cannot be placed in more than one place or the contrast media will leak out. Two milliliters of umbradil is then injected at the rate of one milliliter every four seconds. An anterior-posterior is taken two minutes later. Two milliliters of saline is then injected to wash out the remaining contrast fluid.

In his earlier studies, Hulth found some damage at the site of injection. However, he went from six milliliters to two milliliters since the possibility existed that a large quantity of hypertonic contrast solution in cancellous bone tissue already in a state of stasis might be damaging. The smaller dose did not give the appearance of loading on the film and it was enough to get a good examination. He also found that this minimal damage was cut still further by the use of the saline to dilute and flush out the contrast media.

In a positive venogram, the veins of the head fill instantaneously. In circumflex venograms, the veins of the external iliac system fill from the head which are the retinacular, medial femoral circumflex, femoral and external iliac veins. In ligamentum teres venograms the internal

iliac veins fill which are the foveal vein in the ligamentum teres, the acetabular, obturator and internal iliac veins. In some cases both may be filled at the same time. In negative venograms there are no veins visible and the contrast medium has flowed out into the fracture or remained in the cancellous bone of the head. With proper placement of the cannula this would indicate avascularity. Technical failures due to false positive and false negative venograms are still a problem. His first small series consisted of seventeen cases. In some, the retinacular veins would not fill or the media would cross the fracture lines and not fill the typical pattern. These were read as false positive. The false negatives were those cases when the cannula was not placed correctly. Either the cannula was not far enough into the head, it had to be replaced in the head, or the joint cartilage was perforated. In all these instances, the injected contrast media had no opportunity to come into contact with veins that might have been intact; instead it leaked out into the joint or fracture.

In a later series, he had twelve trochanteric fractures all with positive venograms and no complications. There were sixteen cases of non-displaced valgus fractures and only two had negative venograms. His main interest was with eighty-two patients with displaced neck or varus fractures. Fifty-two had positive venograms. Nineteen cases were circumflex type and thirty-three were ligamentum teres type. Thirteen had negative venograms.

He found the ligamentum teres type more common in the

older patient. He also found that with the displaced fractures, the superior retinacular veins were usually not visible. This is to be expected since they are more liable to damage than the inferior retinacular vessels in this type of fracture.

He followed forty-three patients for at least one year. Thirty-one had positive venograms and twelve had negative venograms. Of the thirty-one positive, there were ten cases of avascular necrosis. All twelve patients with negative venograms showed early signs of avascular necrosis. Of the twelve patients, pseudorarthrosis developed in five, distal resorption of the head with mushroom appearance in four, and the nail ploughed out through the head of the femur in two. One patient had a collapse of the superior contour of the head.

The avascular manifestations of the ten patients with avascular findings out of the thirty-one positive venograms had a different appearance since they represent only a relative insufficiency of the blood supply. This was probably due to damage to the superior retinacular vessels. The fracture usually healed but secondary collapse of the superior portion of the head was common since the remaining vessel supply from the inferior retinacular vessels was inadequate to supply the entire fragment, especially the most superior part of the head. Six of the ten had a collapse of the superior part of the head. There was one non-union, one pseudoarthrosis and one case of the nail ploughing out the side. The other twenty-one patients progressed without trouble.

Laing feels that any material which is injected into the femoral head in a quantity of two milliliters might find its way out along the veins even if the arterial supply was cut off. He also feels that one cannot get anywhere near a quantitative result.

Woodhause criticizes it mainly on the basis that one must wait at least three days to avoid leakage at the site of the fracture. Dahlgren's series supports this. His study used the same techniques as Hulth and got the same results when he did the operation three days after the fracture. However, he found that the contrast material leaked out in a significant number of cases if done on the first day following the fracture. Woodhouse also points out the disadvantage that the cannula can be inserted only once and that it must fit tightly into the femoral head to prevent leakage. He could certainly avoid this last problem by having a threaded cannula that would follow a pre-drilled hole and give a water tight seal similar to the one developed by Laing for his Na_{24} studies.

Hulth recognizes that in all forms of arteriography, many of the pictures obtained are difficult to interpret. These were found usually in the negative venographies where due to poor cannula placement, it could not be determined whether or not avascularity existed.

Some authors have felt that injecting the contrast media would increase the damage to the femoral head. However, I believe that he proved in his series that the injection into the femoral head does not increase the damage.

Harrison believes his false positives could be explained by the work of Trueta. Trueta demonstrated that cessation of the circulation is not followed by dissolution or occlusion of the vessels for three days after death; therefore, it may be possible to demonstrate venous pathways leaving the head hours or days after arterial occlusion.

Dahlgren points out that the technique of venography is not particularly easy and that a certain amount of experience is required before one can insert the cannula in an ideal position. He also points out that the procedure should not lengthen the operating time by more than fifteen minutes.

Some of the cases were followed for only a year. This is not long enough to pick up some of the late manifestations of collapse that some of the other authors report. Hulth and Dahlgren feel that an early definitive diagnosis of avascular necrosis can be made in 50 per cent of the cases. This percentage is not as high as the other methods.

I do not feel that this method will gain general use. The disadvantages such as having to wait three days before operating and complicating the operation with phlebography would offset the 50 per cent chance of predicting avascular necrosis.

MEASUREMENT OF INTRAMEDULLARY PRESSURE

The next method to be considered was the measurement of the intramedullary pressure within the femoral head. Miles [20] did a small series in 1955 and reported on it. He studied thirty patients consisting of femoral neck and intertrochanteric fractures by simply introducing the needle into the femoral head and then connecting it to either spinal fluid manometers or other special types of monometers.

He noted wide variation of pressure within the femoral head with some being as high as 50 centimeters of saline. However, the pressure was not as important as the fluctuation of the pressure which corresponded exactly to the arterial pulse pressure and rate. The pressure and fluctuations were not affected by different anesthesia utilized.

He was able to follow some of these long enough so that he felt he could correlate the findings. Several patients were followed with active fluctuation who had X-rays showing a viable head. He also had several patients who did not have any fluctuation in the intramedullary pressure and these developed avascular necrosis.

It is stated that this method is still being studied. I have not found any follow-up results on this.

Several things would be in favor of this method. The expense of the equipment and the chance for a technical failure due to elaborate equipment would be minimized. It probably would not prolong significantly the length of the operation if a suitable technique for placing the needle could be established. False negatives due to a bone

spicule plugging the needle might be a problem.

The needle might have to be placed in the superior portion of the head since segmental necrosis might be present. If the position of the needle had to be confirmed by X-rays it would prolong the time of the operation.

If this method could give dependable results, it would probably be widely adopted. However, a much larger series must be done to determine if it would be an accurate, easy method.

Laing [24] and his associates believed there would be an isotope more suitable than P_{32}. In 1959, they reported on the use of Na_{24}. P_{32} emits beta radiation which is rapidly filtered out by the tissues, especially bone. Na_{24} emits gamma photons which penetrate tissues easily and can be followed by surface counting. The half life is 15.06 hours and it is therefore relatively safe to the patient.

The method involves the placing of the radiosodium into bone and holding it there for ten minutes while counts are taken. A normal vascular bone will absorb the material and a decreasing surface count indicates clearance of the Na_{24}.

They developed a stainless steel syringe that would deliver the desired amount into the femoral head without leaking. The syringe itself has threads on the tip that cut its way along a pre-drilled hole. This gives a water tight insertion. The screw type plunger in the syringe is designed to empty completely thus placing all the sodium in the chamber.

The authors used a scintillation probe containing a thorium activated sodium iodide crystal to measure the gamma radiation.

They carried out animal experiments on twenty-two dogs. On the right hip of each dog they dislocated the femoral head, severed the ligamentum teres and stripped the vessels from the ligamentum teres. At a later date, they had thirty femoral heads suitable for study in a comparison of the normal left side with the avascular right

side. They were able to demonstrate a striking correlation between the low rate of clearance from the avascular heads of less than five per cent to the high rate of fifty per cent clearance for the vascular heads.

They then applied their method to fifteen clinical cases. In a typical fracture of the femoral neck the patient was prepared as for a blind nailing of the femoral neck. A small piece of cortex was removed and a guide wire was inserted up into the femoral head. The syringe was then inserted to within one-half inch of the end of the hole. It also could not penetrate the articular surface which would cause a loss of the sodium. For the same reason it had to be placed above the fracture line. Since the syringe was screwed in along a predrilled hole, care was needed to avoid displacing the fracture. The position of the syringe was then checked by X-ray.

The scintillation probe is held on an adjustable mechanical arm. It is then swung into position and counts are taken over the area. Counts are taken for ten minutes. If the head is vascular, the count will fall markedly as contrasted to a steady count when the head is avascular.

The clearance is then calculated by various methods on the set-up for measuring the radiation. If the clearance is good the drill is reinserted and the guide wire replaced. The fracture is then nailed in the usual manner. If there is no clearance it should be evident that the head is avascular. However, if the results were intermediary one would have to consider the following possibilities: 1) Is

the head viable with good circulation? 2) Was there a loss of sodium through an error in technique? 3) Is the arterial supply occluded with an intact venous drainage clearing the Na_{24}? Boyd raises the last question since the test does not measure the arterial supply but only the venous drainage which still might be intact.

Placing the sodium is in debate. If the nail is to be inserted along the same tract it has to be in the posterior-inferior portion of the head. It is well known that the most important area is the superior portion. Thus, if there is segmental necrosis in the vital superior area, it would not be evident by this method. This is the reason that Boyd uses a separate guide wire placed in the superior weight bearing area for his readings with radioactive phosphorus.

Woodhouse writes in favor of this method. He states that he thinks this method is of value in giving an index of circulation through the femoral head. He feels it is a direct measure of the adequacy of the circulation and eliminates unknown factors of tissue function.

I cannot agree with the author in his statement that it would not add to the length of the operation. The careful drilling of the hole, placing of the syringe, additional X-rays, counting and interpretation of the results would all add time to the operation. The equipment needed would add to the expense of the operation. The equipment and technique could make the operation more difficult. I feel that the basic principle is very sound

but there are so many opportunities for error in either technique or equipment that I do not feel it would be practical in its present form.

At the time this article was published enough time had not elapsed for a long term follow-up.

X-RAY EVIDENCE

In 1960, Claffey [7] ran a small series in attempting to find a way to determine the fate of the femoral head. He found that the determination of the line of fractures gives the best result. However, this still was not very satisfactory.

The most important factor seemed to be whether the fracture line crossed the area of penetration of the lateral epiphyseal vessels. However, the pre-reduction radiographs of fractures did not give any reliable evidence as to whether these vessels had been damaged or not. Of 50 unselected radiographs, taken after reduction, only 12 cases demonstrated the fracture line crossing the interosseous course of the lateral epiphyseal vessels. They did not feel that this present radiographic technique would be of any real value.

They studied the radiographs of 197 patients. They could trace 178 of them. The radiographs of 24 of these clearly illustrated the fracture line reaching the point of entry of the lateral epiphyseal vessels. In all of them avascular necrosis of the femoral head occurred. Of a further group of 20 cases in which the radiographs were not clear enough to disclose the integrity or otherwise of the lateral epiphyseal vessels, ten suffered from necrosis of the head of the femur.

An x-ray certainly would not be a constant factor in determining the fate of the femoral head. However, if the x-ray of any one patient were to show a clear fracture line crossing the point of entry, or the interosseous course of

the lateral epiphyseal, then it might be wise to recall this limited study. If this observation were made, the surgeon could be more sure that avascular necrosis would occur.

The above study would be the only way in which an x-ray would be of any value in predicting the viability of the femoral head up to the time of surgery. The findings of avascular necrosis by x-ray take at least three to four weeks to detect and it may be many months before an x-ray would show evidence of avascular necrosis.

DYE CLEARANCE TECHNIQUE

In 1961, Price [5,6] reported on a dye clearance technique to be used at the time of surgery.

Five cubic centimeters of Coomassie blue 4 per cent solution is put into the femoral head by means of a special needle. Blood is then withdrawn from a vein at one, two and five minutes. The blood can be either heparinized or clotted. It is then evaluated chemically by the colorimeter method or an oximeter can be used on the patient.

At the time of writing the original article, they had a follow-up of 23 months on 21 patients. They fell into three groups:

1. Dye absent from plasma - 7 patients. All developed avascular necrosis.

2. Dye concentration less than 2 mg% in 1-5 min. specimens of plasma - 4 patients. These developed avascular necrosis. One settled but united.

3. Dye concentration over 2mg% in 1-5 min. specimens of plasma - 10 patients. Nine united. One head collapsed.

They had an apparently good correlation between the absorbtion of Coomassie blue from the femoral head and subsequent viability of the head. This is a simple technique that could easily be adopted to the operating room. The author of the article suggested that a two minute heparinized specimen of blood could be centrifuged and the plasma compared with a standard containing 2 mg% of Coomassie blue. The outcome of this simple test could give the surgeon a better basis for either going ahead with a Smith Peterson pinning if it is bluer than the standard; however, if it is

less blue than the standard, clinical judgment must be used.

The author of this article is continuing to work on this method.

This is another of the methods requiring less equipment and technical skill. However, they would probably have technical problems in placing the dye in the proper place without losing it. If a satisfactory technique can be developed that will give accurate results, it might be readily accepted in the average operating room.

PROOF PUNCTURE AND VENOGRAPHY

In 1961 Harrison reported on the method that he had been studying for seven years. They are two complementary procedures. For reasons discussed below, these procedures are done at a later date following the initial surgical procedure. The venography is similar to that studied by Hulth.

Proof puncture consists of aspiration through a needle placed within the cancellous bone of the femoral head; free withdrawl of blood indicates an intact arterial supply and is called a positive result.

In the operating room, the patient has x-rays of the hip taken with a metal grid on the skin of the groin. Thus, the surgeon can direct a needle into the superior weight bearing segment of the femoral head. The needle is a trochar-pointed, lateral eyed bone needle with a central stylet. This is then introduced into the cancellous bone of the head along an area of local anesthesia. An x-ray is then taken to confirm its position in the head. The stylet is removed and strong aspiration is made with a syringe. The appearance of blood is the positive proof puncture. In some heads without circulation, a limited quantity of brown or yellow opaque fluid is aspirated instead of blood; this is probably liquified necrotic marrow. It may be necessary to rotate the needle point or to inject a small amount of saline to clean the needle before a positive proof puncture is obtained.

If this test is negative, the author will try venography. Any fluid that is injected into the marrow spaces

of cancellous bone ruptures the walls of the venous sinusoids and leaves the bone through the veins. A positive venograph is one where the veins can be demonstrated by radiography after intracapitol injection of radio-opaque substance ten or more days after the fracture.

Trueta and Harrison demonstrated that the venous drainage parallels the arterial supply. The technique involved injecting two milliliters of 40 per cent Hypaque into the needle introduced for the proof puncture. Anterior-posterior x-rays are then taken of the homolateral half of the pelvis to catch the iliac vein also. If the circulation is intact, all opaque fluid will have left the femoral head within five minutes. Embarrassed circulation is represented by a mottled appearance in the head and neck that persists for five minutes. A negative venograph shows no venous drainage. A positive venograph has an opaque pool of fluid for at least five minutes. The author of this article stated that he used venography only if the proof puncture was negative. Therefore, a positive proof puncture or positive venograph indicates that the head has an intact circulation and that one could predict that the head is alive and that the fracture will unite.

This author studied this method over a period of seven years. He reported on 19 of these cases that were technically adequate and that allowed a long enough follow-up. They were followed from 12 to 42 months. In fifteen of these cases, a diagnosis of a viable head was made. Of these, twelve had union with an intact head. Two had a major collapse of the head and one had a minor collapse.

Four patients with a negative proof puncture or negative venograph had the expected complications. Two had non-union with collapse of the head and two had union followed by collapse of the head.

The author had trouble with false positives and false negatives which is understandable since all of the vascular supply might not be destroyed. He feels this problem can be decreased by attempting to place the needle in the superior segment or weight bearing area of the femoral head. If this area is avascular, complications are almost inevitable.

Most of the other techniques are done at the time of surgery in order to help determine what procedure to use. This author argues against this point. He feels that any procedure would just add to the operating time when many times speed is important because of the age or feebleness of the patient. He also feels that too many false positives may be obtained since it may take as long as three days for the vessels to become thrombosed. Trueta and Harrison pointed out that cessation of the circulation is not followed by dissolution or occlusion of the circulation, therefore it may be possible to demonstrate a venous pathway leaving the head hours or days after arterial occlusion.

Thus, this method is done at a later date following the surgery. This might have special application to a younger patient, say age 55. If at a later date this patient's fracture shows signs of impending break-up and if the femoral head can be shown to possess an intact

circulation, the surgeon would be justified in using cancellous bone grafting or abduction osteotomy rather than prosthetic replacement. On other patients, it could be done at an interval following the surgery. If negative results were obtained, the surgeon might want to elect prosthetic replacement at that time rather than waiting for several months when the complications would be manifested and the patient in too poor a condition for further surgery.

This method is a little different approach to the problem. All the other methods are concerned with predicting the status of the femoral head at the time of the initial surgery. Harrison has presented his argument quite well. In a few of the circumstances he describes, this method might be of value, however Block points out that there is still a 25 per cent error margin in the follow-up on this series.

I do not know how to evaluate the proof puncture, but if a positive venograph were obtained ten days or later, it is reasonable that the head must be viable. A pathologist can determine if the bone is alive or dead about three weeks after the injury. I would suggest that if this procedure is delayed three weeks or more after the initial injury or operation that he take a small punch biopsy when the proof puncture is done. By being able to correlate histologic findings with proof puncture and venography he might be able to cut down the 25 per cent error.

MEASUREMENT OF OXYGEN TENSION

In 1961, Woodhouse [1,2] published his first article on the measurement of oxygen tension in the femoral head. This was a completely new concept that had not been previously studied. The instrument, the redox polarimeter, was designed on polarimetric principles.

The function of this instrument is to determine the oxygen tension within the head of the femur which is a measure of the availability of oxygen to the tissues. If this were representative of the circulatory condition of the head, it would help him in the choice of the best treatment.

"Polarographic analysis makes possible accurate quantitative measurements of micromolar concentrations of electroreducible ions or compounds." It is used in this procedure to determine oxygen concentration.

Oxygen acts as an electroreducible solute. When voltage is applied to two electrodes in a solution containing oxygen, the resultant flow is directly proportional to the concentration of the reduciable solute.

When this voltage is applied to an electrode in the femoral head, the dissolved oxygen in the blood is consumed at the electrode surface and replaced by oxygen diffusing from the nearby blood supply. As oxygen is extracted from the blood, it is replaced by the dissociation of oxyhemoglobin. The red cells contain a reserve of oxyhemoglobin. If there is blood circulation to the femoral head, the reserve of oxyhemoglobin maintains a measurable oxygen

tension.

They were able to establish a lung-hip circulation time by increasing the concentration of oxygen in the lung and measuring the time for it to be recorded in the femoral head.

The equipment consists of a small self-contained transistorized polarimeter, probe electrode, cannula and trochar. The set can be heat sterilized. During a hip nailing the cannula can be inserted into the femoral head over a guide pin or it can be drilled directly into bone with its self-contained stylet. The electrode fits inside both the cannula and the hole in the Smith Peterson nail as well as other types of nails. Therefore, the electrode can be inserted through a nail at anytime to check femoral head oxygenation.

The meter circuit consists of a transistorized direct current amplifier. A single button supplies the proper electromotive force which calibrates the instrument at point zero and sets the preadjusted sensitivity. There is only one control to be set, thus the surgeon can read the oxygen percentage directly.

The instrument was accurately calibrated in fresh heparinized human blood. This was checked by using dogs and placing the electrode in the trochanter. The concentration the dog received through the gas machine agreed with that obtained in the in-vitro experiment.

They further tested their procedure by placing the electrode in the femoral head of dogs. The dogs were receiving a normal concentration of oxygen. The circulation was

then adequately shut off to the femoral head by transecting the femoral neck and twisting the femoral head to occlude the supply from the ligamentum teres. The oxygen tension rapidly fell to zero in all cases. When the femoral head was released, normal circulation was restored with reoxygenation of the femoral head from the ligamentum teres which is well developed in the dog.

They also obtained the same degree of calibration by introducing the electrode into cancellous bone of three persons under general anesthesia. Polarograms were then obtained in the calcaneous ten minutes after application of an arterial tourniquet to the thigh. The polarogram revealed complete anoxia of the bone tissue. A repeat polarogram ten minutes after release of the tourniquet showed an increase to near normal of oxygen in the bone.

They then used the procedure in ninteen hips on which operations were performed. Seventeen showed positive correlation between the oxygen tension measurement and results of microscopic study or roentgenographic examination six months after surgery.

The Redox polarimeter was used in this series only to collect data. Further data is still being collected for a definite statistical study.

In 1962 Woodhouse developed a new self-contained portable oximeter. This instrument was developed with the cooperation of the Radiation Instruments Development Laboratories in Illinois. It is calibrated in the bone of a patient on a known anesthetic oxygen percentage. It is then simply turned on. The electronic circuit obtains a

reading for a few milliseconds, shuts the electrode off and rereads every ten seconds thus avoiding the pitfalls of equilibrium polarography. This method avoids the expoential delay of current values which occur in equilibrium measurements because of the establishment of diffusion layers. Thus, it is a more stable system capable of automatic reproducible current values.

At operation, the fracture is reduced and the usual guide pins are inserted. A fine cannula is drilled up over a guide pin into the superior weight bearing portion of the femoral head. The guide pin is then removed and the electrode inserted. The cannula isolates the femoral head from the fracture site and the trachanteric bone, preventing seepage or contamination of the electrode with oxygenated blood. The drill hole is always contaminated with cells, bone, arterial and venous blood. However, this method measures the transport of oxygen to the area by the vascular system. The oxygen content of the trochanteric region can be measured. It can also be demonstrated to increase when the concentration in the inspired air is increased. Thus, if it does not increase in the femoral head when it is increased in the inspiral air, it is known that the vascular supply to the femoral head is seriously impaired.

The author feels this is a very simple method which could be used at any local hospital and without any particular technical knowledge or training.

An advantage of this over P_{32} uptake is that in P_{32} uptake studies, the results may represent a difference in

the physiochemical or metabolic activity of epiphyseal and metaphyseal bone. This variable is not present with the polarimetric measurement.

Comparitive measurements in the trochanteric bone and the femoral head could eliminate some of the possible technical errors such as electrode inactivity. Oxygen that might diffuse in is of no consequence since it could not maintain the level and would soon drop its level.

Block, who did work on radioactive phosphorus, recognizes that this method is still at the research level. He feels it is more accurate and he plans to obtain an oximeter for his work.

This method is similar to the P_{32} uptake or the Na_{24} clearance in that the procedure at the time of surgery is similar. Therefore, it has the same disadvantages of requiring expensive apparatus, prolonging the operating time and increasing the difficulty of the operation. The accuracy of their method will have to be determined on a large series of patients followed for a significant period before the method itself can be fully evaluated.

OTHER METHODS

Supravital staining has been attempted but found to be too unreliable. A punch biopsy of the femoral head does not work since it takes two to three weeks before the pathologist can distinguish between dead and live bone. This time must elapse to allow bone and marrow cells to be autolyzed. Perhaps Harrison could utilize a punch biopsy to correlate with his proof puncture and venography.

There is another method which could be a measure of the red cell circulation. Red blood cells could be labled with sodium or chromium isotopes and then measured in the femoral head. However, this method would probably not be a measure of the true viability of the bone.

There are two other methods suggested that have not been investigated yet. One of these is the succinic dehydrogenase test. A dead fragment of bone will not give a positive reaction. It might be possible to remove a small piece from the drill hole of the femoral head and do the succine dehydrogenase test.

Another author has suggested that flourescein might be injected into the femoral head. If the blood supply was adequate, the whole patient should become flourescent to ultraviolet light. This method does not sound at all practical. Technical problems and difficulty in obtaining a quantitative result would rule it out.

SUMMARY

Avascular necrosis occurs as a complication in forty per cent of the cases of femoral neck fracture. Since 1949, various surgeons have attempted to find a method of predicting whether the femoral head will remain viable and not go on to avascular necrosis. This paper reviewed the methods that have been studied in an attempt to solve this problem.

Radioactive phosphorus was the first to be reported on in 1949 by Tucker. It has also been used by Arden and Veall, Boyd, Calandruccio, Zilversmit and Block. A definite amount of radioactive P_{32} is given intravenously. The uptake of P_{32} is then measured in the trochanter where the blood supply is normal and also in the femoral head. They have all found that this ratio will allow them to predict in about 75 per cent of the cases whether avascular necrosis will develop.

Arteriography was attempted and reported on in 1953 and 1958. Rook and McGinnis injected radiopaque solutions into the femoral artery and then took serial X-rays of the hip. They attempted to determine if avascular patterns would indicate an inadequate arterial supply. They could not find a significant correlation in their studies. This method has not been studied by anyone else.

Anders Hulth thought he could solve the problem by assessing the status of the venous drainage. He injected radiopaque material into the femoral head and then took X-rays as the dye found its way out along the veins. The veins are more friable and follow the arteries. He reasoned

that if they were intact the arterial supply should also be intact. Dahlgren used the same technique and obtained the same results. It has the disadvantages of requiring technical skill in doing the procedure and prolonging the operating time. They have been able to predict accurately the future status of the femoral head in only fifty per cent of the cases. It is also necessary to postpone the operation until the third day so that the contrast media will not leak out.

In 1955 Miles measured the intramedullary pressure in the femoral head by placing a needle in the head and connecting this to a manometer. He found a good correlation of active fluctuation of pressure with viable femoral heads. He did not note any fluctuation of pressure in heads that went on to avascular necrosis. He has not yet published any further results.

Laing and his associates felt that radioactive phosphorus had too many disadvantages. In 1959 they published their work on radioactive sodium. This is basically a clearance technique. A small amount of Na_{24} is placed in the femoral head by means of a special cannula. Circulation is measured by surface counting. Laing has not yet published any follow-up report. It is very similar to the use of radioactive phosphorus. Its accuracy will depend on the results of a long term follow-up.

In 1960, Claffey reported on an observation that might be of value. If the fracture line can be clearly seen to cross the point of entry or the interosseous course of the

lateral epiphyseal vessel, he found that avascular necrosis was more likely to develop.

In 1961 Price reported on his dye clearance technique. The dye is placed in the femoral head. Serial samples are then drawn intravenously and compared with standards. He has found good correlation in limited studies with the amount of dye found in the blood.

In 1961, Harrison reported on his technique of proof puncture and venography. He does not believe any procedure should be done at the time of the initial operation because of the time it would add to the operation. This procedure is done ten days or more following the surgery. Proof puncture consists of introducing a needle into the femoral head under roentgenographic control and aspirating. If blood is obtained the head is considered to have a blood supply and be viable. If no blood is obtained then venography is done by injecting radiopaque material into the head. If the dye finds its way out along the veins the head is considered viable. If the proof puncture gives a negative result and if the venogram is negative, the head is considered avascular. Harrison had a 25 per cent error rate in his series.

In 1961, Woodhause reported on the measurement of oxygen tension in bone. In 1962, he developed a more portable and accurate oximeter. At the time of operation the electrode is introduced into the femoral head and the oxygen tension is measured. The oxygen in the blood acts as an electroreducible solute and maintains a current as long as there is a constant blood flow to the area to supply oxygen. They

have been able to increase the oxygen tension in the alveoli and measure the time it takes for the increased concentration to reach the hip.

They have had excellent results in their animal and human experiments. The preliminary studies leave one with the impression that it might be much more accurate than the other methods. Long term follow-up studies will determine if this method is accurate enough to be applied to the average case.

This problem cannot be denied indefinitely. Continued research, clinical trials and follow-up studies will certainly provide a method to determine the viability of the femoral head.

The uptake of P_{32}, arteriography and venography have all had adequate clinical trials. I do not believe that enough modification could be made in these procedures to adopt them to general use. The other methods, measurement of intramedullary pressure, Na_{24} clearance, dye clearance, proof puncture and venography, and the measurement of oxygen tension have not had an adequate clinical trial.

The measurement of the intramedullary pressure or the dye clearance technique would be the most ideal from the standpoint of expense, technique and technical complications. However, follow-up studies may prove that dye clearance and measurement of intramedullary pressure are not accurate enough.

The measurement of the oxygen tension is the most

promising at the present. Although it has many of the disadvantages discussed, it appears to have the potential of being the most accurate. If the follow-up studies find this method to be more accurate, it may be a big step toward solving the "unsolved fractures".

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