Blood flow to the immature hip

Ultrasonic measurements in pigs

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We quantitatively analyzed blood flow through the major arteries supplying the pig's femoral head during various hip positions and following ligation of various vessels in order to identify the vascular abnormalities which may be responsible for the development of avascular necrosis during the treatment of developmental dysplasia of the hip.

Our findings reveal that a decrease in total blood flow to the femoral head occurs when the hip is held in the frog leg position with ligation of the deep femoral artery and proximal ligation of the lateral femoral circumflex artery, and ligation of the deep femoral artery, together with the lateral femoral circumflex artery proximally. In contrast, neither distal ligation of the medial femoral circumflex artery nor lateral femoral circumflex artery alone nor holding the hip in the Lange position caused a statsitically significant decrease in total flow. We also observed a unique steal effect on total proximal femoral blood flow, with the hip held in the frog leg position. In 4 of 7 pigs, we found a reversal of flow in the medial femoral circumflex artery.

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The etiology and pathogenesis of avascular necrosis of the femoral head following the treatment of developmental dysplasia of the hip remains uncertain. Tightness of the adductor muscles and/or high contact pressures across the hip joint may cause disturbances in the blood flow to the hip in extreme positions (Salter et al. 1969, Ogden 1974) and immobilization in the frog leg position (Lorenz 1920) (hips flexed and abducted 90 degrees) or the Lange (1931) position (full hip abduction, extension, and internal rotation) has been shown to result in avascular necrosis of the femoral head in a substantial proportion of cases (Schoenecker et al. 1978, Salter et al. 1969). The human position (90 degrees of hip flexion and 30–60 degrees of abduction) is currently the accepted (least hazardous) method for immobilization in patients with developmental dysplasia of the hip (Salter et al. 1969). Open reduction of the hip joint with the medical approach increases the risk of avascular necrosis of the femoral head (Kalamchi and MacEwen 1980).

While several anatomical and physiological studies have investigated the circulation of the proximal femoral epiphysis (Trueta 1957, Ogden 1974, Crock 1980, Jones et al. 1982, Nakano et al. 1986) no clear description has been given of the factors responsible for development of avascular necrosis of the femoral head in patients undergoing treatment for developmental dysplasia of the hip. The influence of various positions on the vascular supply of the proximal femur has been studied (Law et al. 1982). Ligations have been performed on different vessels around the hip and the resulting blood flow patterns recorded (Bassett et al. 1991). A quantitative analysis of blood flow (amount and direction) through the major arteries supplying the femoral head during various hip positions and following ligation of various vessels might clarify the pathogenesis of avascular necrosis.

We tried to identify the vascular factors which may be responsible for the development of avascular necrosis during the treatment of developmental dysplasia of the hip. Our aim, using ultrasound transit time technology, was to measure independently blood flow changes in the medial and lateral femoral circumflex arteries during various positions of the immature hip and after ligation of the various arteries, supplying blood to the femoral head.

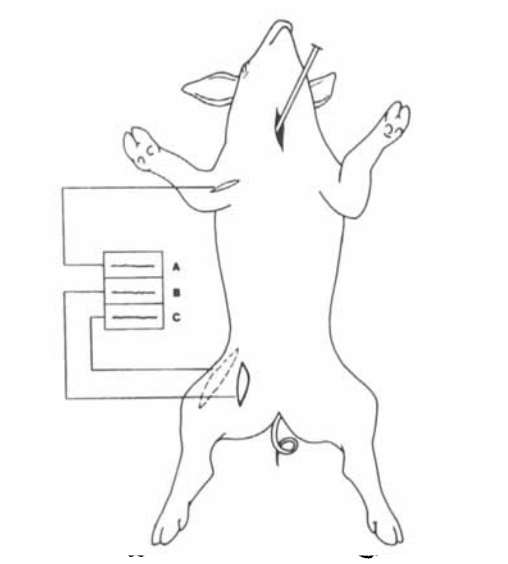

Figure 1. Study design. A – systemic arterial pressure, B – blood flow (LCA), and C – blood flow (MCA).

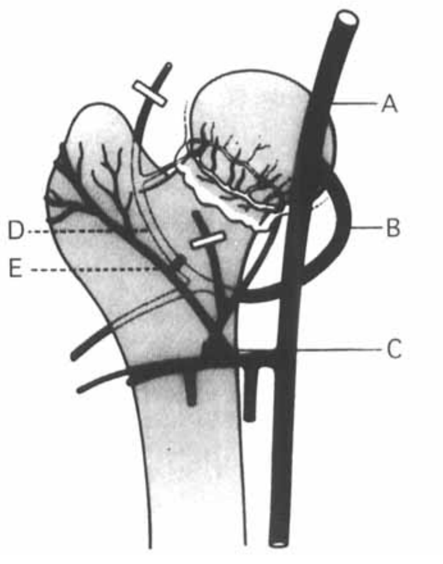

Figure 2. Vascular anatomy of the pig hip. A – femoral artery, B – deep femoral artery, C – probe on LCA (ascending branch, D – MCA, and E – probe on MCA

Animals and methods

7 immature pigs, aged from 6 to 10 weeks, with an average weight of 11.5 (9–13) kg were used. The pig was chosen as a model because preliminary examinations had shown a similar vascular pattern in the immature pig hip and the developing human hip.

After induction with ketamine, intubation was performed and anesthesia was maintained with isoflurane. An arterial line was established in the brachial artery to measure systolic, diastolic and mean systemic arterial pressure. Care was taken to maintain the mean arterial pressure between 80 and 90 mmHg. This was accomplished by varying the rate of fluid administration and the depth of anesthesia. The pig was then placed in the supine position for an anterior surgical approach to the hip (Figure 1).

In the pig, the deep femoral artery branches off the femoral artery just beyond the inguinal ligament. The course of the deep femoral artery is similar to that of the medial femoral circumflex artery in the human. The medial femoral circumflex artery in the pig arises from the deep femoral artery just posterior to the lesser trochanter and ascends in the intertrochanteric groove.

The lateral femoral circumflex artery branches off the femoral artery more distal than the deep femoral circumflex artery. Under the rectus femoris muscle, several branches of the lateral femoral circumflex artery supply the adjacent musculature. One ascending branch of the lateral femoral circumflex artery enters the hip capsule anteromedially between the ascending and transverse bands of the inverted Y ligament of Bigelow (Howe et al. 1950). This ascending branch communicates with the intraarticular ring of anastomoses and supplies most of the anteromedial part of the chondroepiphysis. To gain access to this branch, the rectus femoris muscle was dissected close to its origin and reflected distally. The ascending branch of the lateral femoral circumflex artery was exposed and the anastomoses with the inferior gluteal artery, which were always present, were ligated to avoid measuring blood flow contributions by these arteries. The pig was next placed in a lateral decubitus position and the medial femoral circumflex artery was exposed via a posterior approach to the hip. To gain access to the origin of the medial femoral circumflex artery, the quadratus femoris muscle was transected and branches to this muscle were ligated. After giving off some branches to the posterior aspect of the greater trochanter, the medial femoral circumflex artery dives into the capsule to communicate with the intraarticular ring of anastomoses and supply most of the posterosuperior part of the chondroepiphysis. Anastomoses with the inferior gluteal artery and branches to the gluteus medius muscle were ligated. Proximal to the origin of the medial femoral circumflex artery, an anastomosis from the deep femoral artery ascends to the acetabulum and communicates with the obturator artery.

Ultrasonic transit-time perivascular flow probes for small vessels (1S, Transonic Systems, Inc., Ithaca, New York) were affixed to the ascending branch of the lateral femoral circumflex artery shortly before it enters the hip capsule and to the medial femoral circumflex artery about one centimeter distal to its origin (Figure 2). Blood flow was recorded by a dual channel flowmeter (T101, Transonic Systems Inc., Ithaca). Flow was always confirmed by a strong pulse echo of the flowmeter. Vasospasm was reflected by a decrease in blood flow following dissection and application of the perivascular probes. Flow always recovered after 1–2 minutes.

The use of transit-time ultrasound technology in orthopedics is new, but the method has been used in other studies and has been described in detail elsewhere (Drost et al. 1981). This system has the advantage of continuously measuring flow directly, without the need for cannulation of the vessel. The transit-time system operates by using a uniform level of ultrasound, which illuminates the cross-sectional area of flow in the vessel. Each probe consists of a probe body containing two ultrasonic transducers (on one side of the vessel) and a fixed acoustic reflector bracket which wraps around the vessel and is located midway between the two ultrasonic transducers. The flow probe alternates through an upstream and downstream cycle in which an ultrasonic wave is passed from the probe through the vessel and is reflected by the acoustic bracket back to the opposite transducer. The time the ultrasonic wave takes to reach the opposite transducer is either increased (upstream transit-time) or decreased (downstream transit-time). The difference between the upstream and downstream transit-times is a measure of the volume flow through the probe.

In the first series of experiments, the hip was held in a variety of positions and blood flow was measured in the medial and lateral femoral circumflex arteries. The normal range of motion in the pig hip is 130 degrees of flexion, with a 20-degree lag of extension. At 90 degrees of hip flexion, abduction is limited to 80 degrees, adduction is 20 degrees, external rotation is 40 degrees, and internal rotation is limited to 45 degrees. The hip was placed in the neutral position (approximately 90 degrees of flexion and 10 degrees of abduction), in the Lange (1931) position (full hip abduction, extension, and internal rotation) and in the frog leg position (Lorenz 1920) (hips flexed and fully abducted 90 degrees). The human position was not included in this study because preliminary data had shown no difference in blood flow between the neutral and the human positions. Hips were positioned manually and maintained for a period of 5 minutes by the same investigator for all experiments.

In the second series of experiments, various vessels were ligated using a vascular clamp and flow through the circumflex arteries was recorded with the hip in the neutral position. The following vessels were ligated: the deep femoral artery, the proximal lateral femoral circumflex artery, the distal medial femoral circumflex artery, the distal lateral femoral circumflex artery, and the deep femoral artery together with the proximal lateral femoral circumflex artery (Table 1).

Table 1. Study design of recorded blood flow measurements

First series of experiments (hip positions)	
Neutral position	
Measurement 1.	Lange position
Neutral position	
Measurement 2.	Frog leg position
Second series of experiments (vessel ligations)	
Neutral position	
Measurement 3.	Ligation of the deep femoral artery
Neutral position	
Measurement 4.	Ligation of the lateral femoral circumflex artery-proximal
Neutral position	
Measurement 5.	Ligation of the medial femoral circumflex artery-distal
Neutral position	
Measurement 6.	Ligation of the lateral femoral circumflex artery-distal
Neutral position	
Measurement 7.	Ligation of the deep femoral artery plus the lateral femoral circumflex artery-proximal

Hip positions and vessel ligations were maintained for 5 minutes

Each hip position and vessel ligation experiment was performed for 5 minutes. At the conclusion of the first series of experiments the hip was returned to the neutral position for 5 minutes. During this period, neutral position (baseline) flow was always recorded. Following the second series of experiments the ligation was reversed by releasing the vascular clamp and the hip was maintained in the neutral position for 5 minutes. During this 5-minute period, neutral position (baseline) flow was always recorded.

For each measurement performed, blood flow in the medial femoral circumflex artery and the lateral femoral circumflex artery was very sensitive to changes in positions of small degrees, but total blood flow (medial femoral circumflex artery plus lateral femoral circumflex artery) remained constant. The most consistent flow in each of the circumflex vessels was observed during the last 2 minutes in each measurement. Therefore, data were recorded as the average flow observed during the fourth and fifth minutes of each experiment. For each experiment, a change in blood flow was always observed within 5–10 seconds following the release of a ligation or return to the neu-

Table 2. Total blood flow, mL/min (SD), and medial femoral circumflex artery flow versus lateral femoral circumflex artery flow

Measurements	n	Medial femoral circumflex artery flow	Lateral femoral circumflex artery flow	Total flow	Percent total flow from the preceding neutral position flow	P-value
First series of experiments (hip positions)						
Neutral position	7	0.76 (0.51)	2.21 (1.98)	2.97 (2.03)		
Measurement 1	7	0.41 (0.74)	1.73 (1.54)	2.14 (1.94)	72	0.10
Neutral position	7	1.04 (0.50)	1.46 (0.99)	2.50 (1.29)		
Measurement 2	7	–0.16 (0.25) [a]	1.43 (1.80)	1.27 (1.58) [a]	51	0.02
Second series of experiments (vessel ligations)						
Neutral position	7	1.21 (0.61)	1.57 (1.08)	2.78 (1.35)		
Measurement 3	7	–0.70 (1.51) [a]	2.31 (1.66)	1.61 (1.57) [a]	58	0.02
Neutral position	7	0.93 (0.51)	2.16 (1.96)	3.09 (3.93)		
Measurement 4	7	1.60 (1.33)	–0.38 (1.23)	1.22 (2.10) [a]	39	0.0001
Neutral position	6	1.03 (1.11)	1.95 (1.63)	2.98 (1.92)		
Measurement 5	6	0 (0) [a]	2.03 (1.79)	2.03 (1.79)	68	0.06
Neutral position	6	0.7 (0.44)	1.75 (1.44)	2.45 (1.39)		
Measurement 6	6	1.43 (1.15)	0 (0)	1.43 (1.20)	58	0.06
Neutral position	6	0.93 (0.49)	1.52 (1.19)	2.45 (1.41)		
Measurement 7	6	–0.28 (0.35) [a]	–0.45 (1.1)	–0.73 (1.95)	–30	0.00001

[a] Measured flow is significantly different from the previous neutral position flow ($p < 0.05$).
Total blood flow = medial femoral circumflex artery flow plus lateral femoral circumflex artery flow.
mL/min = mm per minute.

tral position, this indicated that ischemia was not responsible for the observed changes in flow. A hyperemic period (of more than 2–3 minutes) was not observed following changes in position or release of ligations. In one pig, problems developed with anesthesia and there was a substantial drop in the mean arterial pressure. For this pig, only 4 of the 7 measurements could be included in the analysis.

Following all blood flow studies, the animals were killed with a barbiturate overdose and the vascular bed of the lower extremities was filled with silicon rubber (Microfil, Canton Bio-Medical Products, Boulder, Co) via the thoracic aorta. The right hip was held in the neutral position and the left hip was held in forced abduction. To avoid errors due to anatomic differences between hips, both proximal femora were harvested, sectioned, and the Spalteholz technique (Spalteholz 1914) was applied to each specimen.

After fixation in 10% buffered formalin for 2 weeks, and decalcification in nitrous acid, the specimens were bleached in 3.5% hydrogen peroxide for 2 days. Dehydration was achieved by increasing concentrations up to absolute alcohol. The clearing process was initiated by transferring the specimen into water-free benzol and was completed in equal parts of benzol and benzyl benzoate. Finally, the specimens were stored in a mixture of 3 parts per volume of benzyl benzoate and 5 parts per volume of methyl salicylate after the remaining air bubbles had been removed in a vacuum chamber. Photographic documentation was performed on all specimens. Satisfactory filling of the vascular bed of the hip was accomplished in 4 of 7 animals.

For statistical analysis, a block-test of least square means was used. Each measurement served as a block comprised of the average flow recorded over the fourth and fifth minute for each pig. For measurements 1, 2, 3, and 4, there were 7 data points in each block. For measurements 5, 6, and 7, there were 6 data points in each block. Each measurement block was compared to the previous neutral position block consisting of 7 data points for measurements 1, 2, 3, and 4, and 6 data points for measurements 5, 6, and 7. Changes in blood flow in the medial femoral circumflex artery, the lateral femoral circumflex artery, and the total flow (medial femoral circumflex artery plus the lateral femoral circumflex artery) were measured. Differences between the various measurements and the previous neutral position were recorded. A p-value of ≤ 0.05 was considered statistically significant.

Results (Table 2)

Blood flow in the terminal branch of the lateral femoral circumflex artery was higher than in the medial femoral circumflex artery in 5 of 7 pigs. Total blood flow (medial femoral circumflex artery plus lateral femoral circumflex artery) in the Lange position was reduced to 72% of the neutral position flow. A statistically significant reduction of total flow to 51% of the neutral position flow was observed in the frog leg position. Following ligation of the deep femoral artery, total blood flow was decreased to 58% of the neutral position flow. Following ligation of the proximal lateral femoral circumflex artery, total flow was decreased to 39% of the neutral position flow. When the distal medial femoral circumflex artery was ligated, total flow decreased to 68% of the neutral position flow. Following ligation of the distal lateral femoral circumflex artery, total flow decreased to 58% of the neutral position flow. Finally, when both the deep femoral artery and the proximal lateral femoral circumflex artery were ligated, total flow became negative and decreased to negative 30% of the neutral position flow, indicating reversal of flow direction (blood flow away from the femoral head).

In the Lange position (measurement 1), 4 of 7 pig hips showed a substantial decrease in blood flow in the medial femoral circumflex artery. One of these animals demonstrated a negative flow (–0.5 mL per minute). In 3 pig hips in the Lange position, the flow in the medial femoral circumflex artery remained constant. In this position, the lateral femoral circumflex artery was unable to compensate by increasing its flow so that the total blood flow was decreased to 72% of the neutral position flow.

In the frog leg position (measurement 2), 4 of 7 pig hips demonstrated a negative flow (indicating reversal of flow) in the medial femoral circumflex artery and 3 had zero flow. The lateral femoral circumflex artery was unable to compensate for the loss of flow in the medial femoral circumflex artery so that total flow decreased. Following ligation of the deep femoral artery (measurement 3), 4 of 7 pig hips showed a negative flow in the medial femoral circumflex artery. In this experiment, the lateral femoral circumflex artery showed an increase in flow to compensate for the loss in blood flow through the medial femoral circumflex artery.

When the lateral femoral circumflex artery was ligated proximally (measurement 4), 2 of 7 pigs demonstrated a negative flow in the ascending branch. Although the flow in the medial femoral circumflex artery rose immediately, total flow was reduced to 39% of the preceding neutral position flow.

Following ligation of the medial femoral circumflex artery distally (measurement 5), no increase in blood flow was observed in the lateral femoral circumflex artery and total flow was reduced to 68% of the neutral position flow. When the lateral femoral circumflex artery was ligated distally (measurement 6), an increase in flow was recorded in the medial femoral circumflex artery, but total blood flow was reduced to 58% of the neutral position flow. When both the deep femoral artery and the proximal lateral femoral circumflex artery were ligated (measurement 7), we observed a negative flow in the medial femoral circumflex artery in 4 of 6 pig hips and in the lateral femoral circumflex artery in 1 of 6 hips. Furthermore, total blood flow was negative in 4 of 6 pigs indicating reversal in the direction of flow away from the femoral head.

Figure 3. The deep femoral artery is seen passing between the adductor muscle and psoas tendon. Filling with silicon rubber is blocked by the bulging femoral head (left hip).

When the hips were sectioned, no obvious anatomic differences between right and left hips were observed. Filling of the deep femoral artery with silicon rubber ended as the artery passed between the adductor muscles and iliopsoas tendon (Figure 3). Adequate filling of the vascular bed with silicon rubber was accomplished in 4 of 7 pigs. Macroscopically, filling of the deep femoral artery abruptly ended in every instance when the hip was held in forced abduction; this was readily appreciated during anatomic dissections. It was apparent that filling distally was blocked by the anterior bulging of the femoral head in the frog leg position also stretching the psoas tendon. The deep femoral artery sustained additional pressure by the overlying adductor muscles.

Filling of the intraarticular ring of anastomoses was less dense on the experimental side compared to the contralateral control side. This was especially apparent medially, where filling defects were observed in the intraarticular ring with the hip held in a forced frog leg position (Figure 4).

Spalteholz preparations and photography revealed less dense filling in the medial proximal femoral physis and disturbed filling of the minor vessels in the femoral head. Flow to the chondroepiphysis in the pig was not dependent on a single or major epiphyseal vessel but on many small vessels originating from the intraarticular ring (Figure 4).

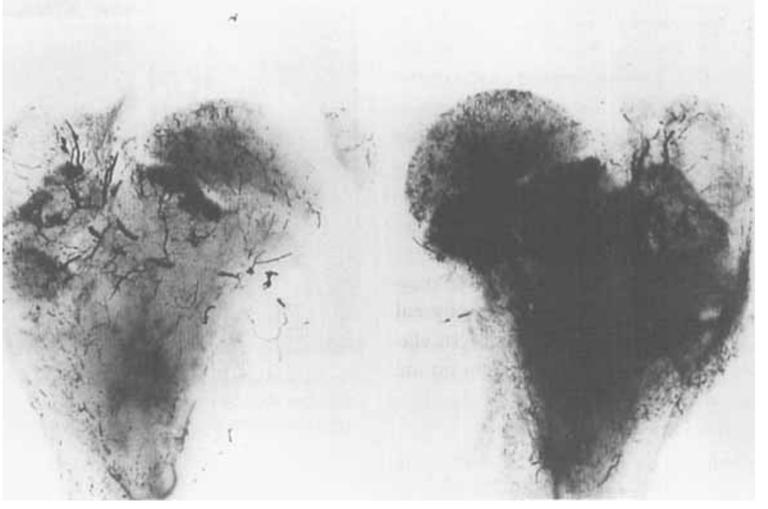

Figure 4. The effect of frog leg position can be seen in the left hip where there is less filling of the intraarticular ring of vessels. The right hip is shown as a control.

Discussion

The anatomy of the immature pig hip is similar to that of the developing human (Salter et al. 1969, Bassett et al. 1991) although there are some important differences. The deep femoral artery branches off the femoral artery just distal to the inguinal ligament. Its course is the same as that of the medial femoral circumflex artery in the human. The deep femoral artery passes over the iliopsoas muscle and enters the spce between this muscle and the adductor muscles. Under the quadratus femoris muscle, there is a branch anastomosing with the obturator artery to supply the ligamentum teres. Just distal to this branch, the medial femoral circumflex artery originates to course in the intertrochanteric groove and supply the hip joint. The course of the lateral femoral circumflex artery in the pig is similar to that in the human.

The extraarticular arterial ring is deficient anterolaterally and anteromedially. The vascular supply to the hip joint is almost exclusively delivered by the major branches of the lateral femoral circumflex artery and medial femoral circumflex artery and not by many ascending branches from the extraarticular ring. Therefore, we were able to investigate the total blood flow to the immature femoral head by positioning perivascular ultrasonic blood flow probes around the terminal branches of these two arteries. Small anastomoses, however, did exist with the inferior gluteal vessels and these were ligated during our experiments. The artery in the ligamentum teres does not play a significant role in the blood supply of the femoral head, and therefore no branches could be seen entering the femoral head from this ligament (Lauritzen 1974, Ogden 1974). We identified a complete subsynovial intraarticular ring of anastomoses where end-arteries were arising to enter the femoral head. This ring has been described by Crock (1980) in the human. From this ring, multiple vessels cross the growth plate on the surface of the femoral neck to supply the chondroepiphyseal end-arteries.

Following injection of silicon rubber with the hip held in forced abduction,we observed no filling of the deep femoral artery and the medial femoral circumflex artery distal to the point where the deep femoral artery courses between the adductors and the iliopsoas. In the pig, the femoral head bulges anteriorly in forced abduction, elevating the psoas tendon and stretching the deep femoral artery, which is also compressed by the overlying iliopsoas and adductor tendons. We found no filling defects in the lateral femoral circumflex artery in the frog leg position. These findings agree with the observations by Ogden (1974). However, we found no occlusion of the medial femoral circumflex artery in the intertrochanteric groove by the labrum in forced abduction (Ogden and Soutwick 1973). Instead, we saw a definite filling of the medial femoral circumflex artery in the groove; most likely due to anastomoses or retrograde filling.

Spalteholz preparations clearly demonstrated a filling defect of the medial physis and the superomedial chondroepiphysis. Our hypothesis is that in the frog leg position, the medial capsule is maximally stretched, thereby exerting a tethering effect on the medial aspect of the intraarticular ring and impairing the vascular supply of the medial physis and epiphysis. In addition, the tight psoas tendon may exert pressure on the small arteries lying medially under the synovial layer.

Every effort was made to isolate the blood supply to the pig's chondroepiphysis so that our blood flow findings would not be influenced by collateral flow. Anastomoses have been found between the epiphyseal and metaphyseal blood supplies on the neck of the femur (Ogden 1974). Although the physis constitutes an almost complete barrier between epiphyseal vessels and nutrient artery and metaphyseal circulation, some vessels traversing the growth plate on the surface were always present, as demonstrated with the silicon rubber injections. We consistently observed anastomoses between the lateral femoral circumflex artery and the inferior gluteal artery anteriorly and between the medial femoral circumflex artery and branches of the inferior gluteal artery posteriorly, which were located close to the sciatic nerve. Such anastomoses have been observed by O'Hara and Domisse (1983) in the human.

Evaluation of blood flow to the proximal femoral epiphysis in various positions and with selective occlusions of vessels has been performed with various methods (Schoenecker et al. 1978, Law et al. 1982, Schoenecker et al. 1984, Bassett et al. 1991). Swiontkowski et al. (1986) measured blood flow using 85Sr-labeled microspheres and using the laser Doppler flowmetry method but found no statistically significant correlation between these two experimental methods in the femoral head (Swiontkowski et al. 1986). Fisher et al. (1993) disrupted the medial femoral circumflex artery via a medial approach in pigs which was not followed by development of avascular necrosis. The authors concluded that damage to the medial vessels alone does not induce avascular necrosis. Bassett et al. (1991) performed a study on immature pigs and used laser Doppler flowmetry to investigate blood flow after selective occlusions of the major arteries to the hip joint. The authors found that the lateral femoral circumflex artery was the major contributing artery to the pig hip in 8 of 9 hips and demonstrated a reduction in femoral head blood flow when the lateral femoral circumflex artery was ligated.

Schoenecker et al. (1984) developed a model of experimental hip dysplasia in puppies and measured blood flow via the hydrogen-washout technique. These investigators placed the dysplastic hip in various positions and noted a significant decrease in femoral head blood flow in forced abduction; the highest flow was consistently observed with the hip held in a flexed position. Law et al. (1982) investigated blood flow to the femur in puppies, with the use of microspheres. The hip was placed in the neutral position and in 60 and 90 degrees of abduction. The authors observed that blood flow was highest in the neutral position, with no significant change at 60 degrees of abduction, but a significant decrease at 90 degrees of abduction.

Our investigation reveals that a decrease in total blood flow to the femoral head occurs: 1) in the frog leg position, 2) with ligation of the deep femoral artery, 3) with proximal ligation of the lateral femoral circumflex artery, and 4) with ligation of the deep femoral artery, together with the lateral femoral circumflex artery proximally. In contrast, neither distal ligation of the medial femoral circumflex artery nor lateral femoral circumflex artery alone nor the Lange position resulted in a significant decrease in total flow. These findings suggest that the frog leg position exerts a more pronounced effect on blood flow to the proximal epiphysis than do individual ligations of the major contributing arteries.

We observed a unique effect on total proximal femoral blood flow with the hip held in the frog leg position. This effect was responsible for the pronounced decrease in flow. In 4 of 7 pigs, we observed a reversal of flow in the medial femoral circumflex artery, with the hip held in the frog leg position. We believe that this reversal of flow may be caused by ischemic muscles which are usually supplied by the deep femoral artery. Since the deep femoral artery is occluded proximally in the frog leg position, the ischemic musculature tends to steal blood from the proximal femur, analogous to the subclavian steal syndrome. This concept is supported by the fact that the reversal of flow in the medial femoral circumflex artery increased over time. In all animals where this phenomenon was observed in forced abduction, it was also observed when the deep femoral artery was ligated. We also found a reversal of flow in the medial femoral circumflex artery in the Lange position in 1 of 7 pigs. The reason why this phenomenon of flow reversal was not evident in all animals cannot be explained by our study.

We confirm the observations by Bassett et al. (1991) that the lateral femoral circumflex artery is the major blood supply to the pig hip. This may explain why Fisher et al. (1993) failed to produce avascular necrosis in the pig following ligation of the medial femoral circumflex artery. This failure is important, since in the human hip the lateral femoral circumflex artery contributes significantly to femoral head circulation during the first years of life (Ogden 1974).

When guiding the hip into abduction, we consistently noted a decrease in blood flow in the medial femoral circumflex artery at approximately 50 degrees of abduction; these results are in agreement with those of Ogden and Southwick (1973), who found tight interlocking of the developing human acetabular rim into the intraepiphyseal groove beyond 45 degrees of abduction. In contrast, Law et al. (1982) found no decrease in flow with up to 60 degrees of abduction in puppies. Of interest is the fact that the developing human hip resembles that of the pig more closely than that of the puppy.

To the best of our knowledge, the independent flow contributions by each of the major arteries supplying the femoral head (the medial femoral circumflex artery and the lateral femoral circumflex artery) have not been previously described. Perivascular ultrasonic flow probes flow meters are the only non-destructive method available for direct measurements of independent vessels simultaneously. Precalibrated probes are used which exhibit good baseline stability and are not influenced by vessel diameter or vessel probe alignment. The handling of the probes is easy, but careful dissection of the arteries is a major prerequisite.

The methods available for blood flow measurement have different applications. While evaluation with microspheres is not suitable for dynamic measurements and is not applicable in clinical trials, it permits measurement of total blood flow to the femoral head. In contrast, laser-Doppler flowmetry permits examination of blood flow in the microvasculature of an organ. Further knowledge might be obtained by a combination of our method with these methods. The advantage of using the ultrasound transit time method is that arterial inflow to an organ may be directly and continuously measured. This technique has the further advantage of being able to distinguish between sources of blood supply to an organ with many contributing vessels. Variables such as anesthetic or surgical manipulation may have influenced our results to some degree, but these problems are inevitable in such experiments. Baseline variability must be accounted for, which is also true of other methods. During our experiments, baseline values in the neutral position in many cases did not return to their previous values. This was due not to anesthetic changes or changes in blood pressure, but rather to the great variability and physiological changes in actual blood flow in the various vessels (Launder et al. 1981, Bassett et al. 1991). To account for this variation in baseline values, we expressed changes in flow values as a percentage of the neutral (baseline) flow just prior to each of the 7 measurements.

In conclusion, our results are in agreement with those of previous investigations. There is a significant decrease in blood flow in the major contributing arteries to the pig hip in forced abduction. The decrease in blood flow in the Lange position failed to reach statistical significance. There is no uniform response in medial femoral circumflex artery flow to changes in position.

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