

BLOOD FLOW IN THE JUVENILE HIP IN RELATION TO CHANGES OF THE INTRAARTICULAR PRESSURE

An Experimental Investigation in Dogs

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The blood flow in the hip joint of puppies was studied by means of the microsphere technique. The flow was determined before, during and after intraarticular pressure increase. A venous tamponade of 50 mmHg resulted in a significantly reduced flow in the femoral head and after an arterial tamponade of 150 mmHg the flow almost ceased. The proximal femoral metaphysis, the acetabulum and the hip joint capsule, on the contrary, showed varying degrees of flow increase. It is suggested that the significantly increased blood flow in the hip joint capsule during the intraarticular pressure increase of 50 mmHg and 150 mmHg is caused by an autoregulatory mechanism tending to restore the blood flow in the suffering femoral head. The demonstrated disturbance of the circulation in the juvenile femoral head after venous tamponade supports the theory that synovitis may be the basic mechanism in the production of Calvé-Legg-Perthes' disease.

Key words: bone blood flow; Calvé-Legg-Perthes' disease; hip joint; intraarticular pressure; microspheres

Accepted 9.ix.82

It is generally believed that the epiphyseal plate is a barrier to blood circulation, meaning that the *juvenile femoral head* is supplied exclusively from the intracapsular extraosseous vasculature. Synovitis with an increased volume of synovial fluid increases the intraarticular pressure (Jayson & Dixon 1970) which may cause a compression of the intraarticular vessels and affect the blood circulation to the femoral head. Some experiments have shown that the blood circulation of the juvenile femoral head is not impaired (Borgsmiller et al. 1980) and no avascular necrosis develops (Tachdjian & Grana 1968) until

the intraarticular pressure is higher than the arterial pressure, whereas others have demonstrated reduced blood flow (Lauder et al. 1981) and development of an avascular necrosis (Woodhouse 1964) when the intraarticular pressure has passed the venous pressure.

The contradictory conclusions concerning the blood circulation and vitality of the juvenile femoral head make it desirable to clarify the relationship between the intraarticular pressure and the blood flow to get a better understanding of different pathophysiological conditions. However, it is also important to elucidate the blood flow of the different components of the hip and not only of the femoral head. In the present study this relationship is examined by means of the

microsphere technique, which has been shown to be a reliable method for measurement of blood flow in bones (Gross et al. 1981).

MATERIAL AND METHODS

Six mongrel puppies (6.0–10.0 kg), 3 months old and from the same litter, were premedicated with 0.5 ml 0.1 per cent Combelin® (10-(3-dimethylaminopropyl)-propionyl phenothiazine). The anaesthesia was induced by intravenous Brietal® (methohexital) 7 mg per kg and after oro-tracheal intubation maintained by halothane 0.5–1.5 per cent through a constant volume respirator. Muscle relaxation was obtained by intermittent doses of Pavulon® (pancuronium bromide). The dogs were placed in supine position on an operating table with the hips in 90° flexion, 20° abduction and neutral rotation to secure the lowest intraosseous pressures (Krebs et al. 1982).

The brachial arteries were cannulated with polyethylene catheters for blood pressure recording and arterial blood gas analyses (Figure 1). A central vein catheter served as central venous pressure recording. Cardiac output and core temperature were measured on a Cardiac Output Computer 9520® (Edwards Laboratories) with a Swan-Ganz® flow-directed thermolulution catheter (model 93-132-5 F) placed in a pulmonary artery via an external jugular vein. The correct position of the catheter tip was secured by pressure wave recording and fluoroscopy. The left carotid artery was exposed and a pigtail catheter (6.0 F) was introduced into the left ventricle for sphere injection. Another catheter (6.0 F) was advanced into aorta descendens via the right carotid artery to the level of the second lumbar vertebra for reference blood sampling. This catheter was connected to a reversed Unita I heavy duty pump. Using an image intensifier a 9.5 cm bone cannula (Radner®) with an outer diameter of 2 mm and an inner diameter of 1.5 mm was introduced



Figure 2. X-ray showing the location of the bone cannula.

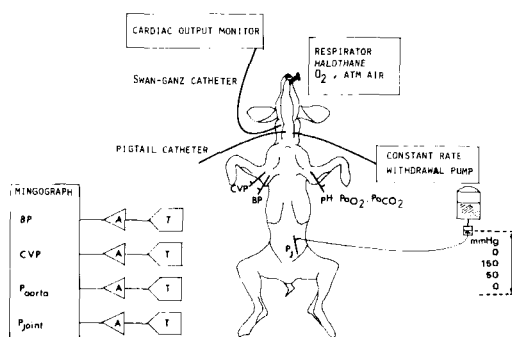


Figure 1. Outline of the experimental model. A, amplifier. T, transducer.

into the hip joint via a skin incision through the antero-lateral part of the acetabulum roof (Figure 2), in three dogs in the right hip and in three dogs in the left hip. The cannula was placed laterally to the femoral artery and vein. The stylet was withdrawn and the cannula was mounted with a three-way stop-cock, flushed with heparin saline solution and connected to the pressure recording system and to a plastic bottle of Rheomacrodex®.

Pressure recording system

The Radner cannula, the artery and the central vein catheters were connected to the pressure recording system (Siemens strain gauge transducer 746, Siemens pressure amplifier 863, Siemens Mingograph 805) via polyethylene manometer tubes (Portex®). To prevent

clotting, a constant perfusion system was established with heparin-saline solution at a rate of 5 ml/h using a Unita I heavy duty pump (Braun Melsungen AG). The intraarticular pressure of the hip was raised by elevating the bottle with Rheomacrodex or by compressing the plastic bottle with a pneumatic cuff. The pressures were continuously monitored, but the perfusion in the pressure-recording system was stopped 3 min prior to blood flow determinations.

Blood flow measurements

NEN-TRAC microspheres (New England Nuclear) with a diameter of 15 μ labelled with ^{141}Ce , ^{113}Sn , ^{46}Sc and ^{51}Cr were used to measure the regional flow in four different measurements in each dog. The spheres were suspended in 10 per cent Dextran with 0.01 per cent Tween 8 added. A volume of 4 ml microsphere solution containing 5.0×10^6 spheres was used at each flow determination. Before injection the batch was agitated for 5 min on a Whirlimixer®. The spheres were injected through the catheter in the left ventricle over a period of 30 s followed by flushing with 5 ml 37° heparin-saline. The reference blood sampling from aorta descendens was started 30 s before the sphere injection and continued until 4 min after the injection.

Blood flow was measured 30 min after insertion of the joint cannula (phase 1), 30 min after raising the intraarticular pressure to 50 mmHg (phase 2), 30 min after raising the intraarticular pressure to 150 mmHg (phase 3) and 30 min after decreasing the intraarticular pressure to 0 mmHg (phase 4). Steady state was controlled before and after each flow determination by means of cardiac output, mean arterial pressure, central venous pressure, core temperature and blood gasses including pH.

After the last flow measurement arthrography of the hip joint was performed with Isopaque-Amin® to control the capsule. Then the dogs were sacrificed with a

saturated dose of potassium chloride. The hind legs were dissected and the location of the bone cannula was controlled. A biopsy was taken from the hip joint capsule. Cancellous bone biopsies with a diameter of 0.8 cm were taken with a bone biopsy drill (Bordier®) from the proximal femoral metaphysis and the acetabulum. The proximal femoral epiphysis was freed from the epiphyseal plate and divided into two pieces. The samples were placed in preweighed plastic vials for gamma radiation counting. The reference blood samples and tissue samples were counted in a 4-channel scintillation system with the channels set for the four principal energies for the used isotopes. The counts in each channel were corrected for background and cross talk from other isotopes. The total counts for the single reference blood sample and the single tissue biopsy were calculated, and the regional blood flow rate determined according to Hales (1974).

Statistics

Mean values and standard errors of the mean (S.E.M.) were calculated from the recorded parameters. Blood flow rates including the haemodynamic responses to changes of the intraarticular pressure were examined by a multi-way analysis of variance. Comparison of the means was performed by the Student t-test. *P*-values of less than 0.05 were considered significant.

For further details concerning the blood flow measurements, see Büniger et al. (1982).

RESULTS

Regional blood flow (Table 1)

In the femoral head the initial blood flow rate, 47.05 ± 10.83 ml/min/100 g, was not signifi-

Table 1. Regional blood flow rates in millilitres per minute per 100 grams (mean $\pm$ S.E.M.)

	Phase 1	Phase 2	Phase 3	Phase 4
Femoral head	E: 47.05 ± 10.83 C: 46.09 ± 12.83	$30.39 \pm 7.04(a)$ 56.46 ± 11.13	$3.88 \pm 2.08(a+b)$ 85.12 ± 13.95	$96.22 \pm 18.58(a)$ 76.23 ± 12.12
Proximal femoral metaphysis	E: 83.01 ± 20.69 C: 68.07 ± 26.93	80.32 ± 14.37 70.33 ± 21.91	$114.08 \pm 14.12(b)$ 88.20 ± 24.80	100.50 ± 12.58 97.47 ± 22.56
Lateral part of acetabulum	E: 43.67 ± 7.65 C: 33.47 ± 4.77	48.25 ± 4.77 46.61 ± 9.54	$83.74 \pm 16.58(a)$ $82.27 \pm 17.81(a)$	$66.19 \pm 10.80(a)$ $76.99 \pm 16.19(a)$
Hip joint capsule	E: $40.70 \pm 28.97(b)$ C: 9.46 ± 3.36	$59.80 \pm 19.37(a+b)$ 10.50 ± 2.01	$113.52 \pm 24.80(a+b)$ 14.11 ± 3.39	$181.01 \pm 72.21(a+b)$ 9.68 ± 1.93

E: side of experiment.

C: side of control.

a: significant difference from the initial flow.

b: significant difference from the flow on the control side.

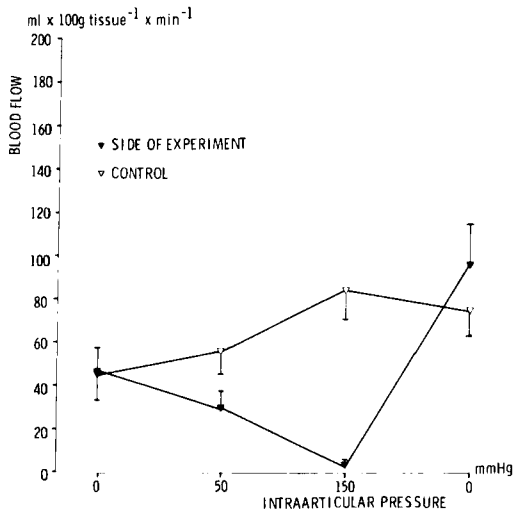


Figure 3. The flow rates in the femoral head during the intraarticular pressure increase.

cantly different from that of the control side. The blood flow decreased in phase 2 to 30.39 ± 7.04 ml/min/100 g (35.4 per cent) and in phase 3 to 3.88 ± 2.08 ml/min/100 g. Both of these values were significantly different from the initial flow rate. In phase 4 the flow increased to 96.22 ± 18.58 ml/min/100 g, significantly different from

the initial flow rate. On the control side the flow was insignificantly increased in phases 2, 3 and 4 (Figure 3).

The proximal femoral metaphysis showed the highest of the measured intraosseous flow rates. In the proximal femoral metaphysis and in the lateral part of acetabulum the flow rates were increased in phases 3 and 4, both on the experimental and on the control side.

In the hip joint capsule the flow rate in phase 1 was significantly higher on the experimental side as compared to the control side. While the flow on the control side remained constant a significant increase of the flow on the experimental side occurred in phases 2, 3 and 4, most pronounced in phase 4 (Figure 4).

Central haemodynamics during the experiments

The blood gasses, the cardiac output, the central venous pressure, the pH and the temperature remained constant during the experiments. The initial blood pressure was 75.0 ± 2.9 . In phase 2 it increased to 82.2 ± 4.5 , in phase 3 to 91.7 ± 6.6 and in phase 4 it was 89.3 ± 3.3 . The values in phases 3 and 4 were significantly higher than in phase 1.

No rupture of the hip joint capsule was observed by arthrography. At the dissection all bone cannulae penetrated into the hip joint and in no case was the femoral head damaged.

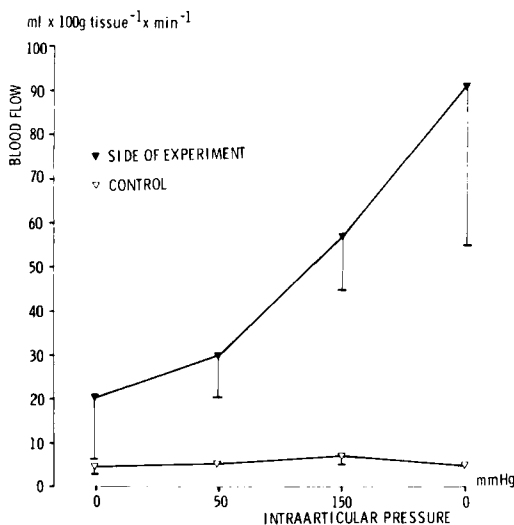


Figure 4. The flow rates in the hip joint capsule during the intraarticular pressure increase.

DISCUSSION

The blood circulation in bone is controlled by neural, hormonal and metabolic mechanisms. Stimulation of the sympathetic nerves decreases bone blood flow, as does administration of vasopressor hormones such as adrenaline, noradrenaline and pitressin. Metabolic factors such as acid metabolites, low pH and high carbon dioxide and low oxygen tensions increase bone blood flow. In addition to these three control mechanisms, many other systemic, regional and local factors apparently affect bone blood flow (Shim 1968).

When the intracapsular pressure of the hip joint in the present study was raised to 50 mmHg,

thus being between the venous and the arterial pressure, the flow in the juvenile femoral head was reduced significantly (35 per cent). After a further increase to 150 mmHg, which is above the mean arterial pressure, the flow almost ceased. The study supports Launder et al. (1981) who, using the same technique for flow measurement, found a significant decrease of the flow of 60 per cent in the femoral head of puppies and an insignificant drop in adult dogs, when the intracapsular pressure was 65 cm H₂O. At the same time a significant intraosseous pressure occurred in the femoral head of the puppies. The authors concluded that as intraepiphyseal pressure rises with tamponade, the intracapsular resistance is finally overcome and a modicum of flow is obtained. The various degrees of impairment of the flow after venous tamponade in the two studies may be due to differences in the animals and the experimental conditions. For example the initial flow in our study was 47.05 ± 10.83 ml/min/100 g and in Launder et al.'s (1981) 11.88 ± 2.17 ml/min/100 g. In different microsphere studies there is a large variability in bone blood flow. Hoffbrand & Forsyth (1969) have concluded that the variance reflects a real difference between animals and not poor reliability of the method. New-born puppies have very high intraosseous flow rates, especially in the juxta-epiphyseal regions, and these are reduced as the animals mature (Light et al. 1981).

In contrast to the present study and the study by Launder et al. (1981), Borgsmiller et al. (1980), using the hydrogen wash-out technique, found that the blood flow in the proximal epiphysis in puppies was unchanged at an intraarticular pressure of 50 mmHg and not impaired until at 100 mmHg.

Placing the cannula in the hip joint we found it very important not to damage the vasculature to the femoral head because this might change the intraosseous blood flow. Instead of dissecting the hip joint capsule, we introduced the cannula through acetabulum, as did Ganz et al. (1981). This did not alter the flow in the femoral head as compared to the control side. Neither did the cannulation of acetabulum cause any significant flow increase in this bone, which is in accordance with other studies (Bouteiller et al. 1979, B nger

et al. 1982). On the other hand the cannulation and the following flushing of the joint resulted in a significant flow increase in the hip joint capsule, which had presumably been even higher after dissection and puncture. With the present mode of entry we also avoided a leakage of the capsule.

Ischaemia of a tissue is usually followed by a period of hyperaemia (Kennedy et al. 1981), and this was also seen in the femoral head. In the hip joint capsule the flow was increasing from phase 1 to phase 4. The flow in the synovium presumably ceases when the intraarticular pressure passes the arterial pressure (McCarty 1974), indicating that the flow in phase 3 occurred exclusively in the fibrous part of the capsule. It may be suggested that the increased flow in phase 3 in the hip joint capsule is caused by an autoregulatory mechanism tending to restore the blood supply to the suffering femoral head and synovial membrane. We also observed elevated flow rates in the proximal femoral metaphysis and in acetabulum, both on the experimental side and on the control side, in phases 3 and 4. The simultaneous significant increase of the blood pressure suggests a systemic effect during and after the intraarticular pressure increase. The cause is questionable, but it could be a resorption of Rheomacrodex from the hip joint. The constant values of the blood gasses and pH during the experiments argue against metabolic factors being the cause.

Woodhouse (1964) showed that puppies developed a complete avascular necrosis of the femoral head after 12 h with an intraarticular tamponade of 50 mmHg. This is in contrast to Tachdjian & Grana (1968) who found that avascular necrosis of the femoral head in puppies was produced when the initial level of increased intraarticular pressure was 200 mmHg or above and the duration of increased pressure was 10 h or more. Ganz et al. (1981) studied the blood circulation in the femoral head of juvenile rabbits by means of Disulfen blue, which after injection colours bone with intact circulation. They found that an increased intraarticular pressure in the hip joint of 80 mmHg for 4 h resulted in permanent circulatory disturbance. The present demonstration of a decreased flow in the juvenile femoral head after venous tamponade is in agreement with Woodhouse (1964), who stated that al-

though the arterial blood supply cannot be occluded by less than systemic arterial pressure, the physiological effect of minor degrees of intracapsular tamponade is equally damaging. Venous stasis with consequent capillary engorgement, fluid extravasation, microcapillary sludging and irreversible intravascular thrombosis leads to avascular necrosis.

There is considerable evidence that Calvé-Legg-Perthes' disease may be preceded by an episode of synovitis (Fox & Griffin 1956, Jacobs 1971, Kemp & Boldero 1966, Spock 1959). As synovitis with an increased amount of synovial fluid is accompanied by increased intraarticular pressure (Jayson & Dixon 1970), it seems likely that a consequent venous tamponade and compromised blood circulation may result in the development of Calvé-Legg-Perthes' disease.

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