Effect of intracapsular hyperpressure on femoral head blood flow

Laser Doppler flowmetry in dogs

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Intracapsular hyperpressure in the hip joint of dogs affected femoral head blood flow, especially in the juvenile animals. Graphic recording of the laser Doppler signal curve using rapid sampling time demonstrated venous hip joint tamponade in both juvenile and adult dogs. Laser Doppler flowmetry seems to be a sensitive and reproducible method to demonstrate femoral-head blood-flow changes.

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Submitted 90-11-15. Accepted 91-02-18

Intracapsular pressure has been suggested to contribute to the pathogenesis of Perthes' disease (Ferguson and Howorth 1934, Kemp 1973). Experimentally, hip joint hyperpressure has been shown to affect blood flow within the femoral head epiphysis (Borgsmiller et al. 1980, Launder et al. 1981, Lucht et al. 1983, Svalastoga et al. 1989) and to cause osteonecrosis (Woodhouse 1964, Tachdjan and Grana 1968, Kemp 1973, Vegter and Lubsen 1987). However, it is controversial whether or not adult hip joint tamponade can alter femoral head blood flow (Launder et al. 1981, Kipfer et al. 1983). Similar findings have been reported by Strömqvist et al. (1985, 1988) and by Wingstrand (1986) in cervical hip fracture and in transient synovitis in children.

Previous methods for evaluation of blood flow to bone tissue have been indirect and could not be applied clinically (Tothill 1984).

Laser Doppler flowmetry (LDF) has been used to measure cancellous bone blood flow experimentally (Hellem et al. 1983, Swiontkowski et al. 1986) and clinically (Swiontkowski et al. 1987).

We studied the influence of intracapsular hip joint pressure on femoral head blood flow in juvenile and adult dogs.

Material and methods

Effect of changes in intracapsular pressure on femoral head blood flow was measured as described by Woodhouse (1964), Ganz et al. (1981), and Vegter and Lubsen (1987). Both hips of 3 adult mongrel dogs (26–35 kg) and 3 juvenile, 3–4-month-old dogs (8.2–12.4 kg) were used for this study. The animals were anesthetized and monitored as described by Launder et al. (1981).

The dorsolateral rim of the acetabulum and hip joint capsule were exposed via a lateral approach, with care being taken to avoid injuring the posterior vessels. A 3.2-mm hole was drilled through the acetabular wall and the weight-bearing area of the socket (Figure 1). Traction to the limb during drilling prevented damage of the femoral head. A specially designed cannula, with two side apertures at its tip to avoid obstruction of the hydrostatic pressure system (Vegter and Lubsen 1987), was screwed into the hole. The correct position of the cannula tip within the joint cavity was controlled by physiologic saline. When the cannula was properly placed, the contact zone between cannula and bone was dried and a watertight seal made using cyano-acrylate.

A Dextran 70 filled hydrostatic reservoir at the same level of the hip joint was connected to the cannula. During the experiment, the patency of the hydrostatic system was verified by observing displacement of an air bubble in the horizontal part of the intravenous tubing with a change in the position of the limb.

Next, a 2.6-mm hole was drilled through the lateral aspect of the subtrochanteric cortex into the femoral neck under the guidance of an image intensifier. The drill hole was directed to the center of the femoral head and to a depth of 5 mm, down to the articular cartilage. The LDF probe (outer diam. 2.2 mm) was inserted, and the connection between probe and bone was dried and watertight-sealed with cyano-acrylate.

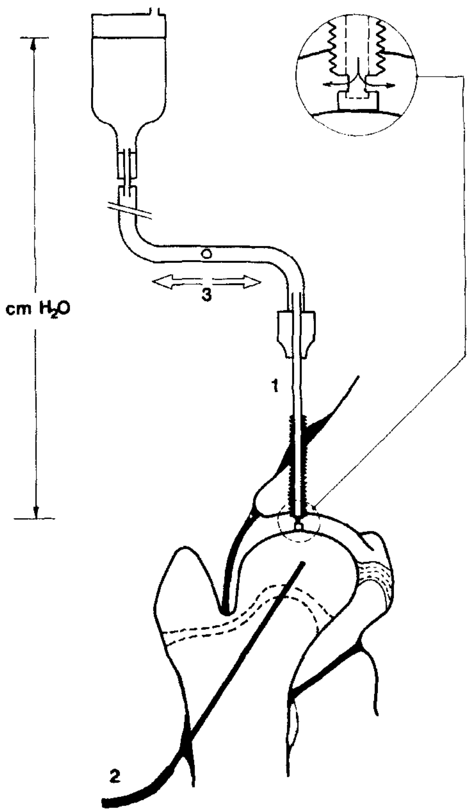

Figure 1. Method of raising intracapsular pressure and flow measurement within the femoral head.
1. The threaded transacetabular cannula.
2. The location of the laser Doppler probe within the proximal femur.
3. Air bubble in the horizontal part of the tubing to check continuity with the joint by movement of the limb.

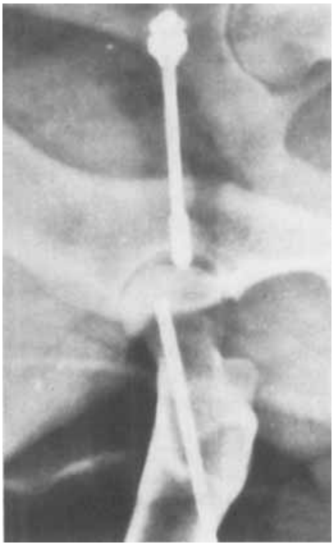

Figure 2. The hip joint with both the transacetabular cannula and laser Doppler probe in situ. Note that the probe tip has passed the physeal growth plate of the femoral head.

In the immature dogs special attention was drawn to the fact that the drill hole had to pass the epiphyseal plate (Figure 2).

The principles of the flowmeter used (Periflux Pf1d; Perimed Co., Stockholm, Sweden) have been published by Nilsson et al. (1980, 1982). The output signal of the flowmeter represents the product of the concentration and mean velocity of the red blood cells within a small volume under the probe, and is expressed in volts. In our study the gain setting of ×100 and cut-off frequency of the laser Doppler signal processing filter of 4 kHz were used, whereas the signal time constant estimated 1.5 sec.

The BCF within the femoral head was measured at atmospheric pressure and with 20–180 cm of water pressure within the hip joint created by elevating the infusion bottle. In every hip, two series of intracapsular pressure elevations were done, and also random application of the various pressure levels was used to check the reproducibility of the results. The laser Doppler curve pattern at the various intracapsular pressures was at last studied using a shorter signal time constant of 0.2 sec.

The obtained relative laser Doppler flow units belonging to each stepwise increase in intracapsular pressure of 20-cm water were expressed as a percentage of the flow value at hip joint pressure, and the data of juvenile and adult dogs were compared using linear regression analysis.

Results

In 11 (of the 12 hips) the laser Doppler signal could be recorded adequately. During the experimental period the blood pressure varied between 115/65 and 135/85 mmHg.

When measured at atmospheric hip joint pressure, there was an extraordinary variability in laser Doppler signal level between both hips within the same dog, as well as between the various animals. In the juvenile dogs the mean LDF signal level was, on an average, 4.1 V (± SD 1.3) and in the adults 3.9 V (± SD 1.1).

A stepwise increase in the hydrostatic hip joint pressure resulted in a reduction of flow values in all 11 femoral heads under study: in most cases there was an

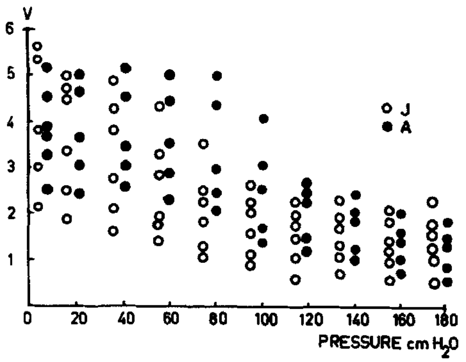

Figure 3. Relation between laser Doppler signal value expressed in volts and intracapsular pressure in six juvenile (○) and five adult hips (●).

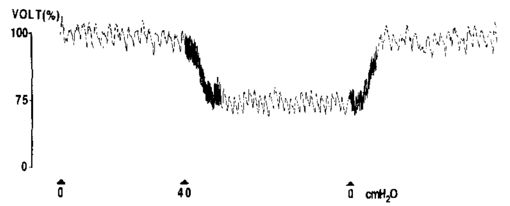

Figure 6. Laser Doppler signal curve in a juvenile dog using a signal sampling time of 0.2 sec. Intracapsular pressure rise to 40-cm water results in a more regular sawtooth type curve pattern, which appeared to be synchronous with cardiac rhythm.

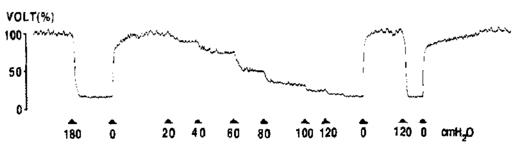

Figure 4. Graphic recording of the laser Doppler signal during stepwise change of the intracapsular hip joint pressure in a juvenile dog resulting in decrease in signal level, as well as amplitude of the curve pattern. Repeated return to atmospheric hip joint pressure (0 cm H_2O) demonstrates the reproducibility of the laser Doppler flow value.

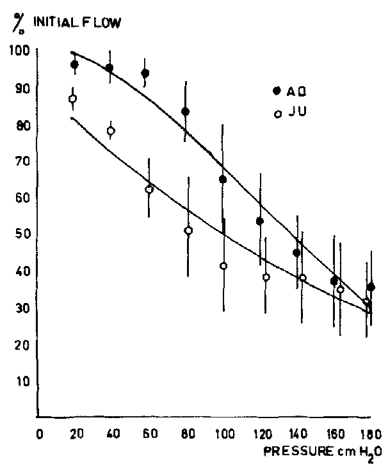

Figure 5. The mean laser Doppler flow values expressed as a percentage of the initial flow values at the various hip joint pressures ± S.D. and the calculated best fitting curves for the adult (●) and juvenile (○) animals.
AD y = a · exp (–x · b) a = 100 · 2 · b = –3.79E – 05; r = –0.99 and JU y = a · exp (bx) a = 93.5. b = –6.41E – 03; r = –0.97, respectively.

exponential relationship (Figure 3). From the two series of intracapsular pressure elevations and random application of the various pressure levels within the same hip joint, the reproducibility of the flow value at the same pressure was estimated to be within 5 percent. Graphic recording of the laser Doppler signal at the various pressure levels (Figure 4) not only showed reduction of the signal value, but also a decrease in amplitude of the signal curve pattern in both adult and juvenile animals.

The mean laser Doppler flow values expressed as a percentage of the initial flow values during the period of stabilization are given with the calculated best fitting curves. The graph (Figure 5) distinctly shows a different relationship between both groups, with differences in flow significant ($P < 0.01$) for intraarticular hip joint pressures up to 100 cm of water.

Recording of the laser Doppler signal using rapid signal sampling time (0.2 sec) showed a change of the characteristic irregular flow curve pattern into a more regular sawtooth type, which appeared to be synchronous with cardiac rhythm (Figure 6) at hip joint pressure varying from 30 to 45 cm water in the puppies and from 55 to 80 cm water in the adult dogs.

Following cardiac arrest, the laser Doppler signal in the immature proximal femur epiphysis tended to decrease not more than 7 percent under the signal level measured at a hip joint pressure of 180 cm water. In the adult dogs, this decrease was not more than 13 percent.

Discussion

Our results demonstrate that hip joint hyperpressure tamponade may affect femoral head blood flow in both juvenile and adult dogs. Swiontkowski et al. (1986), also using laser Doppler, observed a decline in femoral blood flow in adult rabbits at hip joint pressures of 20–40 cm water. Launder et al. (1981) used isotopically labeled microspheres and could not demonstrate a change in femoral head blood flow in adult dogs following a hip joint hyperpressure of 65 cm water. Our findings in the juvenile dogs are in agreement with those of Launder et al. (1981) and Lucht et al. (1983), who also studied the effect of a hip joint hyperpressure of 65 cm water on femoral head blood flow in juvenile dogs. Borgsmiller et al. (1980) used the hydrogen washout technique, and found no impairment of blood flow in the femoral head epiphysis of dogs until a pressure of 136 cm water.

These controversial findings may be explained by limited reliability of the indirect methods available for bone blood flow measurement. Also a transacetabular cannula with an opening at the end of the tip may give artefactual readings. A cannula with two openings at the side of the tip seems more reliable (Vegter and Lubsen 1987).

The greater susceptibility of femoral head blood flow to a rise in intracapsular pressure in skeletally immature dogs when compared with adults, as seen in our study, may be explained by the change in vascular supply of the proximal femur that occurs during growth (Trueta 1957, Ogden 1974). Before closure of the growth plate, the femoral head epiphysis is mainly supplied by intracapsular vessels running along the femoral neck, vasa retinaculae, with no contribution across the growth plate and only a small contribution of vessels in the ligamentum teres.

These intracapsular vessels may be occluded by an increase in intracapsular pressure. As in the adult state there seems to be a collateral epiphyseal circulation due to intraosseous metaphyseal vessels (Trueta and Harrison 1953) and/or incorporation of the retinacular vessels in fibroosseous channels along the femoral neck (Kemp 1973), it is reasonable to suggest that the femoral head is less vulnerable to increased intracapsular pressure.

Our technique included a risk of artefactual flow values. Tight fittings of the probe are necessary (Swiontkowski et al. 1986).

Our observations that venous hip joint tamponade pressures affect adult femoral head blood flow would support the hypothesis that primary coxarthrosis may result from recurring synovitis (Arnoldi et al. 1972).

The healing complications in intracapsular femoral neck fractures, among other things, seem to be dependent on the viability of the femoral head (Hulth 1965, Strömqvist 1983). The possibility that hip joint tamponade may contribute to avascularity of the femoral head in undisplaced femoral neck fractures has been demonstrated by Strömqvist et al. (1985, 1988) and Wingstrand et al. (1986).

We conclude that laser Doppler flowmetry is a sensitive method to demonstrate changes in femoral head blood flow in dogs that are due to hip joint hyperpressure tamponade. This tamponade affects the blood flow more in juvenile dogs than in adults.

Acknowledgement

The authors wish to thank Dr. Ir. J. Oosting for statistical advice.

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