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RELATIONSHIP BETWEEN INTRAOSSEOUS PRESSURES AND INTRA-ARTICULAR PRESSURE IN ARTHRITIS OF THE KNEE

An Experimental Study in Immature Dogs

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The influence of chronic synovial inflammation and effusion on the juxta-articular bone haemodynamics in the juvenile knee was studied in 12 immature dogs with Carragheenin-induced unilateral arthritis.

Using a fluid filled electromanometric pressure recording system simultaneous pressure measurements were taken from the distal femoral metaphysis, juxta-articular epiphyses and knee joint cavity in general anaesthesia followed by intraosseous phlebographies.

During resting conditions the intraosseous pressure of the distal femoral epiphysis and the intra-articular pressure was significantly elevated. The phlebographies showed increased accumulation of contrast in arthritic femoral epiphyses with decreased contrast clearance rate. During increasing intra-articular pressure an augmented vulnerability of the blood supply of the arthritic femoral epiphyses was demonstrated.

The results suggests that joint effusion may play an important role in the bone changes in juvenile degenerative arthritis of the knee.

Key words: bone blood flow; intraosseous pressure; intra-articular pressure; knee joint; experimental arthritis; haemophilic arthritis; juvenile rheumatoid arthritis, dogs

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Pathophysiological characteristics of both juvenile chronic arthritis (JCA) and haemophilic arthropathy (HA) are synovial inflammation and elevation of the intra-articular pressure (Jayson & Dixon 1970a, Stein & Duthie 1981). In both diseases epiphyseal overgrowth and osteoporosis are observed particularly in the knee and elbow (Duthie et al. 1974, Goel et al. 1974, Ahlberg 1965).

Experimental studies in juvenile knee joints have shown an impact of articular pressure on the haemodynamics of the juxta-articular bones (Bünger et al. 1981, 1982a,b). It has been suggested that elevation of intra-articular pressure in juvenile arthritis may play a role in the development of epiphyseal growth disturbances. However, this hypothesis is based on investigations in normal knee joints and further documentation of the influence of synovial inflammation and chronic elevation of intra-articular pressure on juxta-articular haemodynamics is needed.

The aim of the present study was thus to investigate intra-articular and intraosseous pressure changes during experimental arthritis of the juvenile knee and to determine the intraosseous

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pressure response of the arthritic knee to changes of intra-articular pressure.

MATERIAL AND METHODS

Twelve mongrel puppies, 8–10 weeks old and weighing 5.5 kg (3.5–7.9) comprised the material. Unilateral arthritis of the right knee was induced by weekly instillation of 2 increasing to 3 ml Carragheenin solution 1% into the knee joint for 10 weeks (Bünger et al. 1982c).

Pressure investigations were commenced 1 week after the last instillation of Carragheenin. After premedication with 0.5 ml 0.1% Combelen® (10-(3-dimethylaminopropyl)-propionyl phenothiazine) anaesthesia was induced by intravenous Brietal® (methohexital) 7 mg/kg and after oro-tracheal intubation maintained by halothane (0.5–1.0 per cent) through a constant volume ventilator. In order to avoid changes of bone haemodynamics secondary to altered joint position the dogs were placed in supine position with the hips immobilized in 90° flexion, 45° abduction and neutral rotation, while the knees were kept in 90° flexion (Bünger et al. 1981).

Pressure recording

Polyethylene catheters were inserted into the brachial arteries for blood pressure (MAP) recording and blood gas analyses. A central venous catheter served for central venous pressure recording (CVP) and as a route for administration of small volumes of sodium bicarbonate (7.5 per cent) in case adjustment of blood gasses and pH was needed.

A five-channel fluid filled electromanometer system with transcutaneous bone cannulation (Bünger et al. 1981) was used for simultaneous pressure recording in the distal femoral metaphysis (P_{FM}), distal femoral epiphysis (P_{FE}) and proximal tibial epiphysis (P_{TE}) along with intra-articular pressure recording (P_J) and alternating MAP and CVP recording (Figure 1). The level of the heart was chosen as reference zero pressure level for intraosseous and central haemodynamic pressures, while the intra-articular pressure value was measured in relation to knee joint level. An initial intraosseous pressure registration was followed by knee cavity cannulation and P_J recording in the inter-condylar compartment of the knee. The knee joint cannula was then placed in the patello-femoral compartment and connected to an infusion set with normosaline. The intra-articular pressure could be raised by elevating the infusion container (Bünger et al. 1981).

The intraosseous pressures were measured during elevation of P_J with increments of 10 cm H_2O from zero to 120 cm and after evacuation of the knee cavity. An equilibration period of 5 min was used after each change of P_J before pressure recording. Both knees in each dog were examined in a random sequence.

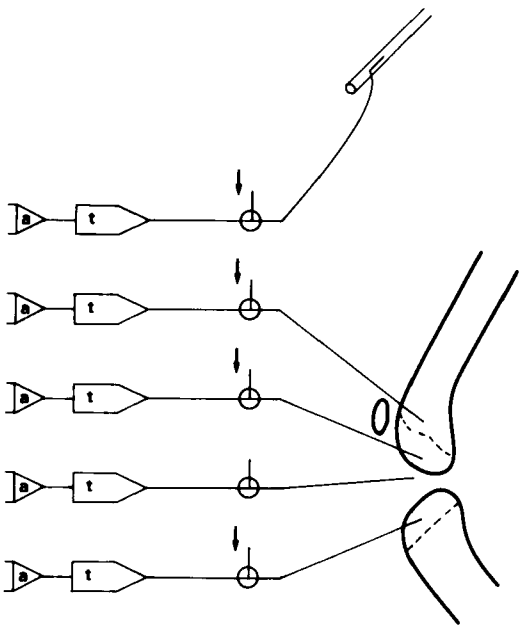

Figure 1. Pressure recording system used for simultaneous pressure measurements in the brachial artery, the superior caval vein, juxta-articular bones of the knee and the joint cavity. (a) Siemens pressure amplifier 863, (t) Siemens strain gauge transducer 746. The arrows indicate constant rate perfusion (5 ml/h).

Intraosseous phlebography

The intraosseous pressure recordings were concluded with intraosseous phlebographies to visualize correct position of the bone cannula in the distal femoral epiphysis and to estimate the X-ray contrast clearance time from the distal femoral epiphyses of the empty arthritic and control knee joints. Five milliliters of Isopaque-Amin® were infused via the bone cannula into the epiphysis at a rate of 10 ml per min followed by 0.5 ml normosaline in order to empty the bone cannula and to eliminate X-ray contrast pooling around the bone cannula tip. The clearance rate was assessed by repeated X-ray exposures (46 KV, 100 MaS) with 1-min intervals from time zero to 16 min on Kodak X-Omat MA films. The film-focus distance was kept at 90 cm.

The dogs were sacrificed with saturated potassium chloride after the measurements and specimens from the knee joint capsule were taken for histological examination.

Statistics

The mean and the standard error of mean (SEM) were calculated from all parameters. Statistical significances were evaluated by Student's t-test for paired data. Dif-

Table 1. Intraosseous pressures in the distal femoral metaphyses (P_{FM}), distal femoral epiphyses (P_{FE}) and proximal tibial epiphyses (P_{TE}) in relation to the intra-articular pressures (P_J) in 12 immature dogs with unilateral Carragheenin-induced arthritis of the knee

	P_{FM} mmHg Mean ± SEM (range)	P_{FE} mmHg Mean ± SEM (range)	P_{TE} mmHg Mean ± SEM (range)	P_J mmHg Mean ± SEM (range)
Arthritic knees	9.9±0.9 (5–14)	*10.3±1.1 (5–17)	12.4±1.0 (7–18)	*6.5±0.6 (3–10)
Control knees	10.3±0.9 (5–15)	7.7±0.9 (3–13)	11.6±0.9 (6–16)	0.1±0.2 (−1–2)

* Statistical significant difference ($P < 0.05$) compared to the control value.

ferences were considered significant, when the P value was <0.05.

RESULTS

Resting pressure values (Table 1)

The intraosseous pressure in the distal femoral epiphyses of the arthritic knees was significantly higher than in the control knees. No significant differences were observed between the intraosseous pressures in the distal femoral metaphyses or the proximal tibial epiphyses. The correspondent intra-articular pressure in the arthritic knees was significantly elevated.

The pressure tracings from the arthritic femoral condyle showed an increased amplitude of the pulse wave compared to the control knee in seven dogs, while no differences were observed in the other five dogs.

Effect of elevated intra-articular pressure (Figure 2)

No changes were observed in P_{FM} on the experimental side or the control side, whereas a minimal increase of P_{TE} was observed on the control side, when the joint pressure was increased. In the control knees a significant P_{FE} increase was observed with a maximal value at a P_J of approximately 80 cm H_2O. In the arthritic knees the P_{FE} increase was insignificant due to an initial elevated level. The maximal level of P_{FE} was reached at a P_J of 70 cm H_2O. Further elevation of P_J resulted in a significant fall of P_{FE} in the arthritic knees compared to the control knees.

The pressure tracings showed generally higher amplitude of the pulse in the arthritic femoral epiphyses during elevation of P_J up to the maximal intraosseous pressure increase. Thereafter the amplitude declined and was eliminated at a P_J of 120 cm H_2O.

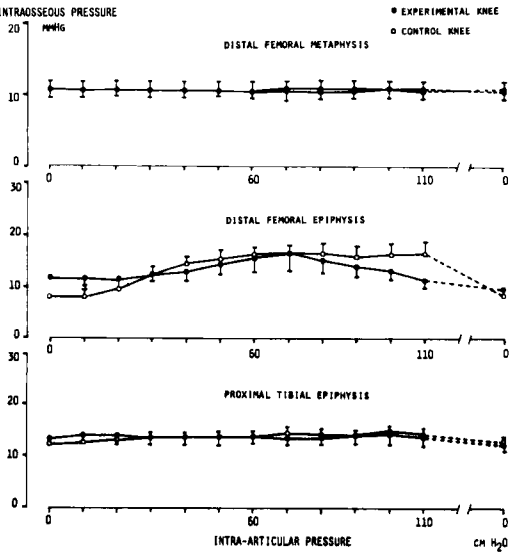

Figure 2. The relationship between intra-articular pressure and intraosseous pressures in the juxta-articular bones of the knees in 12 immature dogs with unilateral Carragheenin-induced arthritis.

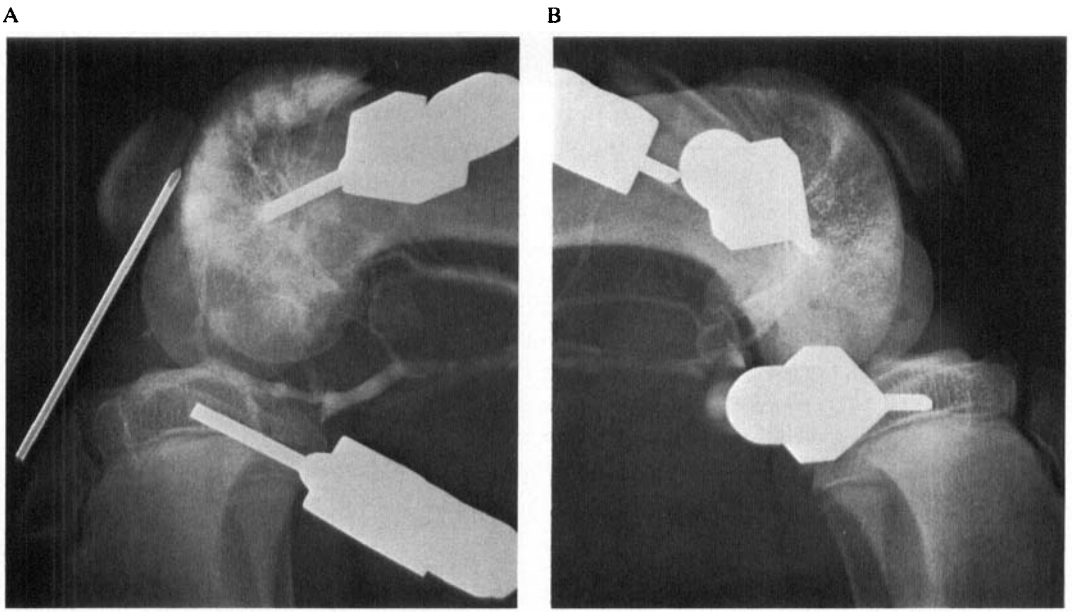

Figure 3. A + B, Intraosseous phlebography during injection of X-ray contrast (30 s) demonstrate accumulation of contrast in the arthritic epiphysis (A) particularly in the trochlea. The epiphyseal draining veins are dilated compared to the control epiphysis (B), where no accumulation of contrast was observed.

Intraosseous phlebographies

The contrast clearance time was 7 min (5–12) in the control epiphyses versus 12 min (8–>16) in the arthritic femoral epiphyses. The injection phase X-rays showed increased volumes of X-ray contrast in the arthritic epiphyses suggesting increase of vascular volume (Figure 3). Hence direct comparison of the clearance rates is difficult.

Central hemodynamics

During the investigations the MAP declined from an initial value of 72.6 ± 2.6 mmHg to 67.6 ± 2.3 mmHg. The CVP was initially 6.0 ± 0.5 mmHg and 6.5 ± 0.6 mmHg at the end of the pressure measurements.

Histological examinations

Microscopy showed synovial inflammatory changes in the right knee of all dogs. Synovial villous hypertrophy and mononuclear cell infiltration was found in all specimens from the right knee joint capsules. No signs of purulent arthritis were encountered.

DISCUSSION

The intraosseous pressure levels of the control knees in the present study are in accordance with our previous observations in immature dogs. The lowest pressure level is generally observed in the distal femoral epiphysis (Bünger et al. 1981, 1982b). The differences between the vascular compartments in the juvenile knee are elucidated by the isolated response of P_{FE} to intra-articular pressure increase. The distal femoral epiphyseal plate separates the metaphyseal and epiphyseal vascular compartments, leaving the metaphyseal venous drainage capacity unlimited during knee joint tamponade. The vascular supply of the proximal tibial epiphysis is largely extra-articularly located in contrast to the vascular supply of the distal femoral epiphysis (Scapinelli 1968) and this probably explains the different intraosseous pressure responses of the epiphyses during elevation of knee joint pressure (Lucht et al. 1981).

The increased resting P_{FE} of the arthritic knees in the present study suggests a sustained change of haemodynamics in the distal femoral epiphysis, while the lack of change of P_{FM} and P_{TE} demonstrates an unimpaired vascular drainage from

these two compartments during experimental arthritis. Several authors have described a direct correlation between intraosseous pressure and regional bone blood perfusion (Shim et al. 1972, Azuma 1964, Shaw 1963), hence the elevated P_{FE} of the arthritic knee might indicate the presence of hyperaemia, which is generally believed to cause the epiphyseal overgrowth in JCA and HA (Brattström 1963, Stein & Duthie 1981). Assuming the presence of decreased venous outlet resistance the unchanged P_{FM} and P_{TE} levels are not contradictory to the presence of hyperaemia in the distal femoral metaphysis and proximal tibial epiphysis. The elevated resting P_{FE} and the decreased contrast clearance rate suggest that the regional blood perfusion in the arthritic condyle is decreased due to increased venous outlet resistance. Both the synovial effusion and the inflammatory changes in the knee joint capsule might affect the epiphyseal draining veins. The reported resting P_J in the arthritic knees must be regarded as a minimal pressure, which was further increased during joint movement and weight bearing (Bünger et al. 1981, Jayson & Dixon 1970b), augmenting the impact on juxta-articular bone circulation.

In normal knees of immature dogs we have measured a 2–3 fold increase of P_{FE} during venous tamponade of the knee joint capsule (Bünger et al. 1982b). The intraosseous pressure increase reflected the venous outlet resistance though a simultaneous regional blood flow increase in distal femoral epiphyses was observed, too. Both local and regional autoregulatory mechanisms were activated and a blood flow increase was observed not only in the juxta-articular bones of the knee but also in the proximal femoral bone during knee joint tamponade.

In the present series the declining P_{FE} and decreasing amplitude of the pulses on the pressure tracings during elevation of P_J above 70 cm H_2O most likely mirror a declining blood supply, i.e. an arterial tamponade of the arthritic femoral epiphyses. The demonstration of increased vulnerability of vasculature of the arthritic femoral epiphysis is so far only based on intraosseous pressure registration, but it is apparent that some qualitative changes have been induced in the vasculature of the knee. This presumption is reinforced by the phlebographic evidence of increased vascular volumes.

Increased intraosseous pressure and phlebographic evidence of venous engorgement are pathophysiological characteristics of degenerative osteoarthritis of the knee and the hip (Arnoldi et al. 1972, Lynch 1974). The cause of impairment of the venous drainage is not fully clarified, but in the hip joint the presence of joint effusion seems of major importance (Arnoldi & Reimann 1980). In rheumatoid arthritis, several authors have demonstrated synovial microvascular alterations (Kulka 1959, Branemark et al. 1963, Goldie 1970). Venular and capillary dilatation are prominent features of synovitis leading to a decrease in corpuscular flow velocity. The progressive circulatory failure is probably due to a combination of several factors such as segmental inflammation of venules and capillaries, increased viscosity of the blood due to plasma leakage from dilated vessels as well as a direct compression of synovial vessels by the increased joint pressure. Using a magnifying arthroscope, Inou et al. (1979) were able to study the changes in the capillary network of the synovium during various degrees of effusion in osteoarthritis of the knee. They found a significant correlation between the volume of synovial effusion and dilatation of the vascular network. In rheumatoid arthritis all capillaries were dilated, suggesting the permanent presence of vasoactive dilatating substances. The intimate relationship between the synovial and juxta-articular blood circulation (Scapinelli 1968) makes it most probable that vasoactive substances like prostaglandins, bradykinins and histamine released from the inflamed synovium (Liew & Dick 1981) influence the juxta-articular bone vasculature competing with the autoregulatory mechanisms released by the ischemia of the synovium and the bone.

An analysis of the growth patterns of the knees in the present studies showed hypotrophy of the diaphyseal and metaphyseal juxta-articular bones of the arthritic knees combined with overgrowth of the distal femoral epiphyses (Bünger et al. 1982c). Venous engorgement including decreased pH and pO_2 with increased pCO_2 stimulates bone formation (Brookes 1971) and the overgrowth might thus be another evidence of the

circulatory changes in the distal femoral epiphysis during chronic arthritis.

In conclusion, the present studies demonstrated that Carragheenin-induced arthritis of the juvenile knee for 10 weeks was followed by chronic inflammatory changes and synovial hypertrophy of the knee joint capsule with significant elevation of the knee joint pressure. The intraosseous pressure measurements suggested a chronic change of the haemodynamics in the distal femoral epiphyses in which the influence of increased intra-articular pressure may play a major role. The additional demonstration of augmented vulnerability of the femoral epiphyseal blood supply during knee joint tamponade may be an important factor in the understanding of the pathophysiology of juvenile degenerative joint disease.

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