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INTRAOSSEOUS PRESSURE IN THE PATELLA IN RELATION TO SIMULATED JOINT EFFUSION AND KNEE POSITION

An Experimental Study in Puppies

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Simultaneous pressure measurements were carried out in the patella, juxtaarticular epiphyses and the knee joint cavity of six mongrel puppies. The mean intraosseous pressure in the patella was 12.2 mmHg, range 8–15 mmHg. An increase in intraarticular pressure in turn caused an increase in the intraosseous pressure of the patella and juxtaarticular epiphyses. The pressure increase in the patella was the most pronounced. During extension of the knee joint, a significant rise in intraosseous pressure of the tibial epiphysis and patella was observed, whereas during flexion femoral epiphyseal pressure and patellar pressure increased significantly. The introduction of moderate intraarticular effusion amplified intraosseous pressure responses during flexion of the knee joint. The intraosseous pressure changes during knee movement could not be explained solely by the corresponding changes in intraarticular pressure.

Intraosseous phlebography revealed a venous drainage system largely parallel to the arterial blood supply. The contrast clearance time was decreased during moderate elevation of the intraarticular pressure, suggesting increased bone blood flow of the patella.

Key words: bone blood flow; intraarticular pressure; intraosseous pressure; joint effusion; joint position; knee joint; patella; venous drainage

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The growth disturbances observed in juvenile degenerative arthritis (JDA) of the knee joint are epiphyseal enlargement and osteoporosis. These are often combined with a thickening and squaring of the patella (Duthie et al. 1972, Goel et al. 1974). Experimental studies on immature dogs have indicated a significant influence of increased intraarticular pressure of the knee joint on intraosseous pressure in the distal femoral epiphysis (Lucht et al. 1981, Bünger et al. 1981).

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Long-standing elevation of intraarticular pressure, which is seen in both chronic rheumatoid arthritis and haemophilic arthritis (De Palma et al. 1956, Jayson & Dixon 1970a, b, Arnold & Hilgartner 1977) may, by provoking epiphyseal hypertension and intraosseous engorgement, be an important factor in the development of epiphyseal growth disturbances.

The aim of the present study was to investigate the intraosseous pressure of the patella during increasing intraarticular pressure and changes of the knee joint position. A supplementary evaluation of the haemodynamics of the patella was carried out by intraosseous phlebography.

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MATERIALS AND METHODS

Both knees of six 10-week-old mongrel puppies, mean weight 8.2 kg, total range 5.4–9.5 kg were investigated. The dogs were premedicated with 0.5 ml 0.1 per cent Combelen® (10-(3-dimetyl-aminopropyl)-propionyl phenothiazine). Anaesthesia was induced by intravenous Brietal® (Methohexital) 7 mg/kg and maintained after orotracheal intubation by Halothane 0.5–1.0 per cent in a 50/50 mixture of oxygen and atmospheric air through a Monaghan 300 D/M ventilator. A Venflon® needle (120/18G) and a vein catheter (Intracath® no. 8) were inserted into the right brachial artery and right brachial vein respectively, for the continuous recording of mean blood pressure (MAP) and central venous pressure (CVP).

Monitored by an image intensifier, Radner® bone biopsy cannulae with an inner diameter of 1.5 mm were inserted transcutaneously and extraarticularly from the medial side of the knee joint into the distal femoral epiphysis (FE) and the proximal tibial epiphysis (TE) to measure the intraosseous pressures P_{FE} and P_{TE}. The patellar cannula was inserted into the centre of the patella (PA) via a small skin incision through the superior patellar tendon. After flushing with heparin-saline solution (5,000 U/l), the Radner cannulae, and the arterial and central vein catheters were connected to a five-channel pressure recording system as described previously (Bünger et al. 1981). To prevent clotting, constant heparin-saline perfusion (5,000 U/l) at a rate of 3.7 ml/h was established. The intraarticular pressure (P_J) was measured via a needle (Terumo®, 120 mm × 38 mm) inserted into the intercondylar compartment of the knee joint (Figure 1).

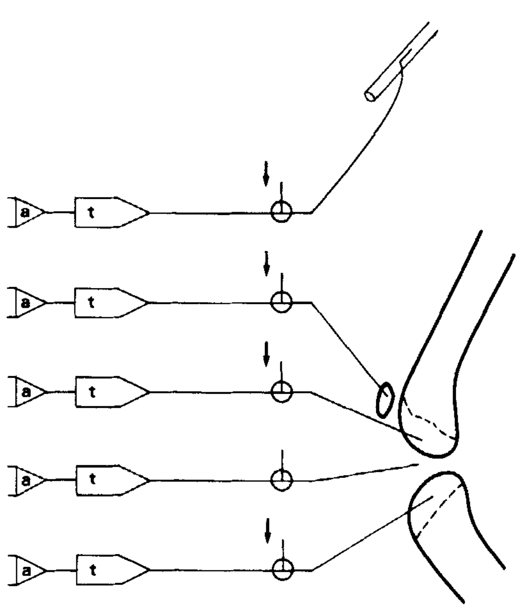

Figure 1. Schematic representation of the pressure recording system. Simultaneous pressure measurements are taken from the brachial artery, superior caval vein, patella, distal femoral epiphysis, knee joint cavity and proximal tibial epiphysis. t: Siemens® strain gauge transducer 746. a: Siemens® pressure amplifier 863. The arrows indicate constant rate perfusions.

Control pressure measurements were performed with the knees at 90° flexion. Thereafter the P_J and intraosseous pressures were recorded during a series of movements ranging from 10° to 150° flexion, with 10° intervals. Two minutes were allowed for equilibration before the pressures were recorded.

Next the relationship between the P_J and the intraosseous pressures was recorded. With the knees maintained at 90° flexion, the P_J was elevated in increments of 10 cmH_2O by heparin-saline infusion (5,000 U/l) into the knee joint via a three-way stop cock connected to the Terumo® needle. The corresponding intraosseous pressures were recorded. An equilibration period of 2 minutes was allowed before each change in P_J.

This procedure was followed by a re-examination of the relationship between the position of the joint and the intraosseous/intraarticular pressures, this time with simulated joint effusion at a knee joint pressure of 28 mmHg in 90° flexion. The positions of maximum flexion and extension were achieved by passive movement until resistance was felt without applying external pressure on the femur or the knee.

A supplementary evaluation of the haemodynamics of the patella in relation to the P_J was carried out using intraosseous phlebography. Two ml Isopaque-Amin® were infused into the patella via the Radner cannula at a rate of 8 ml/min. The contrast clearance time was assessed by repeated X-ray exposures (46 KV, 100 MaS) with 30-second intervals from time 0 to 15 minutes. The film-focus distance was 90 cm. One phlebography was performed on each patella, alternating on the left and right sides at a P_J of 0 and 28 mmHg respectively. Because of technical difficulties complete paired data were obtained only in four dogs. The draining veins from the patella were described on the basis of frontal and sagittal exposures during the injection phase.

At the end of the experiments the dogs were sacrificed with a saturated dose of potassium chloride and the knees dissected to ensure that unintentional perforation of the knee joints had not occurred.

For statistical purposes, the mean and the standard error of the mean (SEM) of the pressure values were calculated. Statistical significances were evaluated by Student's *t*-test for paired data. Differences were considered significant when the P value was < 0.05.

RESULTS

The initial MAP was 73 mmHg (range 35–94), decreasing slightly to 65 mmHg (range 30–95) at

Table 1. Intraosseous pressure (P) in the patella and juxtaarticular epiphyses of the knees of six immature dogs

	*P*patella mmHg		*P*femoral epiphysis mmHG		*P*tibial epiphysis mmHg	
	Right	Left	Right	Left	Right	Left
mean	12.3	12.0	9.2	7.8	10.3	10.5
SEM	0.8	1.0	1.9	1.0	1.5	1.2

the end of the experiments. The CVP was 3.9 mmHg (range 1–7) and remained constant.

The control intraosseous pressure of the patella (P_{PA}) was 12.0 ± 0.6 mmHg (range 8–15). No difference was observed between the right and left patellae (Table 1). The P_{PA} level was significantly higher than the epiphyseal intraosseous pressures ($P < 0.05$).

During increasing intraarticular pressure (P_J) a continuous increase in P_{PA} was observed, whereas the femoral epiphyseal pressure (P_{FE}) reached a maximum value of 16 mmHg (5–38) at a P_J of 80 cmH_2O (Figure 2). A moderate intraarticular pressure increase of 30 cmH_2O resulted in a statistically significant rise of P_{PA}, P_{FE} and tibial epiphyseal pressure (P_{TE}). After evacuation of

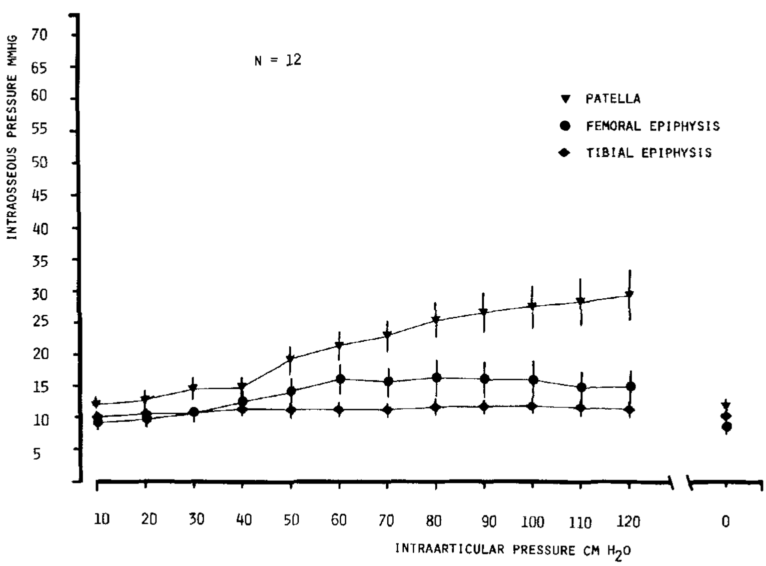

Figure 2. The relationship between intraarticular pressure and intraosseous pressures (mean ± SEM) in the knees of six immature dogs.

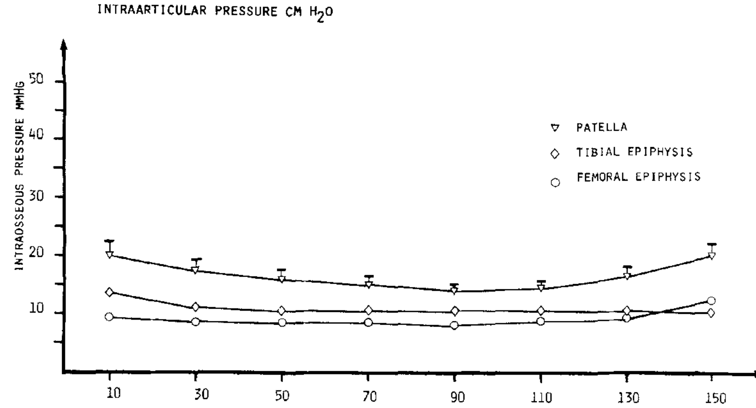

Figure 3. The influence of joint angle on intraosseous pressures (mean) in the knees of six immature dogs. The corresponding intraarticular pressures are shown in Table 2. The bars indicate a SEM exceeding the height of the signatures.

Table 2. Relationship between joint position and intraarticular pressure (P_J) in the knees of six immature dogs: A. Empty joint; B. Simulated joint effusion

	Degrees of knee flexion							
	10	30	50	70	90	110	130	150
P_J								
A. mmHg mean	1.7	3.4	4.1	3.4	0.3	3.5	7.0	10.1
SEM	4.3	2.1	4.5	3.5	0.2	0.5	1.3	2.2
P_J								
B. mmHg mean	27.1	18.0	13.5	14.5	27.7	52.9	106.9	
SEM	9.8	6.0	3.5	2.2	4.0	6.1	18.7	

the knee joint, the P_{PA} decreased to 11.5 mmHg (range 3–20), the P_{FE} to 8.5 mmHg (range 5–15), while the P_{TE} was 10.4 mmHg (range 7–15).

The intraosseous pressures of the patella and juxtaarticular epiphyses were influenced by changes in the knee joint angle (Figure 3). Maximum flexion of the empty knee joint resulted in a significant increase of P_{PA} to 20.3 ± 1.9 mmHg and of P_{FE} to 12.2 ± 1.2 mmHg, whereas during maximum extension, significant intraosseous pressure rises were observed in the tibial epiphysis and in the patella. The corresponding intraarticular pressure changes are presented in Table 2 (A).

Simulated joint effusion augmented the dependency between joint angle and intraosseous pressure (Figure 4). During maximum flexion the P_{PA} increased to 32.0 ± 4.5 mmHg and the P_{FE} to 19.3 ± 2.9 mmHg. During maximum extension the P_{TE} rose significantly to 19.4 ± 2.9 mmHg. The joint position resulting in minimum intraarticular pressure in the presence of joint effusion was found to be between 30° and 70° flexion (Table 2). Only during flexion of over 90° were very high intraarticular pressures observed.

The contrast clearance time from the patella was more than 15 minutes when the knee was empty and 9.6 minutes (range 7–11) with simulated joint effusion. It was in general difficult to estimate clearance time because of residual contrast pooling around the tips of the pressure cannulae.

The location of the draining veins from the patella is shown in Figure 5. A circumferential venous system was consistently found around the patella. This system was supplied by a number of veins radiating from the bone at midpatellar level. However, the most prominent venous drainage was located at the lower pole of the patella behind the inferior patellar ligament. Four

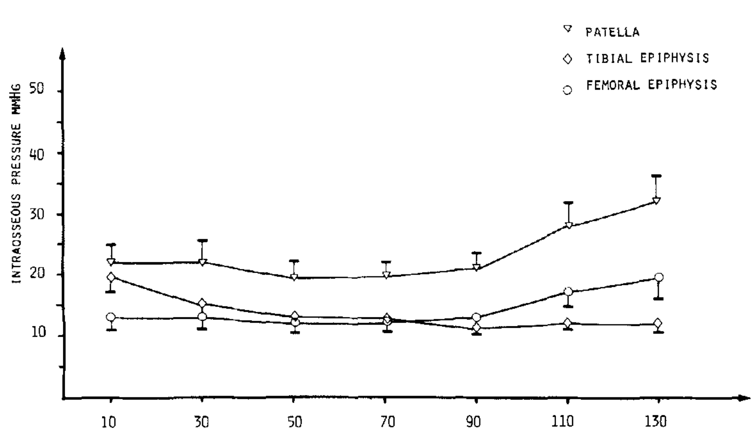

Figure 4. The influence of joint angle on intraosseous pressures in 12 immature knee joints with simulated joint effusion. The corresponding intraarticular pressures are shown in Table 2.

Figure 5. Intraosseous phlebography of the patella in a 10-week-old puppy. Pressure recording cannulae are located in the juxtaarticular epiphyses and in the knee joint cavity. A–D indicate four main veins draining from the peripatellar venous network to the genicular veins. E indicates a supplementary venous drainage located anteriorly on the femur.

major veins drained the "rete venosum patellae". In addition a superficial venous system located anteriorly on the femur was found.

DISCUSSION

Previous experimental studies have shown an interdependence between the intraarticular pressure of the knee and the intraosseous pressure of the distal femoral epiphysis (Arnoldi et al. 1979, Lucht et al. 1981). The relationship was most pronounced in juvenile knee joints (Bünger et al. 1981) where an intraarticular pressure of 30 cmH_2O resulted in a significant increase in intraosseous pressure of the distal femoral epiphysis. The present investigation confirms this result.

The intraosseous pressure of the patella was found to be slightly higher than the epiphyseal pressures. Since the patella is a small closed compartment for pressure measurement, reactive hyperaemia provoked by the insertion of the Radner cannula and initial flushing might affect the P_{PA} level more than the P_{FE} and P_{TE} levels. However, the difference in pressure levels was consistent throughout the investigation. Simultaneous pressure recordings in the patella and the juxtaarticular bones of the knee have not been published so far, but the P_{PA} in adult man has been estimated to be 10–15 mmHg (Ficat & Hungerford 1977), while Björkström et al. (1980) reported an average value of 19 mmHg. In the present study, the P_{PA} was more susceptible to increasing P_J than P_{FE} and P_{TE}, but largely followed the P_{FE} during movements of the knee, particularly during the presence of simulated joint effusion. Thus the concept of the femoropatellar joint as a vascular unit (Ficat & Hungerford 1977) is only partly confirmed.

The initial P_J measurements obtained in this study are in accordance with previous observations on human knee joints (Jayson & Dixon 1970a). However, the values were higher than the pressures reported recently in rabbit knee joints (–4.6 cmH_2O, range 0 to –12 cmH_2O (Lewick 1979)). These pressures were measured in the suprapatellar region of the articular cavity in a different joint position (20°–30° flexion). The markedly increased intraarticular pressure during maximum flexion equals pressures previously reported (Caughey & Bywaters 1963, Jason & Dixon 1970b, Lewick 1979). Pressure increase in the juxtaarticular bone during joint flexion has been described for the knee joint of immature dogs (Bünger et al. 1981) and for the metacarpophalangeal joint of adult horses (Arnoldi et al. 1980). When intraosseous pressures during increasing P_J (Figure 2) are compared to P_J values during changes of the joint angle (Table 2), the intraosseous pressure changes during joint movement cannot be solely explained by changes in P_J. Other factors such as direct influence on periarticular vessels by increased joint capsule and muscle tension may be of equal importance. Maximum extension of the knee joint for prolonged periods results in osteoarthritis (Langenskjöld et al. 1979). The results of the present study suggest that such arthritic changes may be secondary to changes in the haemodynamics of the knee.

The vascular supply of the patella has been thoroughly studied (Björkström & Goldie 1980, Crock 1967, Scapinelli 1967). The cartilage anlage of the patella is supplied by two groups of arteries. One midpatellar group enters the central anterior surface and one group enters the deep surface of the lower pole, providing a dual supply to the lower half of the patella and leaving the upper half more susceptible to ischaemia in the case of fracture (Scapinelli 1967). The phlebographies in the present study revealed a venous drainage from the patella which largely parallels the location of the arterial supply. The venous system is rich in vessels and anastomoses and communicates with the genicular as well as other veins. The difference in the intraosseous pressure response of the patella and the distal femoral epiphysis during increasing P_J probably reflects a difference in vascular anatomy in relation to the knee joint cavity.

The increases in intraosseous pressure in the present experiments may reflect an inhibition of venous drainage with a subsequent decrease in bone blood flow, similar to that observed recently in the hip joint (Launders et al. 1981). Several investigators have, however, found a good correlation between increasing intraosseous pressure and increasing bone blood flow (Azuma 1964, Shaw 1963, Shim et al. 1972). In fact, the decreased contrast clearance time observed in the present study during moderate elevation of P_J suggests increased bone blood flow.

The present study has indicated that the intraosseous pressure of the patella is influenced to a considerable extent by acute changes in intraarticular pressure and joint position compared to the juxtaarticular epiphyses. The haemodynamics of the patella in JDA with chronic elevation of intraarticular pressure are probably influenced to the same extent as the distal femoral epiphyses. Future studies of the pathomechanisms of growth disturbances in JDR should include regional blood flow measurements.

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