THE EFFECT OF INTRACAPSULAR PRESSURE
AND EXTENSION OF THE HIP ON OXYGENATION
OF THE JUVENILE FEMORAL EPIPHYSIS

A STUDY IN THE GOAT

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We have investigated the effect of joint tamponade and of traction in extension on the oxygen and carbon dioxide tensions in the femoral head of the immature goat, using mass spectrometry. Tamponade of 75 mmHg caused the oxygen tension in the femoral head to drop from 48 ± 4 mmHg to 29 ± 3 mmHg. Traction in extension further decreased the oxygen tension. Both these changes were highly significant. The partial pressure of carbon dioxide increased, but to a lesser extent and only effusion together with traction gave a statistically significant effect.

Our study showed that joint effusion can produce hypoxia in the bone as a result of impaired blood flow to the femoral head. The application of traction increases this haemodynamic effect.

Transient synovitis of the hip joint has been related to later development of Perthes' disease, coxa magna and osteoarthritis (Valderrama 1963; Kemp 1973; Kloiber et al. 1983). It has been suggested that articular inflammation has secondary effects upon the vascularity of bone, causing segmental collapse after a time interval (Borgsmiller et al. 1980). The epiphysis is particularly susceptible because the demands of the immature bone have to be met by the epiphysial vessels alone, since the growth plate cartilage presents a vascular barrier. The intracapsular course of these vessels makes them vulnerable to obstruction by raised intra-articular pressure.

It has been shown that it is possible to produce necrosis of the femoral head by increasing the joint pressure (Woodhouse 1964; Tachdjian and Grana 1968; Ogden 1974; Kemp 1981; Vegter and Lubsen 1987). The level and duration of the increased pressure seem to be the major determining factors, and it has also been shown that this pressure in joints with an effusion is influenced by posture. In the hip the pressure rise is most pronounced in forced extension (Eyring and Murray 1964; Kallio and Ryöppy 1985; Wingstrand 1986).

Transient synovitis of the hip is commonly treated by light traction with the limb in extension. We have investigated bone haemodynamics by measuring respiratory gases in the femoral head of the immature goat to study the effect of joint effusion and of traction.

MATERIALS AND METHODS

Seven skeletally immature goats were shown radiographically to have a complete growth plate below the femoral head. They were anaesthetised using Ketamine by intravenous infusion, which allowed spontaneous breathing and eliminated cardiovascular side effects. The animals were heparinised (500 U/kg intravenously) and a polyethylene catheter was inserted into the left carotid artery for the continuous measurement of arterial blood pressure, and for obtaining samples for measurement of blood gases and pH.

The femoral head epiphysis was cannulated percutaneously. The cannula (outer and inner diameters 2.0 and 1.4 mm) was inserted through the lateral aspect of the subtrochanteric cortex and through the femoral neck.
under the guidance of an image intensifier. The tip was placed in the centre of the epiphysis 5 mm deep to the articular cartilage. It was then flushed with a heparin-saline solution and free access to the intramedullary circulation was verified by slow aspiration of blood. To measure intra-osseous \( \text{PO}_2 \) and \( \text{PCO}_2 \), a blood gas catheter (Lundsgaard, Jensen and Grønlund 1980) was connected to a mass spectrometer and inserted into the subchondral bone through the cannula. The mass spectrometer was calibrated before and after the experiment by placing the blood gas catheter in a well stirred blood sample, the partial pressures of which were obtained with a conventional blood gas analyser (ABL3, Radiometer, Copenhagen, Denmark).

Table 1. Results of repeated changes of joint pressure on the partial pressures of oxygen and carbon dioxide in the femoral epiphysis of the goat

<table>
<thead>
<tr>
<th>Animal</th>
<th>Joint pressure in mmHg</th>
<th>Central arterial pressure in mmHg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \text{PO}_2 )</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>( \text{PCO}_2 )</td>
<td>35</td>
</tr>
<tr>
<td>1</td>
<td>( \text{PO}_2 )</td>
<td>41</td>
</tr>
</tbody>
</table>

Again using the image intensifier, a second bone cannula was introduced into the articular space of the hip joint through the acetabular roof. The position of each cannula was confirmed on radiographs taken after injection of a small amount of contrast medium. A pressure transducer was connected to the second cannula via a three-way stop-cock and the intra-articular pressure was raised by infusion of Rheomacrodex into the joint.

**Experimental design.** The intra-osseous levels of \( \text{PO}_2 \) and \( \text{PCO}_2 \) were observed until stable values were obtained. Then the intra-articular pressure was increased to 75 mmHg and the mass spectrometer recordings of \( \text{PO}_2 \) and \( \text{PCO}_2 \) were monitored until steady values were again obtained, usually within 30 to 45 minutes. The three-way stop-cock was then closed to prevent any reflux from the joint and 1.5 kg traction was applied to the extremity. Again the mass spectrometer signal was monitored until a new steady state was reached.

The pressure in the joint was recorded continuously during application of traction in the last four experiments, and arterial blood gas values and blood pressures were also recorded during the manipulations. Finally, when the readings were steady, the tamponade was released and the traction removed. Both the mass spectrometer and the pressure transducer signals were recorded continuously on a strip recorder.

**RESULTS**

In all, we performed seven experiments on joint tamponade and five on the additional effect of traction. In the first animal we also investigated the effect of repeated elevation and release of joint pressure in order to validate the method; these results are given in Table I.

Before any experimental procedure the mean partial pressure of oxygen in the subchondral bone, was \( 48 \pm 4 \) mmHg (mean \( \pm \) s.e.). Tamponade of the joint reduced the mean oxygen partial pressure to \( 29 \pm 3 \) mmHg, 60% of its initial value. This difference is significant \((p<0.001)\). Application of traction in extension further decreased the oxygen tension to 35% of its initial value. This decrease is also significant \((p<0.001)\) (Table II, Fig. 1). After releasing the joint tamponade and traction the partial pressure of oxygen returned to its initial value.

Table II. Partial pressures of oxygen in the femoral epiphysis of the goat: at rest, after establishing joint tamponade of 75 mmHg, after adding traction and after cessation of both tamponade and extension

<table>
<thead>
<tr>
<th>Animal</th>
<th>( \text{PO}_2 ) in mmHg</th>
<th>Arterial ( \text{PO}_2 )</th>
<th>Resting</th>
<th>75</th>
<th>+ traction</th>
<th>Resting</th>
<th>Joint pressure immediately after traction started (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>82</td>
<td>50</td>
<td>27</td>
<td>17</td>
<td>55</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>100</td>
<td>60</td>
<td>40</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>63</td>
<td>37</td>
<td>25</td>
<td>55</td>
<td>450</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>66</td>
<td>51</td>
<td>20</td>
<td>14</td>
<td>52</td>
<td>200</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>65</td>
<td>37</td>
<td>23</td>
<td>14</td>
<td>39</td>
<td>390</td>
<td>-</td>
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<tr>
<td>7</td>
<td>67</td>
<td>34</td>
<td>23</td>
<td>17</td>
<td>37</td>
<td>410</td>
<td>-</td>
</tr>
<tr>
<td>Mean</td>
<td>80</td>
<td>48</td>
<td>29(60)*</td>
<td>17(35)*</td>
<td>47(98)*</td>
<td>360</td>
<td>-</td>
</tr>
</tbody>
</table>

* percentage of resting value

Fig. 1

The effect of joint tamponade and added traction on the partial pressures of oxygen in the immature femoral epiphysis of the goat. Near normal values return when the pressure is released.
The mean partial pressure of carbon dioxide showed an inverse pattern and increased to 102% and 136% respectively of the initial value. The increase in $PCO_2$ produced by both tamponade and traction was statistically significant at $p < 0.05$, (Table III, Fig. 2). Again the values returned to near normal after release of joint pressure. The results from a typical experiment are shown in Figure 3.

The mean pressure in the joint increased from 75 to 360 mmHg ($\pm$ 56) with traction in extension then, during the next hour of observation, the pressure slowly dropped towards the pre-traction value. The mean partial pressures of oxygen and carbon dioxide in the arterial blood throughout the experiment were 80 and 38 mmHg respectively, and the mean arterial pressure was above 90 mmHg in all cases.

**DISCUSSION**

Many methods have been used to examine the circulation in the proximal femoral epiphysis. Our use of mass spectrometry at this site is new, but the method has been used in other studies of bone circulation and has been described in detail elsewhere (Kofed et al. 1983; Svalastoga and Grønlund 1985; Kjaer, Grønlund and Sørensen 1988). Use of the femoral epiphysis of the immature goat as a model seems appropriate because firstly, this animal has a femoral head of a size comparable to that of the human juvenile hip, and secondly the anatomy of the joint is similar (Ghaddially 1983). Tightening of the capsular fibres by extension creates a reduced joint volume and a consequent increase in pressure.

Injection of fluid has been used in several studies to simulate joint effusion. Saline (Lauder, Hungerford and Jones 1981; Bünger, Harving and Bünger 1982; Kofed and Lindenberg 1986), silicone oil (Tachdjian and Grana 1968) and macromolecular plasma substitutes (Lucht et al. 1983) have been used. The choice of fluid is important because of the permeability of the synovial membrane. Saline rapidly leaves the joint by diffusion into the periarticular tissues when the joint pressure exceeds 9 to 10 mmHg (Levick 1980; Knight and Levick 1982), and our preliminary studies on rabbit knees showed that continuous infusion of saline was necessary to maintain raised pressure. In our experiments, a temperature sensor placed in the bone adjacent to the joint surface showed a decrease in temperature from 37.8 to 33.8° during infusion of saline. This would prevent reliable measurements being made with mass spectrometry because of the temperature sensitivity of this instrument. In one of our reported experiments (Number 3) the partial pressures of oxygen and carbon dioxide in the femoral epiphysis were recorded during injection of 2 ml of cold saline into the joint. This amount is too small to influence the joint pressure. However, the oxygen level fell from 53 to 41 mmHg and the carbon dioxide level from 54 to 43 mmHg, an effect probably explained by the influence of temperature on the binding curves of oxygen and carbon dioxide in blood and the calibration effect of the mass spectrometer. No side effects of the infusion of Macrodex were found. The alterations induced by the saline are also likely to disturb other haemodynamic and metabolic parameters and therefore a fluid to which the synovium is impermeable is to be preferred.

The partial pressure of oxygen decreased in all our experiments with distension of the joint, and this decrease was reproducible. If the subchondral consumption of oxygen is assumed to be constant during the experiment, this decrease can only be explained by reduced supply. But the blood gases and pressure were constant during the experiment, so the only explanation can be a decrease in local blood flow. The carbon dioxide tension showed a reciprocal reaction although it was slower, probably due to its higher buffering capacity. Bone tissue contains large exchangeable stores of bicarbonate in the inorganic compartment (Poyart, Fréminet and Bursaux 1975) and a local load can probably be reversibly exchanged.

Our results are comparable to those of one earlier study on the rabbit knee where a decrease in subchondral oxygen tension was found after infusion of saline (Grønlund, Kofed and Svalastoga 1984). Other authors have reported an increase in subchondral pressure which correlated with a simulated pressure increase in the joint (Arnoldi et al. 1980; Bünger et al. 1982) and a decrease in subchondral blood flow (Lauder et al. 1981; Lucht et al. 1983). Ewald et al. (1986) showed metabolic changes in the juxta-articular bone in puppies after joint tamponade to 150% of mean arterial pressure. They found hypoxia, decrease in pH and increase in $PCO_2$ and lactate.

Placing the hip in extension with light traction.

**Table III. Partial pressures of carbon dioxide in the femoral epiphysis of the goat**

<table>
<thead>
<tr>
<th>Animal</th>
<th>Arterial $PCO_2$</th>
<th>Resting 0</th>
<th>75</th>
<th>75 + traction</th>
<th>Resting 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>39</td>
<td>68</td>
<td>-</td>
<td>81</td>
<td>64</td>
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<td>3</td>
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<td>7</td>
<td>53</td>
<td>57</td>
<td>62</td>
<td>62</td>
<td>58</td>
</tr>
</tbody>
</table>

Mean 38 50 51(102)* 68(136)* 56(112)*

*percentage of resting value
caused a further reduction in oxygen tension and increase in carbon dioxide tension associated with a fourfold increase in joint pressure. This is in accordance with other studies, and with reports on transient synovitis in children which have shown the same pressure response to extension and medial rotation. This is explained by tightening of the oblique fibres of the capsule by extension, resulting in a decreased intra-articular volume and reduced compliance of the capsule. The falling-off of pressure after prolonged extension could be due to a stretching of the fibres, but minor leakage could have the same effect. In our experiments, no leakage was found and the stable position of the cannula precludes any complications due to migration.

Some authors have linked the development of Perthes' disease with earlier episodes of synovitis (Ferguson and Howorth 1954; Valderrama 1963; Wingstrand 1986), and believe that the vascular insult is caused by the obstruction of retinacular vessels secondary to tamponade. It has been demonstrated that a tamponade at 150 mmHg for more than 10 hours results in avascular necrosis of the femoral head (Tachdjian and Grana 1968). In another study, total necrosis of the femoral head of rabbits has been shown after six hours of tamponade with trabecular necrosis after only two hours (Vegter 1987). Our study shows that effusion can produce hypoxia in the environment of the bone cells and that extension reinforces this effect. It also demonstrates that increased joint pressure decreases or obstructs the blood supply; however, it has been shown that regulatory mechanisms influence blood supply in bone tissue and this might influence the long term result (Gross, Heistad and Marcus 1979). We monitored respiratory gases for only a few hours, not long enough to allow compensatory mechanisms to act fully. Partial reversal of this negative effect is possible; this could explain the low frequency of necrosis after uncomplicated synovitis.

Our results and those of others have, however, demonstrated a danger in treating hips with a simple effusion by traction. We suggest that aspiration of effusions might be indicated and that free movement would then allow the joint to assume the position of least pressure; this would have the additional advantage of reducing pain.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

REFERENCES


Levick JR. Contributions of the lymphatic and microvascular system to fluid absorption from the synovial cavity of the rabbit knee. *J Physiol (Lond)* 1980;306:445-61.


