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Respiratory gas pressures in the spine

Measurements in goats

Hakon Kofoed and Bo Levander[1]

Normal values of pO_2, pCO_2, pH, and intraosseous pressure were measured in situ in the lumbar spine of goats. In the lumbar bodies and discs no difference existed between values found cranially and caudally. pO_2 was lower and pCO_2 higher in the nucleus pulposus than in the adjacent lumbar bodies. This emphasizes the nutritional route to the disc via the vertebral end plate. Intraosseous pressures in the cranial and caudal levels of the lumbar spine did not differ, and the pressures were the same as otherwise found in cancellous bone. These are the first combined in situ measurements of several basic metabolic parameters in the normal spine using recordings with continuous mass spectrometry. They may constitute a basis for further investigation of metabolism in the structures of the spine.

The nucleus pulposus of the lumbar disc is the largest avascular structure in the body (Nachemson 1976), and it may constitute a sink for surrounding metabolic changes. Knowledge of the basic metabolic parameters in the intervertebral discs may contribute to the understanding of degenerative spinal disorders.

We have developed methods for continuous measurements of pO_2, pCO_2, pH, and pressure in the lumbar discs and vertebral bodies in normal goats.

Materials and methods

Ten adult female 20–35 kg goats were used. The animals were handled under i.v. Ketamin anesthesia (initial dose 400 mg, followed by 5 mg/kg every 30 min). Ketamine was used in order not to interfere with central hemodynamic and metabolic parameters. Continuous suction of the contents of the rumen through a tube was used to relieve the intraabdominal pressure and its effect on respiration in the supine animal.

Via a lateral approach using an image intensifier (Figure 1), special bone cannulae (outer diameter 2.0 mm, inner diameter 1.4 mm) were

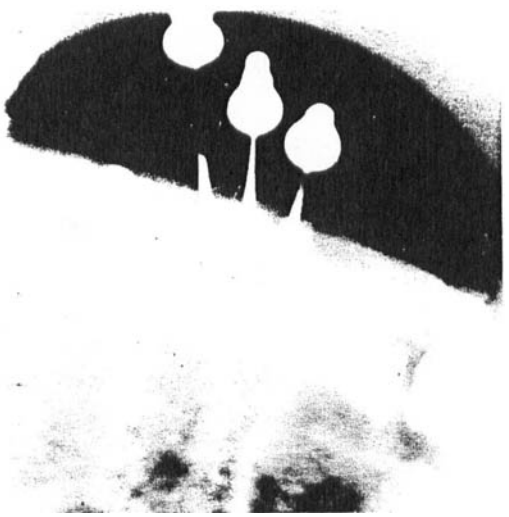

Figure 1. Position of the percutaneously introduced cannulae in the nucleus pulposus and the subchondral bone of the adjacent lumbar bodies. One of the cannulae in the lumbar bodies served as a reference electrode to the pH electrode. The other bone cannula was used for introduction of the blood-gas catheter connected to the mass spectrometer, for introduction of the pH electrode, and for recording of intraosseous pressure. The cannula in the nucleus pulposus served for introduction of the blood-gas catheter and the pH electrode.

Department of Orthopedics, Rigshospitalet, Blegdamsvej 9, DK-2100 Copenhagen Ö, Denmark, and Institute of Experimental Research in Surgery, University of Copenhagen, and [1]Department of Orthopedics, Eksjö-Nässjö Hospital and the Karolinska Institute, University of Stockholm, Stockholm, Sweden

introduced percutaneously into the cancellous bone of the second and fifth lumbar bodies, and into the center of the nucleus pulposus of the discs between the first and second, and the fifth and sixth lumbar bodies. A dorsal foot artery was cut down and catheterized for arterial blood gases and acid-base analysis (ABL-4, Radiometer, DK). The intraosseous pressure was measured via the cannulae in the lumbar bodies by use of Bentley Trantec 800 pressure transducers (UK) and a writer (Elema-Schönander, Sweden). The left lateral sternal edge was the reference point for calibration. Before measurements, the animal was heparinized (10,000 i.v.). Following the intraosseous measurements, the cannulae in the lumbar bodies and disc were used for introduction of a monocrystalline antimony electrode (Edwall 1976) for continuous recording of pH (Kofoed & Lindenberg 1984). Thereafter, the cannula was used for introduction of a blood-gas catheter (Lundsgaard et al. 1980) connected to the high-vacuum chamber of a mass spectrometer (SX-200, VG Gas Analysis Ltd., UK). The mass spectrometer recorded simultaneously $p0_2$, pCO_2, and pAr. pAr was used for in situ calibration of pO_2 according to a previously described method (Kofoed et al. 1983). Arterial blood samples were drawn at the end of every measuring procedure.

Regression analysis and the paired *t* test were used for statistical analysis.

Results

Intraosseous pressures, partial oxygen, and carbon dioxide pressures and pH of the vertebral bodies L_2 and L_5 were correlated, whereas the partial pressures of argon were not (Table 1). Similar correlations of gas pressures and pH were found in the nucleus pulposus L1/L2 and L5/L6. PO_2 was lower in the nuclei pulposi than in the vertebral bodies, a tendency that increased with increasing pO_2 (Figure 2).

The pCO_2 in the nuclei pulposi was correspondingly higher than in the vertebral bodies (Figure 3). The pH values in the vertebral bodies and nuclei pulposi were correlated (r = 0.78, P <0.001) but similar. No correlation existed between partial pressures of argon in vertebral bodies and nuclei pulposi. Arterial values were paO_2 91.0 ± 3.3 mm Hg (mean ± 1 S.E.M.), $paCO_2$ 39.1 ± 2.5 mm Hg and a pH 7.42 ± 0.02.

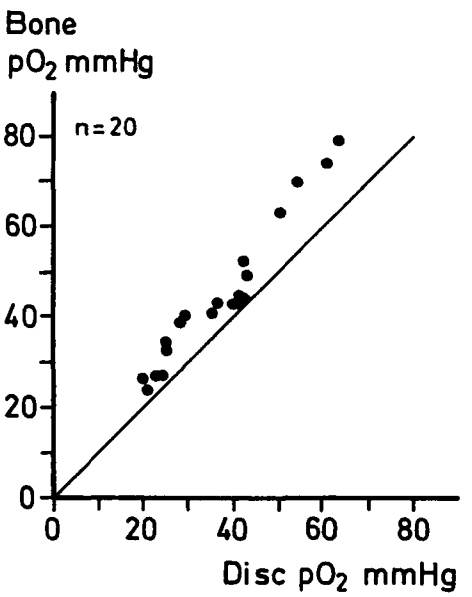

Figure 2. Comparison of P_{O_2} in the lumbar bodies L2 and L5 and the nuclei pulposi L_{1-2} and L_{5-6}, respectively. The line of identity has been added for reference. Significantly lower values were found in the nucleus pulposus. The correlation is significant (r = 0.97, $P<e>$ <0.001). The equation for the regression is y = 0.32 + 1.20x, where the interval for 0.32 is −2,40 to 3.04 (95% confidence limits) and the interval for 1.20 is 1.13 to 1.27.

Table 1. Tissue gases, pH, and intraosseous pressures (IOP) in the lumbar spine. Figures are mean (SEM). Pressures are given in mm Hg

	P_{Ar}rel.	P_{O_2}	P_{CO_2}	pH	IOP
Vertebral	0.79±0.04	44.8±5.1	53.2±3.8	7.39±0.07	23.8±4.0
body L2	r = 0.20, p>0.05	r = 0.98, p<0.001	r = 0.95, p<0.001	r = 0.89, p<0.001	r = 0.66, p<0.05
L5	0.77±0.04	45.4±5.3	54.5±4.1	7.41±0.05	23.8±5.0
Nucleus	0.65±0.02	37.5±4.2	56.4±6.3	7.39±0.04	
pulposus L1–2	r = 0.39, p>0.05	r = 0.99, p<0.001	r = 0.96, p<0.001	r = 0.89, p<0.001	
L5–6	0.70±0.03	37.5±4.1	58.9±6.0	7.36±0.05	

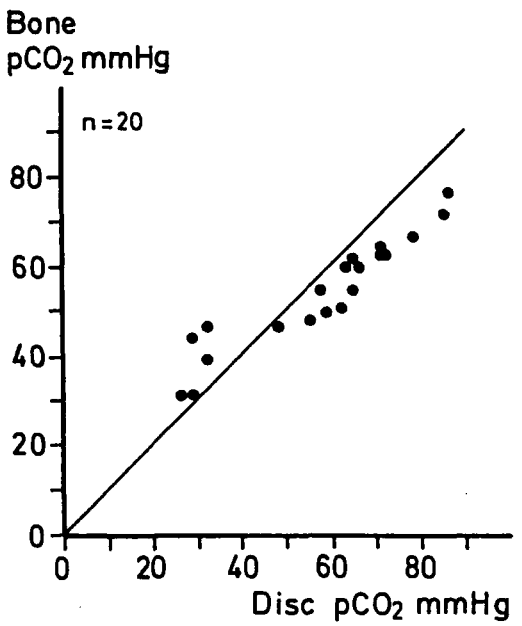

Figure 3. Comparison of p_{CO_2} in the lumbar bodies and corresponding values in the nucleus pulposus. Significantly higher values of pCO_2 were found in the nucleus pulposus. The line of identity has been added for reference. The correlation is significant (r = 0.94, P <0.001). The equation for the regression is y = 18.6 +0.61x, where the interval for 15.6 to 21.6 (95% confidence limits) and the interval for 0.61 is 0.56 to 0.65.

Discussion

Our results confirm previous studies of pO_2 in the nucleus pulposus (Holm & Nachemson 1982) showing no difference between cranial and caudal levels in the lumbar spine. Our intraosseous pressures were similar to normal values in the long bones of dogs (Tøndevold et al. 1979) and in the spinous processes in humans (Arnoldi 1972).

The relatively low pO_2 and high pCO_2 in the nuclei pulposi with no difference for pH seem to indicate the existence of a close relation in these parameters between the corresponding lumbar bodies and discs. This was not unexpected because one of the major nutritive pathways for the nucleus pulposus has been shown to be the lumbar end plate (Nachemson et al. 1970, Maroudas et al. 1975, Urban et al. 1977). Lower pO_2 and higher pCO_2 in the nucleus pulposus may reflect either a diffusion barrier or a difference in metabolism in the two environments. However, a diffusion barrier does not seem to include hydrogen ions. The metabolism in both environments is probably aerobic, contrary to previous suggestions of an anaerobic metabolism in the nucleus pulposus (Holm et al. 1981), because a substantial lactate concentration in the nucleus pulposus should have resulted in lowering of pH, which was not found in our experiments.

The internal argon standard used (Kofoed et al. 1983) gives an impression of the diffusion pattern in the two environments; argon is always in equilibrium as long as spontaneous respiration with atmospheric air is used; it has been shown that the diffusion gradient divided by the bulk partial pressure is effectively identical for argon and oxygen (Lundsgaard et al. 1978). The argon signal in the nucleus pulposus did not differ from that in the bone, and the previously suggested diffusion gradient throughout the nucleus pulposus (Holm et al. 1981) could not be established. The tip of our gas catheter occupied a considerable part of the nucleus pulposus. Thus, apart form applying an internal pressure on the nucleus pulposus, which could impair diffusion, it also brought the catheter tip nearer to the lumbar end plate, which made the distance for diffusion shorter, and thereby tended to raise the pO_2 value. If it could be anticipated that these two adverse effects roughly balanced each other, the actual values of pO_2 were very much higher than previously shown (Ejeskär & Holm 1979, Holm et al. 1981, Holm & Nachemson 1982). This raises the question whether the methods used give reliable results. The above-mentioned studies used polarography for oxygen measurements, a method that has several disadvantages – lack of an internal calibration technique, a difficult and not quite reproducible in vitro calibration technique. Further, oxygen is used by the electrode to establish the polarographic signal – a possible serious error in an avascular area, and only one parameter is measured at a time. We feel that our mass spectrometric method may be a more reliable method because it offers simultaneous measurements of an internal standard for diffusion, the relative argon signal, and has an inborn control by simultaneous measurement of a metabolically opposite directed gas, CO_2. We therefore conclude that the methods used in our experiment may be suitable for further studies of the metabolic environment of the spine.

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