Intraosseous pressures of oxygen and carbon dioxide in coxarthrosis

We have investigated the intraosseous partial pressures in 15 patients suffering from primary arthrosis of the hip. The measurements were performed by a mass spectrometer via a specially designed inlet system. The average pO_2 and pCO_2 values in the femoral head were 8.2 and 6.8 kPa (62 and 52 mmHg), respectively, and in the greater trochanter 6.6 and 5.1 kPa (51 and 39 mmHg). The average intraosseous pressures in the femoral head and greater trochanter were 5.5 and 3.0 kPa (42 and 23 mmHg). The differences between the intraosseous pressures, pO_2 and pCO_2 in the greater trochanter and the femoral head were all significant.

Thomas Kiær
K. Harry Sørensen
Jørgen Grønlund[1]

Departments of Orthopaedic Surgery O, Odense Sygehus, DK-5000 Odense C, and [1]Physiology, Odense University, Denmark

The subchondral bone of patients with primary arthrosis of the hip is characterized by elevated intraosseous pressure (Arlet et al. 1968, Arnoldi et al. 1972, Termansen et al. 1981) and venous engorgement (Phillips 1966, Brookes & Helal 1968, Arnoldi et al. 1972), ascribed to partial obstruction of the venous drainage. An increased outflow resistance would cause a fall in the regional blood flow with an associated decrease in the subchondral pO_2 and an increase in pCO_2 (Arnoldi & Reimann 1979). However, a recent study (Svalastoga et al. 1984) in rabbits showed no effect of unilateral arthrosis on partial pressures of oxygen and carbon dioxide.

We have measured the subchondral oxygen and carbon dioxide tensions in the femoral head and greater trochanter of patients with primary coxarthrosis. The relationship between these partial pressures and the intraossous pressure was also investigated.

Material and methods

The oxygen and carbon dioxide tensions in the femoral head and greater trochanter were measured by a mass spectrometer (Balzers QMG 112 M1-100) via a blood gas catheter (Lundsgaard et al. 1980, Kofoed et al. 1983).

The measurements were performed in ten males and five females before total hip replacement for arthrosis. Informed consent was obtained before the measurements. Apart from arthrosis, none of the patients suffered from serious disease, and all were normotensive with normal cardiopulmonary function; the median age was 68 (57–75) years (Table 1). Gaseous anaesthetics which interfere with the main peaks of O_2 and CO_2 in the mass spectrum were not used and the patients breathed atmospheric air without oxygen enrichment. Respiration was controlled and the partial pressures of carbon dioxide and oxygen in the expiration gas were monitored continuously, and adjusted to give arterial oxygen and carbon dioxide partial pressures of 10.5–13.2 kPa and 4.6–5.9 kPa, respectively.

After exposure of the fibrous capsule of the joint, a cannula (outer and inner diameters 2.0 and 1.4 mm) was inserted into the femoral head from the anterior aspect of the femoral neck (Figure 1). The blood gas catheter was inserted into the spongiosa through the cannula, and the tip was advanced to a position close to the joint space. The intraosseous partial pressures of oxygen and carbon dioxide were measured by the mass spectrometer. When the signal was stable, usually 5 min after the insertion of the catheter, the blood gas catheter was retracted and an arterial blood sample was taken. The cannula was connected to a Siemens Elema pressure transducer via a 2-m polyethylene catheter, and the signal was fed to a y-t recorder (Mingograph). The transducer was calibrated against two water columns. The described procedure was repeated in the ipsilateral greater trochanter. The pressure measurements were accepted only if pulsation was obtained in the signal from the pressure transducer.

The femoral heads were conserved and cut up through the channel made by the cannula to determine the distance between the tip of the cannula and the joint cartilage.

The measurement of oxygen failed in three cases due to failure of the mass spectrometer signal to

Table 1. pO_2, pCO_2 and intraosseous pressure (kPa) in femoral head and the greater trochanter.

Sex	Age	Femoral head			Greater trochanter			Arterial blood	
		pO_2	pCO_2	Pressure	pO_2	pCO_2	Pressure	paO_2	$paCO_2$
F	74	9.02	6.84	8.82	6.45	3.95	5.00	15.3	5.26
M	73	8.95	7.76	3.29	7.50	6.71	3.55	12.8	5.53
M	75	9.21	6.84	7.24	7.38	4.87	2.63	13.0	5.39
M	66	5.79	7.32	6.71	4.21	4.21	5.53	11.3	4.61
M	69	10.1	6.18	3.95	11.3	5.13	1.97	13.3	5.79
M	73	7.37	8.16	3.29	3.29	4.61	1.97	11.3	6.05
F	66	10.6	7.24	3.55	7.73	4.87	3.42	12.9	5.00
M	60	8.82	6.45	6.32	6.84	5.26	3.42	10.0	5.92
F	61	5.53	6.71	–	3.95	6.45	–	13.9	5.39
F	73	–	5.39	9.02	–	4.47	4.47	14.2	4.87
M	69	–	5.66	5.92	–	5.39	1.58	9.61	5.26
M	68	7.24	–	4.34	5.39	–	1.58	8.82	7.11
M	68	–	8.42	2.76	–	5.53	1.05	9.08	6.71
F	66	9.34	–	6.71	8.95	–	2.89	11.5	5.53
M	57	6.32	–	5.26	5.26	–	4.08	12.1	5.92
Mean (SEM)		8.2 (0.53)	6.8 (0.26)	5.5 (0.53)	6.6 (0.66)	5.1 (0.24)	3.0 (0.39)	11.8 (0.53)	5.7 (0.13)

reach a plateau (two cases) and failure in the calibration (one case). The carbon dioxide measurement failed in three cases, one caused by accidental N_2O contamination, and two caused by a protracted response curve for the CO_2 signal. In one experiment, no pulsation was obtained, probably due to air in the connecting catheter.

Results

Twelve paired observations of oxygen and carbon dioxide partial pressures and 14 paired observations of intraosseous pressure were obtained (Table 1). The oxygen partial pressure in the femoral head was 8.2 ± 0.53 kPa (mean ± SEM) and in the greater trochanter 6.6 ± 0.66 kPa ($p < 0.001$) (Figures 2 and 3). In the femoral head and the greater trochanter, the carbon dioxide partial pressures were 6.8 ± 0.26 kPa and 5.1 ± 0.24 kPa respectively ($p < 0.001$).

The mean intraosseous pressures in the femoral head and the greater trochanter were 5.5 ± 0.53 and 3.0 ± 0.39 kPa, respectively. The arterial oxygen partial pressure was 11.8 ± 0.53 kPa and the carbon dioxide partial pressure 5.7 ± 0.13 kPa. The carbon dioxide partial pressure in the femoral head was higher than the partial pressure in the arterial blood.

The intraosseous pressure in the greater tro-

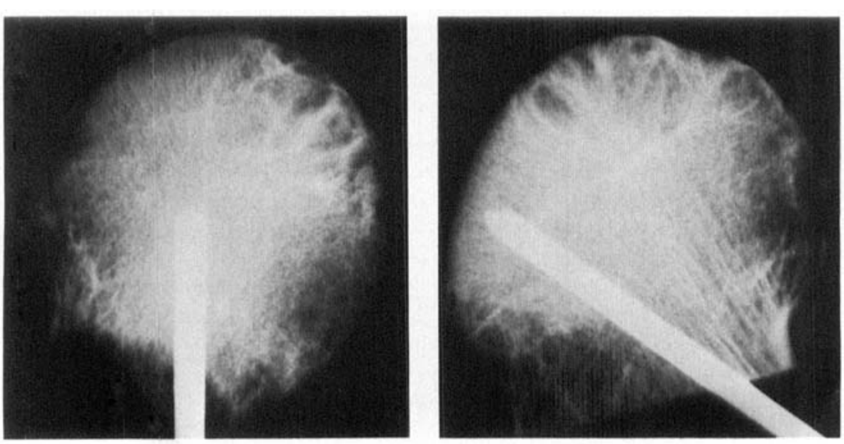

Figure 1. Typical position of the cannula in the femoral head.

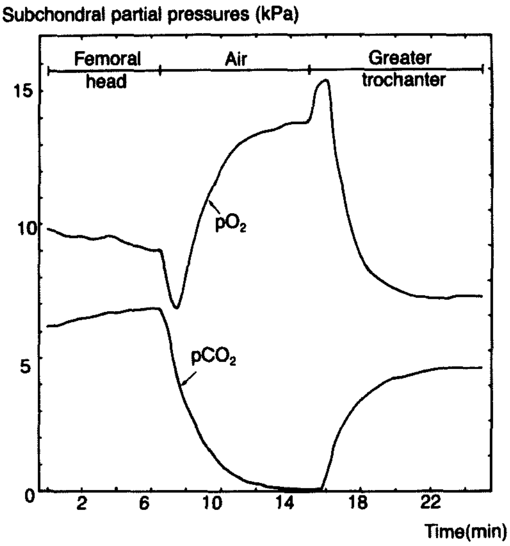

Figure 2. Mass spectrometer recordings of pO_2 and pCO_2 in the greater trochanter and femoral head from a typical experiment.

chanter was positively correlated to the pressure in the femoral head ($r = 0.61$, $p < 0.05$). The subchondral pO_2 in the femoral head was positively correlated to that in the greater trochanter ($r = 0.61$, $p < 0.05$).

The median distance between the tip of the cannula and the joint cartilage was 6 (1–11) mm.

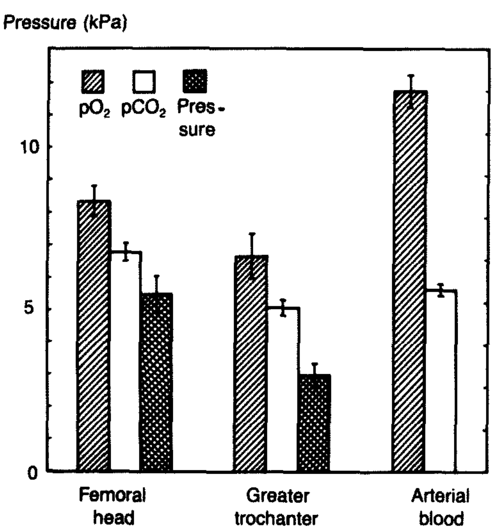

Figure 3. Mean pO_2, pCO_2 and pressure obtained in the femoral head and greater trochanter, and mean arterial pO_2 and pCO_2. Vertical bars show standard error of the mean.

Discussion

The measurement of oxygen partial pressures in tissue by membrane-covered oxygen sensors is complicated by the so-called stirring effect, which is due to an oxygen diffusion gradient in front of the membrane (Lundsgaard et al. 1978). In previous studies with the blood gas catheter (Svalastoga et al. 1984) the stirring effect was evaluated by an *in situ* technique based on the measurement of an inert reference gas of known partial pressure. The catheter used in our study was slightly modified compared to the original version (Lundsgaard et al. 1984). The surface of the sintered material supporting the membrane was ground by a new technique, which ensures a large number of very small and separate diffusion areas. This geometry of the diffusion area ensures a negligible stirring effect on the catheter (Svalastoga & Grønlund 1985).

The average intraosseous pressure in the femoral head observed in our study agrees with the average values obtained in a previous study (Termansen et al. 1981) in a comparable group of patients, and hence indicates that the outflow resistance is increased. The simultaneous increase in both the oxygen and carbon dioxide partial pressures cannot be explained solely by a reduced regional blood flow. At a constant oxygen consumption, a decrease in the regional blood flow would lead to a fall in pO_2. A possible explanation for the increased oxygen partial pressure is that the oxygen consumption decreased relatively more than the regional blood flow either because of severe damage to the cellular elements of the bone or because of impaired oxygen diffusion from the blood to the mitochondrias in the bone tissue. The rise in pCO_2 suggests that the carbon dioxide production is increased. Therefore, the respiratory quotient of the arthrotic bone tissue is probably abnormally high, which can be taken as an indication of anaerobic metabolism. A possible explanation for the existence of anaerobic metabolism at an elevated oxygen partial pressure is that the diffusion resistance between the blood and the mitochondrias has increased due to morphological changes in the bone matrix (Christensen & Arnoldi 1980).

References

Arlet, J., Ficat, P. & Sebbag, D. (1968) Intéret de la mesure de la pression intramédullaire dans la massif trochantérien chez l'homme, en particulier pour le diagnostic de l'ostéonécrose fémorocapitale. *Rev. Rhum.* **35**, 250–256.

Arnoldi, C.C., Linderholm, H. & Müssbichler, H. (1972) Venous engorgement and intraosseous hypertension in arthrosis of the hip. *J. Bone Joint Surg.* **54**-B, 409–421.

Arnoldi, C.C. & Reimann, I. (1979) The pathomechanism of human coxarthosis. *Acta Orthop. Scand.* Suppl. 181.

Brookes, M. & Helal, B. 1968) Primary arthrosis, venous engorgement and osteogenesis. *J. Bone Joint Surg.* **50**-B, 493–504.

Christensen, S.B. & Arnoldi, C.C. (1980) Distribution of 99^m Tc-phosphate compounds in osteoarthritic femoral heads. *J. Bone Joint Surg.* **62**-A, 90–96.

Kofoed, H., Svalastoga, E., Grønlund, J., Jensen, B., Kofod, J. & Svendsen, P. (1983) Continuous measurement of subchondral P_{O2} and P_{CO2} by mass spectrometry. *IRCS Med. Sci.* **11**, 583–584.

Lundsgaard, J.S., Grønlund, J. & Einer-Jensen, N. (1978) *In vivo* calibration of flow dependent blood gas catheters. *J. Appl. Physiol.* **44**, 124–128.

Lundsgaard, J.S., Jensen, B. & Grønlund, J. (1980) Fast responding flow independent blood gas catheters for oxygen measurement. *J. Appl. Physiol.* **48**, 376–381.

Phillips, R.S. (1966) Phlebography in arthrosis of the hip. *J. Bone Joint Surg.* **48**-B, 280–288.

Svalastoga, E., Grønlund, J. & Kofoed, H. (1984) Subchondral P_{O2} and P_{CO2} are unaffected in experimental arthrosis. *Acta Orthop. Scand* **55**, 514–516.

Svalastoga, E. & Grønlund, J. (1985) Experimental arthrosis in the rabbit. III. Acute arthrosis: subchondral P_{O2} and oxygen consumption and diffusion capacity in synovial membrane. *Acta Vet. Scand.* In press.

Termansen, N.B., Teglbjærg, P.S. & Sørensen, K.H. (1981) Primary arthrosis in the hip. Interrelationship between intraosseous pressure, X-ray changes, clinical severity and bone density. *Acta Orthop. Scand.* **52**, 215–222.