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Oxygen Consumption, Diffusing Capacity and Blood Flow of the Synovial Membrane in Osteoarthritic Rabbit Knee Joints

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Svalastoga, E. and T. Kiær: Oxygen consumption, diffusing capacity and blood flow of the synovial membrane in osteoarthritic rabbit knee joints. Acta vet. scand. 1989, 30, 121–125. – In osteoarthritis the changes of the synovial membrane may seriously alter the oxygen transfer characteristics from the capillaries of the membrane to the synovial fluid and hence impede or deprive the joint cartilage of its sole source of oxygen.

In the present study we have estimated the blood flow (Q), diffusing capacity (DO_2) and oxygen consumption (VO_2) of the synovial membrane in the chronic non effusive stage of experimental osteoarthritis.

In 14 osteoarthritic knee joints we found a statistically significant increase in oxygen consumption, compared to previously reported results from normal joints, whereas the diffusing capacity and the blood flow were unchanged. The implication of this is that the partial pressure difference required to overcome the increased oxygen consumption was increased with a factor 4.3 and that the oxygenation of the joint cartilage was reduced with approx. 30 Torr.

joint perfusion; mass spectrometry; blood flow.

Introduction

Osteoarthritis is a progressive disease involving all joint structures with increased morphological alterations as the disease progresses. In the synovial membrane the end stage of the disease is characterised by proliferation of the lining cells, villous hypertrophy, fibrosis and dilation of venules (*Arnoldi et al* 1980, *Arnoldi & Reimann* 1979, *Svalastoga & Reimann* 1985). Oxygenation of the joint cartilage depends on diffusion of oxygen across the synovial membrane and the synovial fluid.

These complex of structural changes in the synovial membrane might hamper the diffusive oxygen transfer from the capillaries of the synovial membrane to the synovial fluid.

A previous series of experiments have shown a considerably reduced oxygen transfer across the synovial membrane in the acute stage of experimental osteoarthritis (*Svalastoga & Grønlund* 1985a, *Svalastoga & Grønlund* 1985b).

The fact that the changes in the synovial membrane in chronic osteoarthritis coincide with a progressive deterioration of the joint cartilage warrants a study to elucidate whether synovial hypoxia is a persistent phenomenon in osteoarthritis. On this basis we have investigated the oxygen consumption, diffusing capacity and the blood flow in the synovial membrane in the osteoarthritic end stage.

Materials and methods

Four months prior to the experiments 14 full grown New Zealand White rabbits underwent an instability operation a.m. *Hult* to induce unilateral osteoarthritis (*Hult et al.* 1970). This operation which was performed under intravenous anaesthesia (Pentobarbitone 5 %), includes resection of the medial collateral ligament, extirpation of the medial meniscus and transsection of both cruciate ligaments. At the 4 months stage of induced osteoarthritis the rabbits were utilized to study the oxygen consumption, diffusing capacity and the blood flow of the synovial membrane. A detailed description of the method is given elsewhere (*Svalastoga et al* 1989). The principle of the method is to perfuse the joint cavity with 2 saline solutions: one with high O_2 and N_2 partial pressures. Using a model of gas exchange between the joint cavity and the synovial membrane a set of 5 equations is derived expressing the relationship between oxygen and nitrogen flowing to and from the perfusate in the 2 situations and the diffusing capacity, metabolism and blood flow of the synovial membrane.

The experimental procedure and setup were very similar to that of a previous study (*Svalastoga & Grønlund* 1985a). The rabbits were anaesthetized (pentobarbitone 5 %) and kept on spontaneous respiration throughout the study. The right carotid artery was cannulated to facilitate arterial blood sampling. The skin over the medial collateral and the infrapatellar ligament was anaesthetized (0.5 ml lidocaine 2 %). A 20 gauge cannula was inserted into the joint cavity via the infrapatellar ligament and a second cannula was inserted into medial femoro – tibial joint compartment through a medial horizontal approach. The joint was flushed with saline to remove synovia and debris. The rabbit was then moved to a heated box 37°C and the joint was perfused with an infusion pump (Harvard Apparatus, Millis, U.S.) at a rate of approximately 2.0 ml/min, with the saline solution with either the low or the high partial pressures of nitrogen and oxygen first.

A blood gas catheter (*Lundsgaard et al.* 1980) connected to the mass spectrometer (Balzers, QMG, Balzers, Lichtenstein) enabled continuous and simultaneous measurement of the oxygen and the nitrogen partial pressures in the perfusate flowing from the joint cavity (Fig. 1). After attainment of steady O_2 and N_2 signals an arterial blood sample was taken to measure PaO_2.

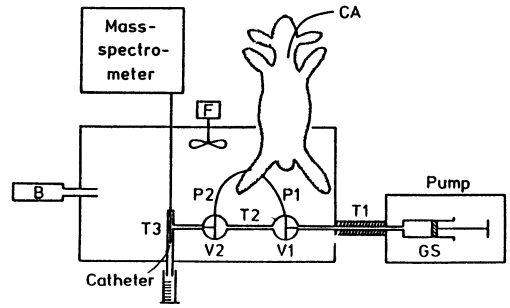

Figure 1. Experimental setup. For details see text and *Svalastoga et al.* 1989, *Svalastoga & Grønlund* 1985.

Results

The results of the investigation are summarized in Table 1. The first 2 columns show the experiment number and the actual values of PaO_2. Columns 3 to 5 represent the calculated oxygen consumption (VO_2), diffusing capacity (DO_2) and the blood flow (Q) in the synovial membrane of the osteoarthritic knee joints.

Discussion

The methodology and the assumptions on which the method used is based have been

Table 1. Calculated oxygen consumption, diffusing capacity and blood flow in osteoarthritic synovial membrane.

No	PaO_2 (Torr)	VO_2 (µl/min)	DO_2 (µl/min/Torr)	Blood flow (ml/min)
1.000	93.800	0.938	0.017	0.280
2.000	73.200	1.317	0.029	0.360
3.000	79.700	3.751	0.050	0.320
4.000	117.900	1.800	0.022	0.440
5.000	106.900	2.374	0.029	0.890
6.000	81.800	1.223	0.028	0.750
7.000	86.400	1.937	0.014	1.000
8.000	93.800	0.938	0.017	0.280
9.000	101.100	6.585	0.071	0.320
10.000	87.700	1.106	0.025	0.480
11.000	103.500	5.148	0.040	0.380
12.000	65.800	1.333	0.020	0.290
13.000	93.300	3.259	0.033	0.150
14.000	52.000	1.540	0.041	0.450
MEAN	88.350	2.375	0.031	0.456
STD	16.636	1.660	0.015	0.240
SEM	4.613	0.460	0.004	0.067

Column 2) shows the measured values of the arterial oxygen tension (PaO_2), and column 3), 4) and 5) the calculated oxygen consumption (VO_2), diffusing capacity (DO_2) and the blood flow (Q).

described in detail elsewhere (*Svalastoga et al* 1989). The experimental model used in this study is based on a surgical technique producing medial instability of the knee (*Hult et al* 1970). The main advantage of this approach compared to studies on clinical cases of osteoarthritis is that it enables investigation of a uniform material at a well defined stage of the disease. A similar model has been widely used and the similarity to genuine osteoarthritis is well documented in osteoarthritic research (*Bohr* 1976, *Christensen* 1985, *Christensen et al.* 1982, *Telhag & Lindberg* 1972).

When the results in this study are compared with the results obtained from normal rabbit knee joints (*Svalastoga et al.* 1989) a statistically significant increase in the oxygen consumption (VO_2) is seen ($p < 0.01$, Wilcoxon rank sum test), whereas there is no difference in diffusing capacity (DO_2) and blood flow (Q). This implies that there is an increase in the partial pressure difference across the synovial membrane required to overcome the cellular demands and hence a reduced oxygen transfer capacity from the synovial membrane to the cartilage. A previous analysis of the joint model (*Svalastoga & Grønlund* 1985b, *Svalastoga et al.* 1989) has shown that the magnitude of the partial pressure difference across the synovial membrane (δPO_2) required to overcome the oxygen consumption can be estimated by insertion of the values of VO_2 and DO_2 in the equation:

$$\delta\ PO_2 = VO_2 / 2\ DO_2.$$

Insertion of the present experimentally obtained values gives a mean δ PO_2 of 37.6 Torr, which is 4.3 times greater than the normal value of 8.7 Torr reported by *Svalastoga et al.* 1989 ($p < 0.05$, Wilcoxon rank sum test). Hence the oxygenation of the joint cartilage is reduced with approx. 30 Torr. In vitro experiments have shown that cartilage cells exhibit both anaerobic and aerobic respiration (*Lane et al.* 1977, *Stockwell & Meachim* 1979, *Stockwell* 1983). However, the cell function and synthesis is highly dependent upon the oxygen tension (*Taylor* 1981, *Stockwell* 1983). The interpretation of our results are that the cells of the joint cartilage are partially deprived their oxygen supply in late stage of osteoarthritis. In combination with other factors such as increased mechanical wear the metabolic demands of the cartilage cells may not be fullfilled (*Richman et al.* 1981).

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Sammendrag

Iltforbrug, diffusionskapacitet og blodgennemstrømning i synovialmembranen i knæled hos kaniner med induceret osteoarthritis

I artrotiske led reduceres iltoverførslen fra synovialmembranens kapillærer til synovi, herved kan ledbrusken helt eller delvis berøves sin eneste oxygenkilde.

I nærværende arbejde har vi beregnet blod flow (Q), diffusionskapacitet (DO_2) og metabolisme (VO_2) i 14 knæled i det kroniske stadie af eksperimentel artrose. Vi fandt, sammenlignet med undersøgelse af normale led, en statistisk signifikant øget metabolisme, hvorimod de øvrige parametre var uforandrede. Dette medførte, at den partialtryksdifferens, som er nødvendig for at overkomme den øgede metabolisme, stiger med en faktor 4.3 og at iltforsyningen til ledbrusken reduceres med 30 Torr.

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