Intra-articular pressure in rheumatoid arthritis of the knee

I. Pressure changes during passive joint distension

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In any compartment with stiff walls the excess pressure of fluid within is determined by a combination of the volume of fluid and the elasticity of the walls. The elastance of the space as a whole can be represented as a change in pressure for unit change in volume (dP/dV or mm. Hg/ml.). It follows that within the knee joint higher pressures will develop in the presence of effusions and when the elasticity of the joint capsule is increased.

The intra-articular pressure, that is the pressure in the synovial fluid (not that between the contact areas of the articulating surfaces), has been determined in the resting, passively distended knees of rheumatoid and control subjects with various volumes of simulated effusion.

Subjects studied

The purpose and possible hazards were fully explained to the 25 volunteers who were the subjects of this study. Fifteen experiments were conducted on the affected knees of fourteen patients with definite or classical rheumatoid arthritis (RA) (Ropes, Bennett, Cobb, Jacox, and Jessar, 1959). Thirteen experiments were performed on normal knees of eleven control subjects. Both knees of one control subject were studied and the investigation was repeated on one control and on one rheumatoid knee after intervals of 4 and 3 months respectively. The repeated studies were not used in the statistical analysis.

It did not prove possible to match the controls with the patients for age, sex, height, and weight, as the rheumatoid subjects were mainly small, female, and middle-aged or elderly, whereas one's colleagues who volunteered as controls were younger, larger, and more often male.

Method (Fig. 1, overleaf)

A Braun Size 2 cannula, passed under local anaesthesia into the knee joint from the lateral side so as to lie in the supra-patellar pouch, was connected to a three-way tap (Tap A), then by tubing to three-way taps (Taps B and C) and to a Stathem P23 Gb pressure transducer the output

of which was amplified and recorded. The transducer was calibrated against a mercury manometer. A solution of 4·3 per cent. dextrose and 0·18 per cent. sodium chloride, used as a simulated effusion, could be added to the joint from an infusion bottle attached to the side-arm of Tap B. Volumes of fluid added or withdrawn were measured by a syringe attached to the side-arm of Tap A. By turning the appropriate taps, the lumen of the joint was placed in hydrodynamic communication with the transducer. Sterile precautions were observed throughout.

The intra-articular pressure was first measured in the relaxed extended knee. Any fluid present was aspirated and its volume noted, and the pressure was again recorded. The joint was then distended with a simulated effusion and the pressures at increasing volumes were measured. The planned range of simulated effusions was in 5, 10, or 20 ml. increments from 0 to 100 ml. However, some subjects could not tolerate so much and in them the investigation was stopped at smaller volumes.

After maximum distension the joint was aspirated in regular decrements and the pressures recorded at each point. The total volume of fluid removed was measured and compared with the volume injected.

Symptoms due to joint distension

Progressive distension of the joint produced symptoms in the majority of subjects. The initial sensation was of 'tightness'. With more fluid this became more extreme until it felt as if the joint were about to burst. Pain was not present at the lower pressures. The study was stopped when the subject reported moderate pain. However, symptoms only lasted a few seconds and then rapidly diminished, especially at smaller volumes. It was impossible to quantify the sensations because of their subjective nature and their rapid disappearance.

After-effects

The patients with rheumatoid arthritis were confined to bed for 24 hours after the investigation and suffered no after-effects. Many reported that the knee felt much better. Although this effect could not be analysed statistically, it was sufficient to suggest a controlled trial of synovial
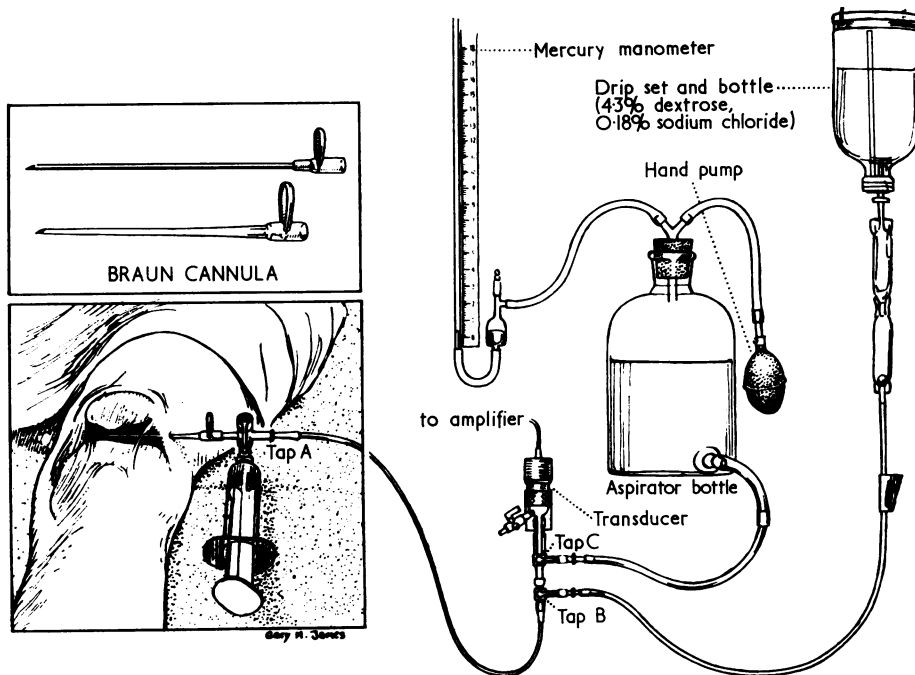
FIG. 1   *Experimental design.*

lavage in rheumatoid knees (Lindsay, Ring, Coorey, and Jayson—to be published). The control subjects carried on with normal activities immediately after the study. They often showed a mild synovitis with some pain on exertion and a small effusion lasting about 24 hours.

There was no infection or haemarthrosis. Many specimens of synovial fluid and simulated effusion were cultured and all were sterile.

Results

Intra-articular pressure and volume at initial puncture (Table)
Fluid was found in eleven of the fourteen rheumatoid knees, the volume varying between 3 and 62 ml. No measurable quantities of fluid were found in the twelve control knees.

Table   *Initial intra-articular pressure and effusion volume*

Series	Rheumatoid arthritis	Controls	t	P
Mean Pressure (mm. Hg)	$18 \cdot 9 \pm 10 \cdot 7$	$0 \cdot 8 \pm 1 \cdot 5$	$6 \cdot 25$	$<0 \cdot 001$
Mean Volume (ml.)	$23 \cdot 6 \pm 21 \cdot 4$	$0 \cdot 0 \pm 0 \cdot 0$	$4 \cdot 13$	$<0 \cdot 001$

The mean resting pressure in the knees of patients with R.A. varied between 4 and 36 mm. Hg and in the twelve control knees between −2 and +3 mm. Hg. The difference was statistically highly significant ($P < 0 \cdot 001$).

No correlation was found between the volumes and pressures of effusions in the rheumatoid knees ($r < 0 \cdot 001$; $P > 0 \cdot 1$).

Intra-articular pressure during joint filling
With increase in volume of simulated effusion, intra-articular pressure increased, slowly at first and then more rapidly at larger volumes. The rheumatoid knees developed higher pressures than the controls, especially at larger volumes. Results from a typical rheumatoid and a typical control subject are illustrated in Fig. 2.
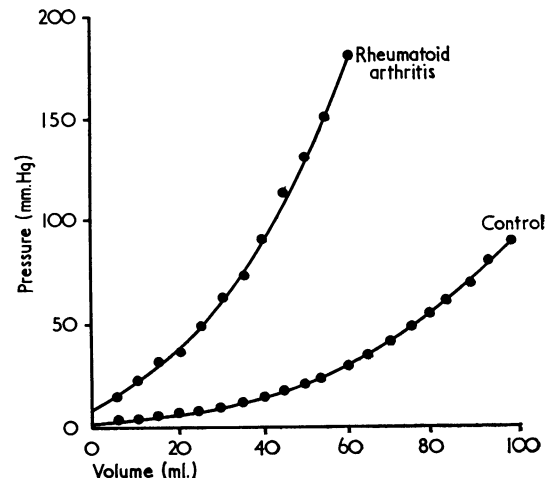

FIG. 2   *Typical pressure/volume curves from rheumatoid and control knees.*

The mean intra-articular pressures with their standard errors, the numbers of control and rheumatoid knees studied at each volume, the values for Student's t, and the probability (P) of any difference occurring by chance are illustrated in Fig. 3. At all volumes the rheumatoid knees were at higher intra-articular pressures than the controls. These differences were not significant (N.S. = P > 0·05) with simulated effusions of 0 and 20 ml., but they were significant at 40, 60, and 80 ml. Very high levels of significance (P < 0·001) were achieved at the last two volumes. As the rheumatoid patients developing the highest pressures were unable to tolerate the larger volumes of effusion, the true differences between the two groups were probably underestimated by this analysis.
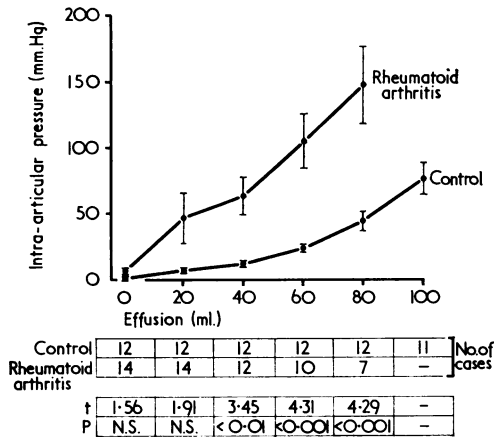

Control	12	12	12	12	12	11	No. of
Rheumatoid arthritis	14	14	12	10	7	–	cases
t	1·56	1·91	3·45	4·31	4·29	–	
P	N.S.	N.S.	<0·01	<0·001	<0·001	–	

FIG. 3 *Pressure/volume relationships in rheumatoid and control knees.*

When similar comparisons were made between the intra-articular pressures developed at excess volumes above those of the initial joint effusion (Fig. 4), the rheumatoid intra-articular pressures were considerably higher than the controls and at all volumes the differences were highly significant (P < 0·001).
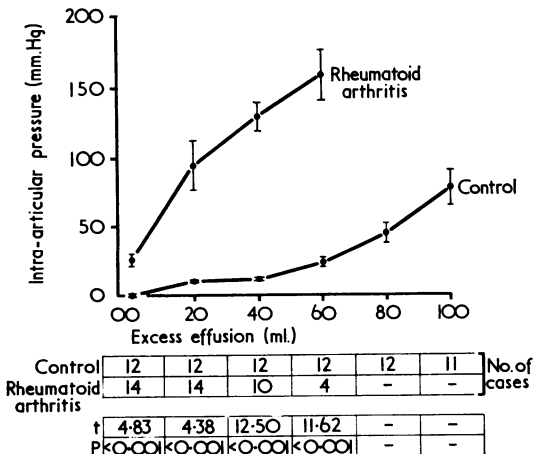

Control	12	12	12	12	12	11	No. of
Rheumatoid arthritis	14	14	10	4	–	–	cases
t	4·83	4·38	12·50	11·62	–	–	
P	<0·001	<0·001	<0·001	<0·001	–	–	

FIG. 4 *Pressures in rheumatoid and control knees at excess volumes above initial effusion volumes.*

Intra-articular pressure during joint emptying

The pressures during joint emptying were almost always lower than the filling pressures at the same volume. In some subjects the volume of fluid injected was slightly higher than that withdrawn, suggesting that some fluid might be lost by diffusion through the wall or by being trapped in a communicating bursa. Even when the volumes at which each pressure measurement were made were recalculated to take account of this discrepancy, the emptying pressures were still lower.

These lower pressures seemed to depend on the amount the joint had been distended between the two readings, and the time during which the capsule had been allowed to recover its original length and elasticity. The pressures therefore also depended upon the rate at which the joint was emptied. For these reasons, less value was attached to the pressures recorded during joint emptying.

Reproducibility of results

Only limited opportunities were available for repeating the studies in the same knees, but in the two subjects in which they were repeated, both the pressures and volumes of the joint contents at initial puncture and the pressure/volume data obtained during distension were similar. In addition, results obtained from both knees of a healthy control subject resembled each other.

Discussion

The volumes of fluid found in normal and rheumatoid knees were similar to those reported elsewhere (Ropes, Rossmeisl, and Bauer, 1940; Ragan, 1946; Ropes and Bauer, 1953; Caughey and Bywaters, 1963).

The resting pressure in the empty normal control knee joint was almost exactly atmospheric pressure. Müller (1929) found the pressure in normal living joints to be several cm. of water less than atmospheric pressure, but Caughey and Bywaters (1963) suggested that this was due to some blockage in their measuring apparatus. However, Reeves (1966) confirmed that the resting pressures in the knees of normal humans and of animals was usually between −2 and −10 mm. Hg, and Dixon (1966) stated that the intra-articular pressure in normal joints was approximately equal to atmospheric pressure.

At initial puncture the pressures in the rheumatoid joints were significantly higher than in the controls. The increased pressures were probably due to a combination of stiffness and tension in the joint lining and hypertrophied synovium within the joint lumen.

No direct relationship was found in the rheumatoid knees between the volumes and pressures of the initial effusions. This suggested that the elastance of the knee joint capsule in rheumatoid arthritis varied widely and was probably much greater in those joints without effusions than in those in which large

effusions developed but were nevertheless at relatively low intra-articular pressures.

Previous studies of human knee joint elastance have been limited. Caughey and Bywaters (1963) published a pressure/volume curve from one patient. De Andrade, Grant, and Dixon (1965) made readings of intra-articular pressure at rest with varying volumes of simulated effusion. However, after each pressure measurement, the quadriceps muscle was contracted, considerably increasing the intra-articular pressure and stretching the unsupported parts of the synovium. This would alter the elastance of the joint so that at the next higher volume the reading would have been lower than if the quadriceps contraction had not been performed. During the present study, quadriceps contraction was avoided. Although this was somewhat artificial, it enabled comparisons to be made under similar conditions.

Significant differences were found between the rheumatoid and control joints. However, the control subjects were younger and larger than the rheumatoid patients and more often male. Nevertheless, there was no correlation in the controls between the body size and the results obtained. The two smallest controls did not develop the highest pressures in that group, one of them developing the lowest found. This difference in body size could only account for a part of the differences between the two groups.

Distension of a joint by a naturally occurring effusion may lead to chronic stretch of the joint capsule, so that measurements of the pressure at lower volumes would not be meaningful. Should comparisons between patients and normal controls have been made in terms of increase in effusion volume over that of the initial joint contents rather than with reference to the empty joint? When this analysis was made, the differences between the rheumatoid and control subjects were increased.

We interpret these findings as showing that rheumatoid joints have a higher elastance. This increased elastance could be due either to hypertrophied synovium acting as an addition to the intra-articular volume or to fibrosis of the joint capsule. Wright and Johns (1960a, b) and Johns and Wright (1962) showed that the changes in the capsule were the most important causes of stiffness during joint movement. This type of stiffness is probably related to the pressure/volume changes as measured here.

A statistical analysis suggested that the joints with the highest elastance were those with the lowest initial volumes of effusion and *vice versa*. A number of factors influence the development of synovial effusions, including the magnitude of inflammatory changes and the degree of capillary permeability, but it would seem possible that an excessive intra-articular pressure rise with each increment of effusion volume could resist further passage of fluid into the joint. Joints with a low elastance would therefore be more likely to form effusions. However, an alternative explanation is that the effusion had stretched the joint lining to a degree directly related to the volume of fluid present. Greater laxity of the joint capsule occurred and lower pressures developed, in those joints from which larger volumes were removed.

The fluid in a joint distended by a naturally occurring effusion is in dynamic equilibrium, formation balancing reabsorption. After aspiration, such an effusion rapidly reforms until equilibrium is again achieved. Even if low elastance in the empty joint is the result rather than the cause of a large effusion, it would seem likely that this may enable transudation and exudation to take place more easily.

The sensation of joint distension appeared at much lower intra-articular pressures in the control subjects than in the patients with rheumatoid arthritis. Very much higher pressures than these developed during active use of the same joints with quadriceps muscle contraction, but this type of symptom did not develop. This suggested that the symptoms were not directly due to changes in intra-articular pressure but rather to stretch of the joint lining. Quadriceps contraction squeezes the joint contents and increases the intra-articular pressure without stretching the joint lining (Jayson and Dixon, 1970). The rheumatoid lining is stiffer than the control so that during passive distension the receptors would be stimulated at higher intra-articular pressures. Andrew and Dodt (1953) showed that distending the joint produced increased impulses travelling up the medial articular nerve of the cat knee, and Wyke (1967) and Freeman and Wyke (1967) described four types of joint sensory nerve endings. It would seem likely that the sensation noted by the subjects would be due to the stimulation of the Type I corpuscles or Type IV plexuses and free nerve endings.

Summary

Measurements of intra-articular pressure were made using joint catheterization and an external transducer. At initial puncture the volumes and pressures of the joint contents were significantly higher in rheumatoid knees than controls. After aspiration of the joints and re-distension with increasing volumes of a simulated effusion, higher pressures again developed in the rheumatoid group. These differences were increased by measuring the pressure at effusion volumes related to those of the original joint contents. Distension of the joint produced a sensation of tightness which was probably due to stimulation of the stretch receptors rather than the pressure receptors.

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RÉSUMÉ

La tension intra-articulaire dans l'arthrite rhumatoïde du genou
I. Les changements dans la tension pendant la distension passive de l'articulation

Les estimations de la tension intra-articulaire ont été faites en employant la cathétérisation et un transduceur externe. A la ponction initiale les volumes et les tensions des contenus de l'articulation étaient plus élevés d'une manière significative dans les genoux rhumatoïdes que dans ceux des témoins. Après l'aspiration des articulations et la distension de nouveau en employant des volumes qui vont en augmentant afin de causer un épanchement simulé, des tensions plus élevées ont de nouveau eu lieu chez le groupe rhumatoïde. Ces différences ont été augmentées en mesurant la tension quand les volumes causant une effusion étaient en relation aux volumes du contenu original de l'articulation. La distension de l'articulation produisait une sensation de raidissement qui était probablement due à la stimulation des récepteurs de traction plutôt qu'a ceux de tension.

SUMARIO

Presión intraarticular en la artritis reumatoide de la rodilla
I. Cambios de presión durante la distensión pasiva de la articulación

Se llevaron a cabo mediciones de presión intraarticular usando cateterismo articular y un transductor externo. En la punción inicial, los volúmenes y presiones del contenido de la articulación fueron significativamente más altos en las rodillas reumatoides que en los testigos. Después de aspirar las articulaciones y redistender con mayores volúmenes de un derrame simulado, se volvieron a desarrollar altas presiones en el grupo reumatoide. Estas diferencias aumentaron al medir la presión de los volúmenes en relación con aquellos del contenido original de la articulación. La distensión articular produjo una sensación de tirantez que se debía probablemente a la estimulación de los receptores extensores más que a la presión de los receptores.

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