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THE CONTACT BETWEEN THE ARTICULAR CARTILAGE AND THE MEDULLARY CAVITIES OF THE BONE[1]

By

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INTRODUCTION

In connection with the studies of the structure of the articular cartilages under various functional conditions (Holmdahl and Ingelmark 1946, 1947, 1948) it has also become of interest to investigate the nutritional conditions of the articular cartilages. The knowledge already acquired through the use of different techniques makes it probable that there is an exchange of liquid between the articular cartilage on one side and the medullary cavities of the epiphyses on the other (Ingelmark and Sääf 1948, Ingelmark and Ekholm 1948, and also Ekholm 1950). Since there are, as far as we could find in medical literature, no morphological investigations that explain how such an exchange of liquid can take place, we have studied the space between the basal portions of the articular cartilage and the underlying bone with its system of canals and its cavities.

LITERATURE

In medical literature it is usually maintained that a continuous bone-lamella separates the medulla from the fully-developed articular cartilage. Petersen (1930) however, describes curved surfaces of contact between the articular cartilage and the medulla. According to his opinion, their only importance lies in the fact that, at the growth of the

[1] The complete paper is published in Upsala Läkareförenings Forhandlingar 55, 147, 1950.

epiphysis, the cartilage is dissolved from underneath by action of osteoclasts. It seems likely that lamellar bone would then be formed between the articular cartilage and the medulla and over the deficiencies mentioned. If such contacts between the medullary cavity and the articular cartilage are found, according to Petersen, this indicates that there is no fixed limit between cartilage and bone.

This author also describes dead-end canals that stretch perpendicularly from the medulla to the articular cartilage via the compact bone layer which supports the articular cartilage. Petersen calls these Volkmann's canals.

Thus Petersen connects the canals described above with the development of bone and does not attach any nutritive significance to them. As far as we have found in literature, no other author has expressed such an opinion.

As we see it, these canal-like contacts between the articular cartilages and the medullary cavities of the epiphyses should be considered chiefly as constricted parts of the medullary cavity, formed during the last stages of the skeleton development when the articular cartilage obtain a firm layer of bone.

MATERIAL AND METHODS OF THE INVESTIGATION

The material is as uniform as possible and consists of approx. 10 months' old rabbits. The number of investigated joints of various kinds is made clear in Table 1. For a more detailed description of the origin and breeding conditions of the animals as well as of the histotechnical treatment, see the third group of material in Holmdahl and Ingelmark 1948.

The study of the uniform rabbit material has taken place in the

TABLE 1

		Left	Right	Total
Shoulder-joints	Humerus prox.	21	1	22
	Scapula	21	1	22
Elbow-joints	Humerus dist.	13	6	19
	Radius prox. / Ulna prox.	13	6	19
Hip-joints	Femur prox.	19	—	19
	Acetabulum	19	—	19
Knee-joints	Femur dist.	13	12	25
	Patella	11	5	16

Number of rabbit joints investigated.

following way. One histological section from each joint has been examined under the microscope. A magnification of about 300 has been used. A micrometer was mounted in the ocular. One division on the scale of the micrometer corresponds to approx. 7.0 γ in the sections. During study of the sections, the whole boundary line between the calcified cartilage on the one side and the underlying bone and medullary cavity on the other, has been minutely and systematically followed.

All portions where the medullary cavity was definitely in direct contact with the inferior surface of the cartilage have been measured in such a way that the longest rectilinear distance between the two limits of the surfaces of contact has been registered. In the cases when cut-off portions of medulla were found inside the articular cartilage, the main axis of the ellipse-shaped surface of the medulla was measured.

As a result of these findings, the surfaces of contacts have been divided into two categories, i.e. wide (ampulla-like) contacts, where, within a comparatively large area, the medulla lies against the cartilage, and canal-like (dendritic) ones, where tubular offshoots of the medullary cavity connect via comparatively compact bone with the inferior surface of the cartilage. Furthermore we noted the order in which the different contacts were found, when the boundary-line between cartilage and bone was systematically followed around the whole extremity of the joint.

In order to get an idea of the relative surface occupied by contacts between the articular cartilage and the medullary cavity, we have drawn the boundary-line between the cartilage and the joint cavity. For the shoulder-joints, hip-joints and knee-joints we used a magnification of 10, and for the elbow-joints one of 25. In this way, a rough conception is obtained of the length of the boundary-line between cartilage and bone, if no notice is taken of the undulation of the boundary-line in question.

The significance the undulation has for the enlargement of the inferior surface of the cartilage has been ascertained by drawing sections magnified 200 times. We have then measured the rectilinear distance between the two ends of the examined boundary-line, and we have also registered, by means of a map-gauge, the prolongation caused by the undulation mentioned.

Through the calculations briefly described here, it has been possible to obtain a fairly reliable estimation of how much of the inferior surface of the cartilage is in direct contact with the medullary cavity, the extent to which these surfaces of contacts consist of wide contacts

and canal-like ones respectively, and also the actual sizes of these two types of contact and the numerical ratio between them.

Naturally, the method here described is in many respects open to error, and the real values must therefore be very carefully judged.

Of course, the histological sections do not reproduce the intravital conditions correctly; but since, in this case, the question is concerned with almost firm tissues, it may be justifiably assumed that the relative values obtained by the calculations are on the whole reliable. So as not to overestimate the number of contacts, we have carried out the revision very carefully and have always rejected findings that did not seem to be quite reliable.

Considering the limited space, we shall not here enter into a detailed discussion of the reliability of the method of the investigation, but with regard to these questions, we refer to our more extensive mutual study in this field (Holmdahl and Ingelmark 1950). In brief, it should, however, be pointed out that the points of uncertainty concerning this method are numerous, but are all of quantitative character. As with the microscopic findings, there should be no need to fear any qualitative errors occurring. The quantitative sources of error will be roughly the same in the different parts of the material, and therefore, it seems justifiable to make a comparison between them and also to draw suitable conclusions from the differences obtained and statistically verified.

RESULTS OF THE INVESTIGATION

The Occurrence of Contacts between Cartilage and Medullary Cavity.

In all the joints examined, we have been able to prove the existence of direct contacts between the medullary cavities of the epiphyses and the basal portions of the articular cartilages. In the great majority of cases it is the calcified portion of the articular cartilage that is in contact with the medullary cavity. In isolated cases we have found offshoots of medullary cavity tissue reaching into the un-calcified articular cartilage. In the human joints examined, there are small parts of the articular cartilages where we have not found any calcified cartilage. In these portions it is not unusual to find direct contacts between the cartilage and the medullary cavity.

In the material investigated, we have been able to distinguish two different types of contacts. The one, the so-called *wide (ampulla-like) contacts,* consists of comparatively wide surfaces of contact between the medullary cavities and the inferior surface of the arti-

cular cartilage (Figs. 1-2). The average size of these contacts when directly measured in the microscope is reproduced in Table 2.

Fig. 1.
Microphoto, caput humeri, rabbit. (× 85). Wide (ampulla-like) contact between medullary cavity and articular cartilage.

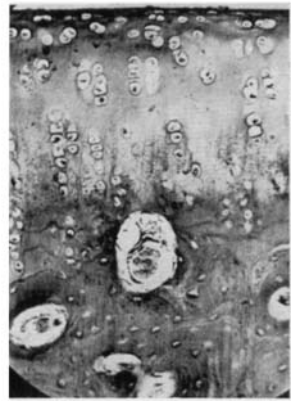

Fig. 2.
Microphoto, scapula, rabbit. (× 50). Wide (ampulla-like) contact between medullary cavity and the calcified as well as the un-calcified portions of the articular cartilage.

Fig. 3.
Microphoto, caput humeri, rabbit. (× 73). Canal-like (dendritic) contact enclosed in bone socket.

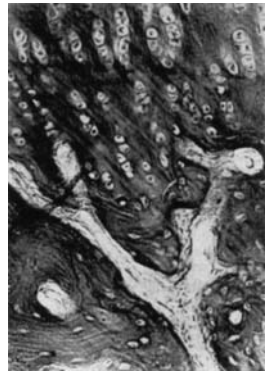

Fig. 4.
Microphoto, distal end of femur, rabbit. (× 73). Canal-like (dendritic) contacts.

In several cases, we have observed a seemingly special arrangement of the bone in relation to the point of contact. Apparently, here we have to deal with a conical bone socket whose apex points upwards

and whose parietal thickness decreases towards the articular cartilage (Fig. 3).

The other type of contact between the cartilage and the medullary cavity, the so-called *canal-like (dendritic) contacts*, consists of narrow canals which branch outwards to a varying degree and finally extend

TABLE 2

	Surfaces of contacts	
	Canal-like	Wide
Humerus prox.	16.74 ± 0.58	51.6 ± 3.2
Scapula	17.8 ± 1.4	40.1 ± 2.0
Humerus dist.	12.08 ± 0.44	30.0 ± (3.1)
Radius prox.	11.41 ± 0.88	25.8
Ulna prox.	14.5 ± 1.1	45.9
Femur prox.	15.28 ± 0.65	41.9 ± 2.9
Acetabulum	16.7 ± 2.0	45.81 ± 0.74
Patella	13.8 ± 2.4	34.6 ± 2.9
Distal region of femur dist.	15.7 ± 1.8	30.7
Proximal region of femur dist.	17.0	45.5 ± 1.4

The size of the surfaces of contacts in μ.

into the most basal portions of the articular cartilage (Fig. 4). Their arrangement seems on the whole to correspond to that of the so-called *Haver*'s canals but their diameters are greater throughout and, in addition, seem to vary more than those of the *Haver*'s canals. The diameter of these contacts within the various joints is clear from Table 2.

The Occurrence of the two Forms of Contact between the Cartilage and the Medullary Cavity.

The frequency of canal-like contacts in relation to the wide contacts varies to a great extent between the different joints (Table 3).

If we examine the size of that part of the basal surface of the articular cartilage which is occupied by canal-like contacts, the values given in Table 3 are obtained. The numerical values are remarkably uniform, with the exception of the comparatively high values for the patella, and, above all, for the distal region of the distal end of the femur, and the excessively low value for the proximal region of the distal end of the femur. Thus, in most joint surfaces, the canal-like contacts occupy less than one per cent of the cower surface of the articular cartilage.

On the other hand the portion of the basal surface of the cartilage occupied by the wide contacts varies a great deal (Table 3). The

TABLE 3

	The percentile surface, occupied by contacts		The percentile number of canal-like contacts
	Canal-like	Wide	
Humerus prox.	0.65 ± 0.09	3.86 ± 0.84	46.8 ± 6.8
Scapula	0.78 ± 0.13	2.95 ± 0.73	53.6 ± 7.3
Humerus dist.	0.67 ± 0.07	0.17 ± 0.05	98.2 ± 2.4
Radius prox.	0.85 ± 0.20	0.37 ± 0.17	91.5 ± 7.1
Ulna prox.	0.79 ± 0.14	0.71 ± 0.26	89.7 ± 6.2
Femur prox.	0.73 ± 0.10	1.71 ± 0.67	70.3 ± 6.5
Acetabulum	0.83 ± 0.20	3.44 ± 0.60	22.2 ± 8.4
Femur dist. (Proximal part)	0.08 ± 0.02	7.08 ± 1.05	3.0 ± 1.2
Femur dist. (Distal part)	1.40 ± 0.13	0.15 ± 0.05	95.9 ± 1.5
Femur dist. (Whole length)	0.85 ± 0.09	2.24 ± 0.36	60.8 ± 7.0
Patella	1.11 ± 0.15	1.43 ± 0.45	83.7 ± 6.6

highest value, 7.1 per cent, is found in the proximal part of the distal end of the femur, the lowest value, 0.15 per cent, within the distal region of the same joint surface. All joint-surfaces in the elbow-joint show remarkably low values in this respect. The values for the joint surfaces of the shoulder-joint, the hip-joint and the patella are considerably higher. From this it is clear that, with regard to their total size, the wide surfaces of contact are very much larger than the canal-like ones in the shoulder-joint, the hip-joint and the proximal region of the distal end of the femur, while on the other hand, the difference is comparatively insignificant in the elbow-joint and the distal part of the distal end of the femur.

If one compares the total size of the contacts in relation to the basal surface of contact of the articular cartilage between the various joints, the proximal part in the distal end of the femur is in a class by itself with as much as 7%. The values for the shoulder-joint are about 4%, those for the hip-joint between 2-4%. On the other hand, the values for the elbow-joint and the distal region of the distal end of the femur do not exceed 1.5%.

It seems to be of interest to point out that the canal-like contacts as well as the wide ones are, on the whole, of the same size in the various limb joints examined and that the variation in size is noticeably less for the canal-like contacts than for the wide ones.

DISCUSSION OF THE RESULTS OF THE INVESTIGATION

As we have mentioned before, in medical literature hitherto published no particular attention has been paid to the fact that there is a direct contact between the medullary cavities and the articular

cartilages. When we earlier analysed the structure and nutritional conditions of the articular cartilages, this question, however, became of very great importance, above all through the investigations by Ingelmark and Sääf, 1948, and also by Ingelmark and Ekholm, 1948, concerning the passage of liquid through the articular cartilages. To understand the results, it must be supposed that there are always contacts between the medullary cavities and the articular cartilages.

In this paper, we have been able to state that in all big limb joints in rabbit there exist such direct contacts between the cartilage and the medullary cavity in the joint head as well as in the socket. Thus, the above mentioned investigations have secured a purely morphological foundation and explanation. This gives them a more reliable basis.

It must be presumed that the distal, convex part of the groove between the two femur condyles is exposed to particularly strong mechanical strains in a rabbit, which generally keeps the knee-joint in a highly flexed position on the contraction of m. quadriceps femoris, and similarly that the proximal, almost smooth part of the same groove, is exposed only to slight pressure. Consequently, as the distal portion has in most cases canal-like contacts and the proximal portion practically only wide ones (Fig. 10), we may reliably conclude that there exists a causal connection between the mechanical strains of the joints and the shaping of the contacts between the medullary cavities of the bones and the basal parts of the articular cartilages.

Through the earlier mentioned investigations it has been proved likely that the contacts referred to form passages for liquid from the medullary cavities of the bones into the articular cartilages or vice versa. Therefore, it seems surprising that in portions which are mechanically the most strained, there is a comparatively smaller surface of contact than in portions where the mechanical requirements are much less. Without being able to define our position in relation to the certainly very complicated elements that determine the passage of liquid between the medullary cavities and the articular cartilages, we nevertheless wish to point out a few facts that should be of importance.

The reason why there are almost exclusively canal-like contacts in the portions of the surface of the joints subjected to strong pressure, may be that the part of the bone supporting the pressure, "die Druckaufnahmeplatte", must be strong enough to give satisfactory and almost continuous support to the basal part of the articular cartilage. By the investigations mentioned we have been able to prove that intensified function of the articular cartilage in the form of iterative

compressions causes an increased amount of liquid to pass through. Therefore, it seems possible that the articular cartilages, in more actively functioning portions of joints, may obtain adequate nutrition even though they have smaller surfaces of contacts than slightly strained areas.

From what has been said it will be clear that within this hitherto hardly studied problem, we are concerned with facts important to the structure and function of the joints and perhaps also to joint pathology. As it has become clear in our preliminary investigations, that the contacts between the medullary cavities and the articular cartilage observed in rabbit are to be found also in man, we have considered it valuable to extend our investigations to include man as well. We shall then primarily examine the state of the knee-joints at varying ages and in connection with various pathological conditions.

SUMMARY

1. In all joints examined we have been able to prove the existence of direct contacts between the medullary cavities of the epiphyses and the basal portions of the articular cartilage.
2. In the great majority of cases it is the calcified part of the articular cartilage that is in contact with the medullary cavity.
3. In isolated cases, offshoots of medullary cavity tissue have been found extending into the un-calcified articular cartilage.
4. The size of the wide (ampulla-like) contacts when directly measured in the microscope is reproduced in Table 2. The characteristics of the contacts is made clear in Figs. 1 and 2.
5. In several cases a special arrangement of the bone in relation to the point of contact has been observed. Here we are apparently dealing with a conical bone socket whose apex points upwards and whose parietal thickness decreases towards the articular cartilage (Fig. 3).
6. The size of the canal-like (dendritic) contacts when directly measured under the microscope is reproduced in Table 2. The characteristics of the contacts are made clear in Figs. 4 and 5.

ZUSAMMENFASSUNG

1. In sämtlichen untersuchten Gelenken konnten direkte Kontakte zwischen den Markhöhlen der Knochenenden und den basalen Partien des Gelenkknorpels nachgewiesen werden.
2. In der Mehrzahl der Fälle ist es der verkalkte Teil des Gelenkknorpels, welcher der Knochenmarkhöhle anliegt.

3. In einzelnen Fällen konnten Aufläufer von Markhöhlengewebe bis hinauf in den unverkalkten Gelenkknorpel festgestellt werden.
4. Die Grösse der breiten (ampullären) Kontakte bei direkter Messung im Mikroskop wird in Tab. 2 wiedergegeben. Das Aussehen der Kontakte geht aus Figg. 1 und 2 hervor.
5. In mehreren Fällen konnte eine spezielle Anordnung des Knochens im Verhältnis zur Kontaktstelle beobachtet werden. Es handelt sich hier anscheinend um eine konische Knochenmanschette, deren Spitze nach oben gerichtet ist und deren Wanddicke zum Gelenkknorpel hin abnimmt (Fig. 3).
6. Die Grösse der kanalförmigen (dendritischen) Kontakte bei direkter Messung im Mikroskop wird in Tab. 2 wiedergegeben. Das Aussehen der Kontakte geht aus Figg. 4 und 5 hervor.

RESUME

1. Dans tous les articulations examinées on a pu constater un contact direct entre les cavités médullaires des extrémités osseuses et les parties basales des cartilages de l'articulation.
2. Dans la grande majorité des cas, c'est la partie calcifiée du cartilage de l'articulation qui est placée contre la cavité médullaire.
3. Dans des cas isolés, on a trouvé des ramifications du tissu médullaire se terminant dans le cartilage articulaire non calcifié.
4. La grandeur de ces larges contacts (ampoulaires) mesurée directement au microscope est reproduite au tableau 2. L'aspect de ces contacts apparaît aux figures 1 et 2.
5. Dans la plupart des cas, on a constaté une structure spéciale de l'os à l'endroit du contact. Il semble qu'il se soit formé ici une manchette osseuse conique à la pointe dirigée en haut et dont l'épaisseur des parois diminue du côté du cartilage (fig. 3).
6. La grandeur des contacts en forme de canal (dendritiques), mesurée directement au microscope est reproduite au tableau 2. L'aspect des contacts apparaît aux fig. 4 et 5.

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