In recent years there has been increasing interest in the surface detail of both synovium and cartilage (Gardner and Woodward, 1968; Fujita et al., 1968; Gryfe et al., 1969; Gardner and Woodward, 1969; Walker et al., 1969; Highton and Donaldson, 1970). The precise topographical details of the synovial surface are of considerable importance in helping to elucidate the physiology and pathology of joints, and similarly, the details of microscopic anatomy of the surfaces of the articular cartilage are important not only with regard to the lubrication of the joint, but also in showing the early lesions of disease processes.

Generally, ultramicroscopic methods available to workers who study the structure of joints may be divided into three broad classes:

(a) ultra-thin sections, less than 70 nm in thickness,
(b) replicas of the surface, or
(c) the scanning electron microscope, used to study the topography of the entire joint surface. This has the advantage of a great depth of focus, and is the method used in this study.

Materials and Methods
Samples were obtained from the joints of rabbits and also from patients. The knee joints of seven healthy rabbits aged from six months to four years were examined. The synovium from around the patella and of the suprapatellar pouch was sampled and the articular portion of the patella was also examined. In some cases the tibial tubercle and the femoral condyle or portions of these were also included. Samples of human material were obtained from the following sources:

1. synovia and cartilage of two patients undergoing meniscectomy;
2. portions of the femoral condyle from a patient with degenerative joint disease undergoing total hip replacement;
3. the knee joint (post mortem) of one patient with rheumatoid arthritis; and
4. the operative specimens of seven other patients with rheumatoid arthritis who were undergoing synovectomy.

Small pieces of these tissues were fixed for five hours in cacodylate buffered glutaraldehyde containing 0.15 per cent ruthenium red (modified from Luft, 1964), followed by three washes (each of 20 minutes) in buffer containing 0.1 per cent ruthenium red and post-fixed in 2 per cent osmic acid containing 0.15 per cent ruthenium red. Samples were then vacuum-dried prior to metal coating, as described earlier (Highton and Donaldson, 1970).

RESULTS

Synovium

In the rabbit, two morphological types of synovium were generally present. These may be seen in Fig. 1, which shows material from the knee of a six-month old rabbit. On the left-hand side of the illustration both types of synovium are seen. That tentatively designated Type 1 consists of a series of spherical or hemispherical projections of varying diameter that, in turn, are grouped together to form large clusters bearing some resemblance to a bunch of grapes. Between these larger structures, and overlying them, may be seen a matrix presumably composed of mucopolysaccharides. The second type of synovium, designated Type 2, is seen at the top of the picture, and is made up of a labyrinth of small ridges and projections. The articular cartilage of the patella at the lower right of the figure at this magnification is reasonably smooth, but has on its surfaces a number of minor prominences and small fibre-like projections. The synovium is apparently withdrawn from the articular cartilage of the patella, although this may probably be a fixation artefact. Type 1 synovium is seen in more detail in Fig. 2, where the spherical types of projection, varying in this illustration from 50 to 60 μm in diameter, are clearly seen. At this order of size they probably comprise a collection of synovial cells known to be between 10 and 20 μm in diameter (Highton et al., 1968). Projecting from the surface of these spherical prominences may be seen small papilliform structures which are probably the collapsed or displaced pseudopodia of individual cells. In between the cells may be seen rope-like structures, and in some cases the same material appears to form a continuous weft or net covering the cells, as may be seen in the right half of the picture.

Normal human synovium in general resembles that seen in normal rabbits. An example is illustrated in Fig. 3, where the synovium is thrown into a series of ridges with small projections between them. This is overlaid by sheets of mucopolysaccharide material, or possibly aggregated synovial fluid, which forms a continuous surface at A. An example of synovium from a patient with
rheumatoid arthritis is seen in Fig. 4. Here the synovial surface is thrown into a series of irregularly disposed ridges and undulations which are warty in appearance. A is a projection which, with the aid of stereoscopy, is seen to rise towards the observer. The structure is, in general, more complicated than that seen in the normal synovium, and there are, projecting from the surface,
many small rounded structures, 4 to 8 μm in diameter. The large ridges and undulations are probably parts of villi with pseudopodia of the component cells projecting from them.

It is clear from these micrographs that the architecture of the synovium is such that its surface area is greatly increased by the many plications and protuberances, and thus its facility of absorption and secretion must be very large.
Cartilage
Details of cartilage construction are shown in Figs 1 and 5 (synovial-patellar junctions). In Fig. 5 the synovium occupies the foreground of the picture; the patella lies in the upper part of the figure, and between it and the synovium can be seen 'guy-rope-like' structures approximately 2 μm wide, apparently linking these two different areas together. These structures may have been revealed by shrinkage of the synovium from the patella; they appear to have footplate-like insertions into the cartilage.

In Fig. 6 may be seen cartilage from an older rabbit. The surface is no longer as smooth as it was in the younger animal (Fig. 5), and small prominences and ridges are visible. In the middle of the picture is a fissure in the surface structure, from which rounded structures (probably cellular surfaces) are protruding. It is thought that this formation possibly forms the early stage of degeneration of the articular cartilage. Cracks are sometimes seen in the articular cartilage, not accompanied by a cellular reaction, and sometimes extending for a comparatively long distance over the cartilage: these are probably fixation artefacts, because pathological changes in cartilage are usually accompanied by cellular reaction. An example of artefactual splitting may be seen in Fig. 7 (cartilage from a patient with degenerative joint disease). The cartilage has lost its smoothness and the surface is thrown into a series of ridges, folds and depressions. In the upper part of the figure, at A, there is a narrow, rather straight crack which runs across structures irrespective of topographical demarcations: this is almost certainly an artefact. This may be compared with the natural fissure seen in Fig. 6, where there is evidence of cellular reaction within a broad, less sharply defined split at the cartilage surface.

The advanced stage of degenerative joint disease (Fig. 8) shows that the smooth cartilage is markedly changed, pitted and ridged with large holes through which granulation tissue projects. There is no evidence now of the fine linear array of fibres, such as is seen in normal cartilage (Fig. 1); the early eruptions through fissures (Fig. 6) appear to have developed into larger rounded lesions.

In rheumatoid arthritis the cartilage is known to be destroyed not only by overgrowth of a pannus over the surface, but also by the growth of granulation tissue from the bone marrow. The coarse structure of the cartilage may be seen in Fig. 9, but this has been largely disrupted by granulation tissue which is projecting from under the cartilaginous surface and pushing up a large plate of cartilage at A, thus leading to the destruction of the surface. With regard to the surface structure of cartilage, the later changes in rheumatoid arthritis resemble the later changes in degenerative joint disease. The cartilage
is now broken up by granulation tissue erupting from beneath the surface, so the surface of the remaining cartilage is roughened, split, and apparently quite thin. This is illustrated in the side of a vertical knife-cut in the cartilage (A in Fig. 10). Beneath this surface, granulation tissue similar to that seen in Fig. 8 is apparent (such areas as seen at B, where granulation tissue appears to have been compressed and flattened by the movements of the joint).

**DISCUSSION**

The scanning electron microscopic study of joints shows that the synovium has a complicated surface, well adapted for secretion and excretion. The
proliferation of the lining cells, known from light and electron microscopic study of rheumatoid synovium, is confirmed. The results in general agree with the findings of Fujita et al. (1968) and Gryfe et al. (1969). However, the latter authors attributed appearances rather similar to the rope-like structures in Fig. 3 to inflammatory exudate. The mass of mucopolysaccharide material previously described (Highton et al., 1968) is visualised covering the synovial surfaces and occupying spaces between the synovial cells. However, some of the details seen in scanning electron microscopy will have to be studied by further transmission electron microscopy for unequivocal analysis of the nature of the structures seen at the surface. The relatively large surface visualised...
by the scanning electron microscope makes it particularly suitable for certain types of experimental studies in animal joints. The irregular surfaces of articular cartilage, as described by Gardner and Woodward (1969) and Gardner and McGillivray (1971) at low magnification were not seen. The differences may be due to differences in preparation.

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