Histologic Changes Associated with Experimental Partial Anterior Disc Displacement in the Rabbit Temporomandibular Joint

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Aims: *To correlate histologic changes with the stress developed by various disc interferences via a model of partial anterior disc displacement in the rabbit temporomandibular joint (TMJ).* **Methods:** *Eighteen male New Zealand rabbits were operated on to expose the temporomandibular disc without severing its attachments. A suture was passed around the lateral part of the disc over the condylar attachments and the 2 strands were fixed in the orbital cavity. In 9 rabbits, a resorbable suture was used to secure the disc displacement. In the other 9, a nonresorbable suture was fixed with a nickel-titanium spring to displace and maintain tension on the disc. Three non-operated animals served as controls. The animals were sacrificed at 12 and 24 weeks after surgery, and the TMJs were prepared for undecalcified histology.* **Results:** *In the first group, the disc remained in a normal position, but its morphology was modified and small histologic changes were observed in the cartilage. In the second group, the disc was displaced in various positions corresponding to the strength delivered by the spring.* **Conclusion:** *Adaptive changes were observed in joints with a slightly displaced disc, while degenerative changes were associated with larger disc displacements. In each experimental joint, histologic changes increased from the medial to lateral parts. This phenomenon was related to the stress gradient induced by axial disc rotation over the condyle. Any disc displacement always resulted in changes in the cartilage.*
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Key words: temporomandibular joint disc, temporomandibular joint, internal derangement, animal study, histology, mandibular condyle

The biologic processes of temporomandibular joint (TMJ) adaptation and disease induced by disc displacement are poorly understood, despite the large amount of data collected from cadaver studies, experimental animal models, and magnetic resonance imaging (MRI) on both patients and cadavers. In the past, reports that osteoarthrosis was associated with disc displacements in cadavers and surgical specimens resulted in all therapies, such as orthopedics, surgical techniques, orthodontics, and physiotherapy, focusing on repositioning the disc as the means to treat pain and dysfunction. Recently, the true significance of disc position in the pathology of internal derangement has been questioned, and the lack of correlation between internal derangement and pain demonstrated when imaging and clinical studies were combined led to the development of symptomatic treatment.[1–3] Nevertheless, these noninvasive approaches raised the question of the joint's capacity to undergo either an adaptive response or degenerate under such abnormal mechanical conditions. Moreover, the effects of this altered stress distribution on the joint may vary according to its intensity and frequency and lead to various responses in the adult or growing TMJ.[4]

Histologic changes in the disc proper, the bilaminar zone, the condyle, and the articular eminence have been described in human specimens.[5,6] However, little is really known about the onset and the progression of these disorders, as these studies lacked any outline of clinical history. To counteract these drawbacks, animal models of disc displacement were developed in the rat, rabbit, and small pig to reproduce degenerative changes similar to those observed in human specimens. All of these experimental protocols used surgical procedures to induce anterior disc displacement without reduction by severing the posterior or the anterior discal attachments.[7–9] The structural TMJ integrity was markedly altered by these procedures and always led to osteoarthrosis. These procedures did not correspond to the usual occurrence of disc displacement observed in humans, except in the rare case of a direct traumatic injury to the mandible. These studies also did not allow an investigation of the primary effects of disc displacements, and little attention was given to the possibility that the TMJ structures might develop an adaptive response, as observed in some human anatomic specimens.

Recently, the development of MRI has allowed the documentation of a great variety of disc displacements in humans and a focus on the high prevalence of partial and rotational displacements.[10–13] In these types of displacement, the posterior band of the disc was medially in the normal position and laterally in an anterior position. These different positionings offered a range of progressive disc interference that could be used to document the effects of various strains on the articular surfaces.

The purpose of this study was to create a partial disc displacement model to mimic the human condition described as disc displacement with reduction and to correlate histologic changes with the stress developed by various disc interferences.

Materials and Methods

Experimental Animals

Twenty-one male New Zealand white rabbits were used in this study. On average, they were 4 months old, and their mean weight was 3.5 kg. Animals were checked for closure of the growth plate. Animals were housed individually in metal hutches with an ambient temperature of 21°C and with 50% air humidity according to the European guidelines for care and use of laboratory animals (Directive du conseil November 1986, 86/609/cee). Artificial lighting was used to maintain a normal day/night rhythm. They were fed on c.15 extralab diet (Pietrement) that contained 16.2% raw protein, 11.9% raw cellulose fiber, 10.5% water, and 2.9% fat. Three non-operated rabbits were used as controls, and the remaining 18 animals were divided into 2 experimental groups (A and B) according to the disc displacement procedures.

Surgical and Experimental Protocols

All rabbits were weighed before surgery and were weighed postoperatively for each day of the experimental study. Each rabbit was anesthetized by intramuscular injection of ketamine hydrochloride (2 mL/kg) and Domitor (Farmos) (0.15 mL/kg). The preauricular region was shaved between the external meatus and the lateral canthus of the eye and the animals were operated on to expose the zygomaticosquamosal suture. An arciform incision (with its left concave side facing anterosuperiorly) was made to bone contact, 1 cm behind the lateral and inferior orbital borders to the zygomatic process. The overlying soft tissue was reflected to expose the bony lateral wall of the TMJ.

The joint capsule was incised along the superior border of the zygomatic arch to identify the squamosozygomatic notch. A V-shape osteoplasty of this landmark was performed with a dental hand drill under irrigation to obtain access at the lateral disc attachment on the condyle. The lower part of the zygomatic process was also resected to facilitate the surgical procedure, and a small hole was made in the inferior border of the orbital rim to anchor the traction device. The suture was passed from the orbital cavity to the temporal fossa below the zygomatic process laterally to the joint. Then, the mandible was pushed posteriorly to reveal the lateral pole, and the suture was passed from the temporal fossa to the orbital cavity between the lateral part of the disc and the condyle, over the disc-condyle attachment. The 2 strands running under the zygomatic process were drawn into the orbital cavity and twisted together (Figs 1a to 1d).

In 9 rabbits (group A), a resorbable suture (Monocryl, Ethicon) was used to pull and displace

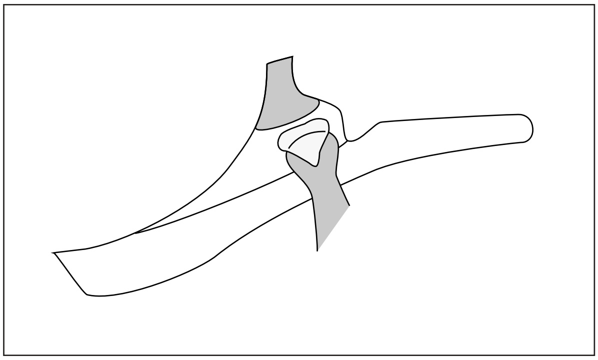


Fig 1a Lateral aspect of rabbit right temporomandibular joint. The zygomatosquamosal process covers the disc-condyle complex and the articular tubercle.

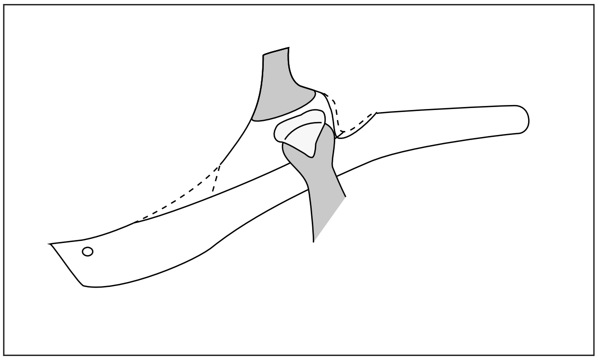


Fig 1b The surgical technique required anterior and superior osteotomies to obtain access to the disc and a small hole in the inferior orbital border of the zygomatic bone to anchor the traction device.

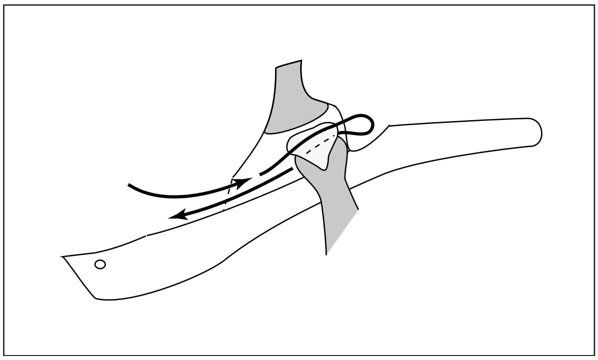


Fig 1c A suture was passed from the orbital cavity to the temporal fossa laterally to the joint, and then from the temporal fossa to the orbital cavity between the lateral part of the disc and the condyle, over the disc-condyle attachment.

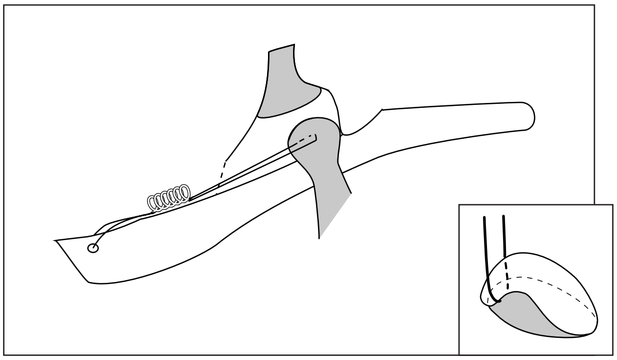


Fig 1d In group B, the 2 strands of a nonresorbable suture were connected to a nickel-titanium spring anchored in the inferior orbital rim. *(Inset)* Superior view of the condyle showing the rotation of the disc under the effect of the traction device.

the disc anteriorly. In the other 9 animals (group B), a nonresorbable suture connected to a nickel-titanium spring was used to displace the disc. The spring was elongated to apply a tension of 1 N on the lateral disc attachment when the teeth were in occlusion. In all 18 specimens, the lateral part of the disc was submitted to a tension oriented forward and downward. As a consequence, the disc rotated in the axial plane around its medial attachments and was more anteriorly displaced laterally than medially. The surgical site was then closed in a layered fashion with 4.0 vicryl suture. The contralateral joint was either left intact or submitted to a sham surgery. An injection of Rilexine (Reading) (25 mg/kg) was administered after each surgery.

Tissue Fixation and Processing

The animals were killed by an overdose of Dolethal (Parke-Davis) (1.5 mL/kg). Some animals from each group were killed at 12 weeks (n = 4) and some (n = 5) at 24 weeks. The heads were skinned, removed, and fixed for 3 weeks in 10% buffered formalin. The TMJs were then removed en bloc, prepared for undecalcified histology, and embedded in methyl methacrylate according to Lebeau et al.[14] After polymerization, the blocks were radiographed and oriented perpendicular to the condylar transversal axis before they were sectioned.

Sagittal 750-μm-thick sections were cut with a Microtom saw (Leica 1600). Each transverse section was thinned down to 300-μm thickness with a grinding machine (Exakt), polished by a 0.5-μm alumina slurry, mounted on an acrylic glass slide, and stained with Stevenol blue and picrofuchsin. The lateral and medial edges of the condylar poles were discarded from examination to eliminate artifacts from tangential cutting.

Results

No postoperative problems were observed in the 2 groups of rabbits after surgery. A soft diet was prepared, but the rabbits returned to their normal diet within 24 hours. There was no weight loss during the experiment, and all the animals increased their weight from 600 g to 1,000 g, depending on the length of the experimental period.

The TMJ changes induced by disc rotation were analyzed from the medial to the lateral part of the joint in the 2 groups. Since there was no obvious difference between the nonoperated and sham-operated contralateral joints, the term "opposite joint" will be used hereafter to refer to both types of contralateral joints.

The Disc Proper

Control Group. In the control group, the disc displayed a typical bow-tie shape observed on sagittal sections, with an intermediate zone correctly interposed between the functional cartilage surfaces (Fig 2). Scarce prechondrocyte cells could be distinguished inside the collagenic disc network.

Group A. In this group, the gross anatomy of the joint was preserved and the congruence between the disc and the articular surfaces was maintained. In the lateral part of the joint, the posterior band was lightly wedged up between the functional cartilage areas, while the intermediate zone appeared thinner and longer laterally than medially. This entrapment of the posterior band between the articular surfaces could be observed in sequential sagittal sections and increased from the medial slices to the more lateral ones (Figs 3a and 3b).

Group B. In all the experimental joints, the amount of disc displacement varied from 1 rabbit to another but was always more pronounced in the lateral part of each joint. In some animals, the disc and the condyle were positioned more anteriorly than those in the control group.

Since the gross anatomy of the disc was affected more or less according to the amount of displacement, group B was divided in 2 subgroups based upon this criterion. Observation of histologic sections showed the interposition of the bilaminar zone for the large-displacement group and interposition of the posterior band of the disc for the small-displacement group.

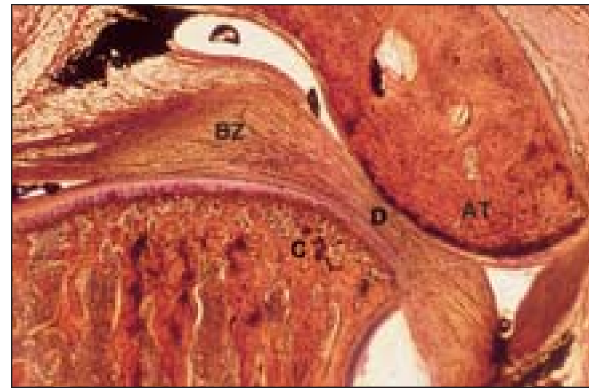
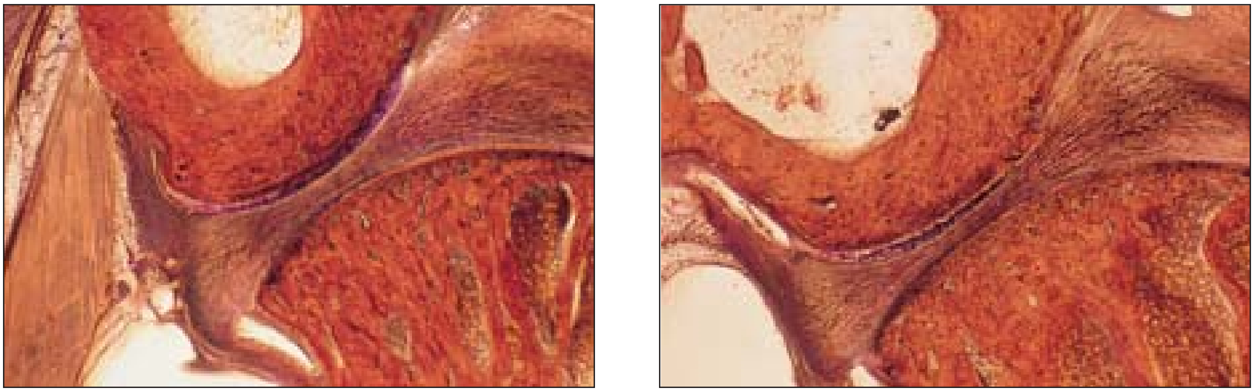


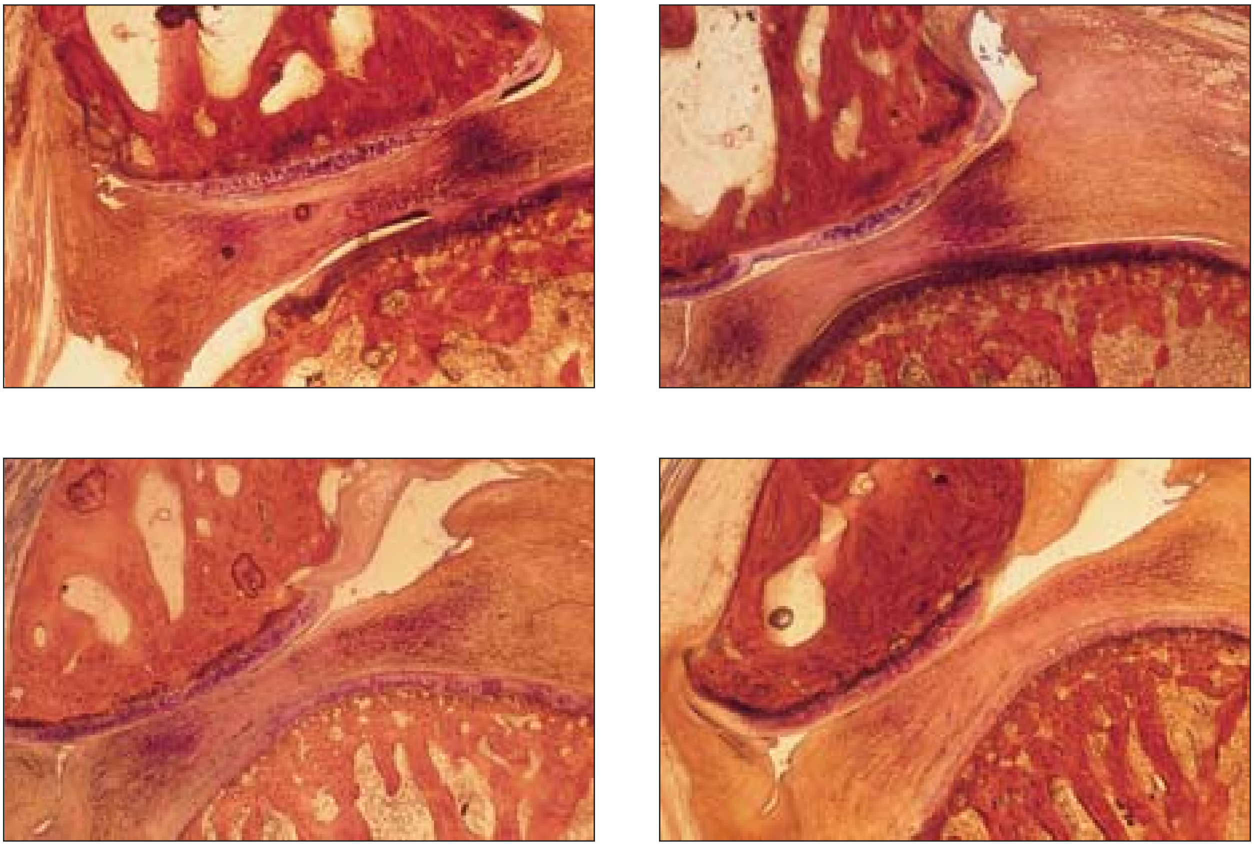
Fig 2 Mid-parasagittal section through a control joint with the jaw in the closed position. The disc showed its typical bow-tie shape (magnification ×100). AT = articular tubercule; C = condyle; BZ = bilaminar zone; D = disc.

Small-Displacement Group. In the lateral part of the joint, the thickness of the posterior band was maintained, leading to a lack of contact between the articular surfaces and the disc (Fig 4a). However, in the contact wedge area, where the stress was concentrated, the posterior band displayed thickening of its collagen fibers and differentiation of chondrocyte-like cells into chondrocytes. In this area, the mechanical stresses resulted in an impingement of the posterior band in the articular cartilage as a consequence of the disc displacement. Disc unfolding occurred within the anterior recess of the upper and lower compartments. On the contrary, more medial sections demonstrated a better congruence of the joint related to a posterior band flattening occurring progressively from the lateral to the medial parts (Figs 4b to 4d). The relationship between the disc and the articular bones was subnormal, but the persistence of an anterior fold in the upper compartment attested to the disc displacement.

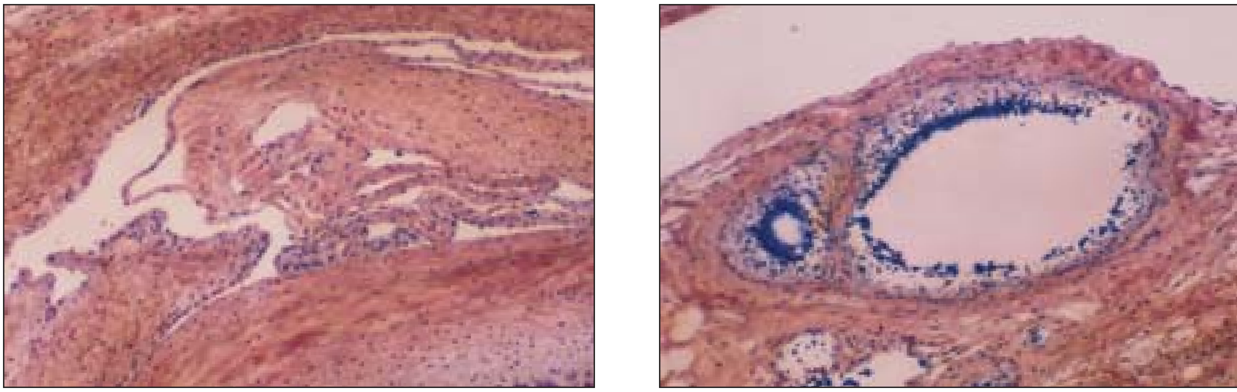
The synovial membrane became hyperplastic in the anterior recesses of the synovial compartments. The hyperplastic synovial cells appeared to extend over the articular surfaces, and increased vascularity could be seen (Figs 5a and 5b). In all experimental rabbits, a negative gradient of cell density was observed in the posterior band from lateral to medial. Chondrocyte-like cells were scattered among the collagen fibers in the medial sections and clusters of chondrocytes appeared in the lateral sections, where thickening of the collagen fibers occurred (Figs 6a to 6d).



Figs 3a and 3b Parasagittal serial sections through an experimental joint (group A, from medial to lateral sections). The congruence between the disc and the articular surfaces was preserved. In the lateral section *(left)* the changes were significant: posterior band pinching and thinning and lengthening of the intermediate zone (magnification ×100).

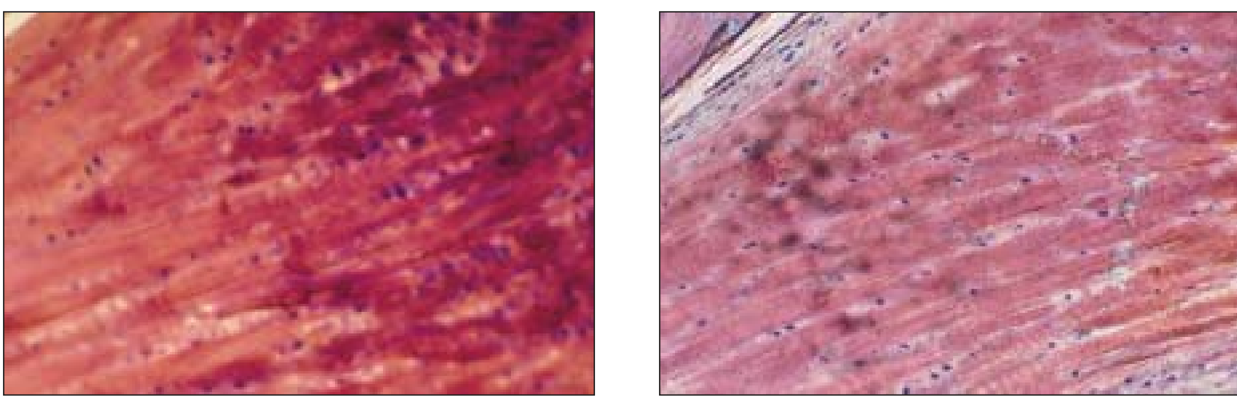


Figs 4a to 4d Parasagittal serial sections through an experimental joint (group B, small displacement group, from lateral to medial sections). Interposition of the disc posterior band between the articular surfaces led to a lack of congruence on the lateral sections as a consequence of axial disc rotation *(above)* and to a flattening of the posterior band on the medial sections *(below)*. This set of sagittal sections illustrates the axial disc rotation and the stress gradient induced on the articular tissues (magnification ×100).

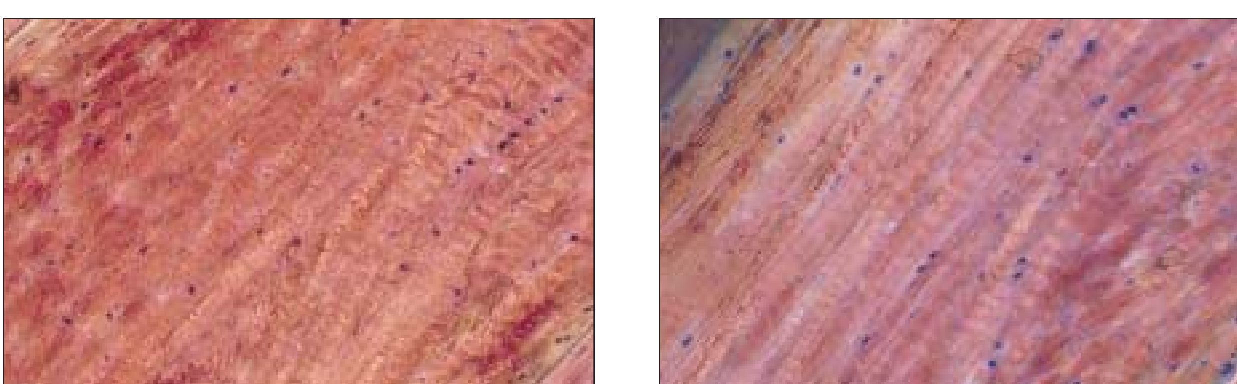


Figs 5a and 5b Hyperplasia of *(left)* the upper posterior synovial membrane with *(right)* an increase in vascularization (magnification ×500).

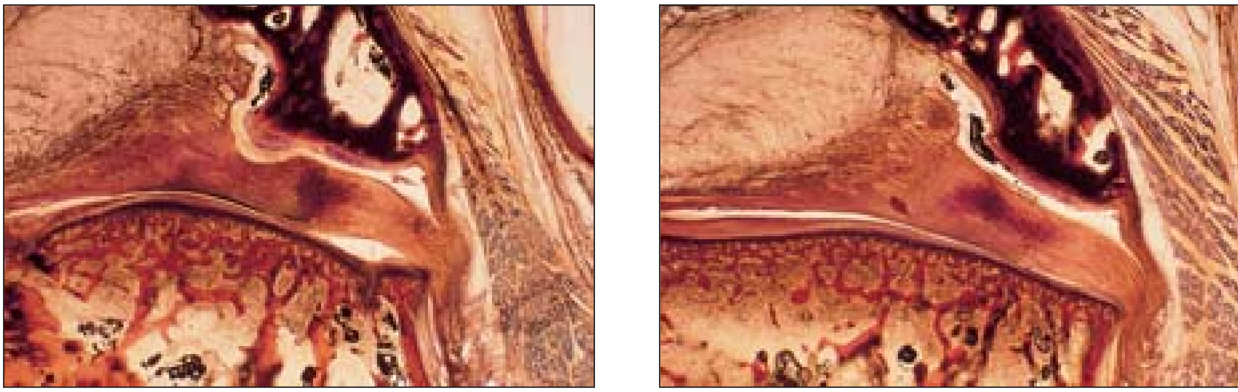
Figs 6a to 6d Parasagittal serial sections of experimental disc (group B, small-displacement group, from lateral to medial sections) (magnification ×1,000).



Figs 6a and 6b Lateral sections characterized by thickening of the collagen network and clustering of chondrocytes.



Figs 6c and 6d On the medial sections, only a few chondrocyte-like cells are observed scattered among the collagen fibers.



Figs 7a and 7b Parasagittal serial sections through an experimental joint (group B, large-displacement group, from lateral to medial sections). The congruence between the articular surfaces was lost, and the bilaminar zone interposed between the functional articular areas became fibrous, as in the disc. Characteristic alterations of the cartilage surfaces facing the posterior band are evident (magnification ×100).

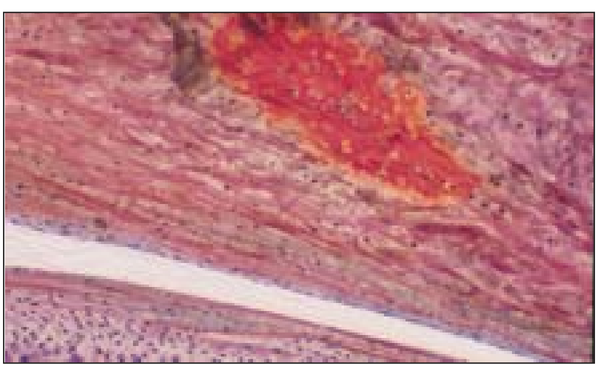
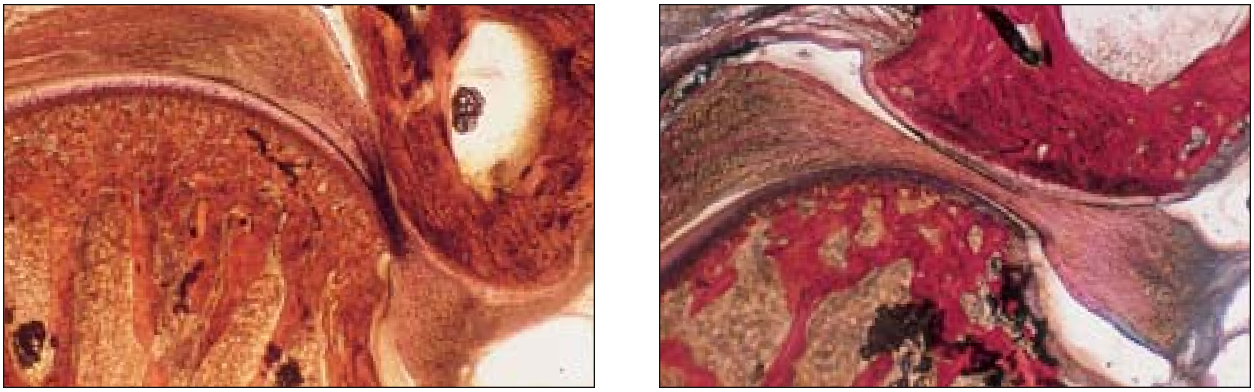


Fig 8 Islets of chondrocytes and mineralized areas in the interposed fibrous bilaminar zone in an experimental joint with large displacement. (magnification ×1,000).

Large-Displacement Group. In this group, the tissue changes were more pronounced, with a pattern of alterations from lateral to medial similar to that seen in the small-displacement group. The lack of congruence between the articular surfaces was obvious, as shown in Fig 7a. This was associated with *(1)* the interposition of the bilaminar zone between the functional area, *(2)* the compression of the posterior band, and *(3)* the expansion of the intermediate zone and the flattening of the anterior band. The most characteristic event concerned the bilaminar zone, with a loss of fatty tissue and thickening of the sagittal collagen fibers that were similar to those observed in a normal intermediate zone.

In the medial sections, the disc lost its typical bow-tie shape, but its congruence with the bony parts increased progressively when compared to the more lateral sections (Fig 7b). The morphologic borders of the posterior band with the intermediate zone and the bilaminar zone disappeared, but the area could be identified by its high density of collagen fibers. In 1 rabbit, islets of chondrocytes and mineralized areas were observed in the compressed bilaminar zone, mostly in the lateral sections (Fig 8).

Opposite Joints. The joints opposite to experimental TMJs were not identical to normal joints. Regardless of the mechanical device employed to displace the contralateral disc, a definite pinch of the intermediate zone of the disc was observed, while the congruence between the articular surfaces was still optimal (Fig 9a). When a spring was used on the experimental joint, the opposite disc appeared longer, with a thinning of the intermediate zone, and the condyle was lightly displaced posteriorly in comparison to the control joints (Fig 9b).



Figs 9a and 9b Mid-parasagittal sections through opposite joints in closed pack position showing *(left, group A joint)* pinching of the intermediate zone and *(right, group B joint)* pinching and lengthening of the intermediate zone (magnification ×100).

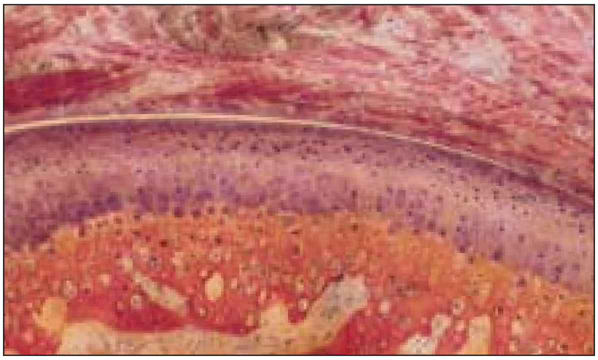


Fig 10 Mid-parasagittal section through control condylar articular cartilage showing the 5 characteristic cellular layers (magnification ×500).

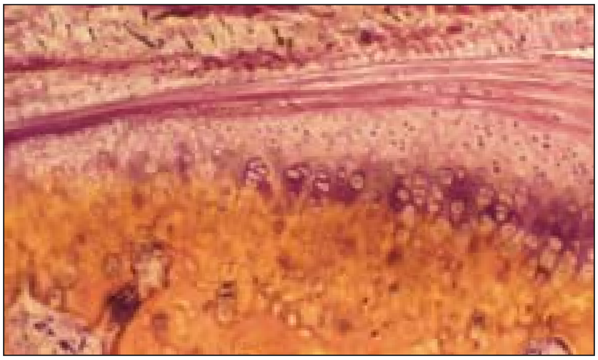


Fig 11 Mid-parasagittal section through experimental articular cartilage (group A). The regular layered organization is preserved, with a thickening of the fibrous layer (magnification ×1,000).

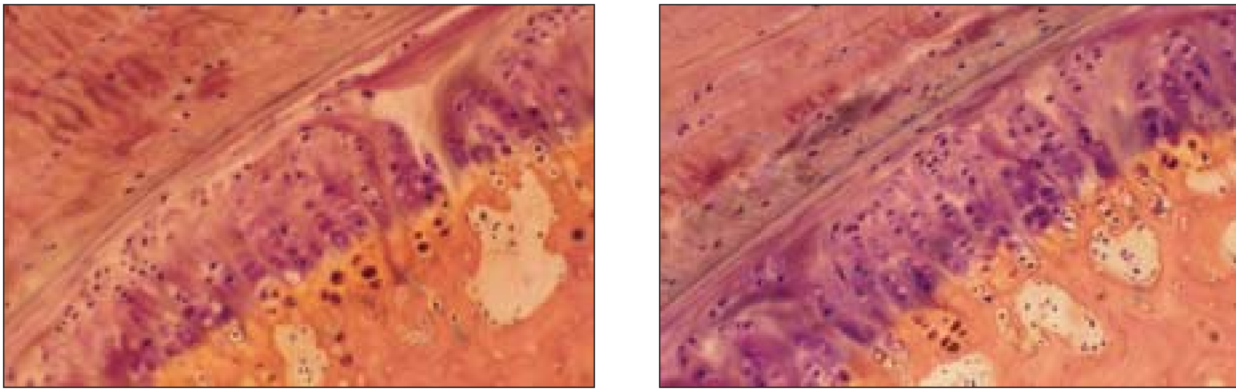
Cartilage Surfaces

Control Group. In control rabbits, the articular cartilage was characterized by 5 basic layers: an articular or fibrous layer made of type I collagen fibers and fibroblasts, a prechondroblastic or proliferative layer containing undifferentiated mesenchymal cells, a chondroblastic layer with ovoid-shaped chondrocytes in the upper zone and hypertrophic chondrocytes in the deeper zone, and a fifth inner layer of endochondral ossification containing vascular medullary canals and chondroid bone (Fig 10).

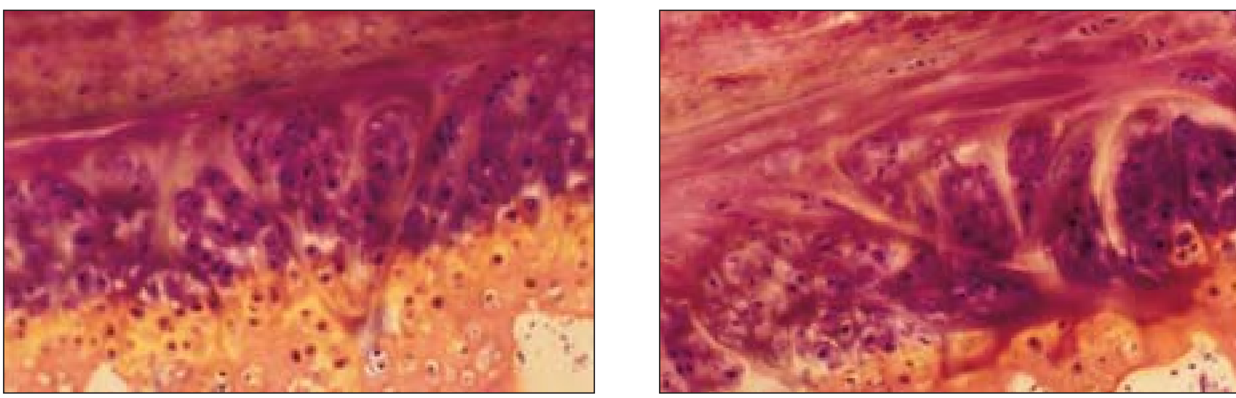
Group A. In all sections, the cartilage surface displayed a regular round shape, but its thickness and organization varied according to the mediolateral position of the section and the location within the section (articular eminence or condyle). In spite of the low tension applied to the disc, all the joints displayed variable histologic changes in the cartilage surfaces. The articular condylar zone facing the posterior band was selected in each section to describe sequentially the modifications related to local overstress.

The articular layer showed a progressive thickening (Fig 11). The other layers also demonstrated a significantly increased thickness in the lateral sections. Cartilage alterations related to local loading were detected in the zone facing the posterior band and also in all the other functional areas, even when the disc's articular congruence was maintained.

Figs 12a to 12d Parasagittal serial sections through an experimental joint (group B, small disc displacement, from medial to lateral sections) (magnification ×1,000).



Figs 12a and 12b Progressive thickening of the fibrous layer from medial to lateral sections with thick, sagittally oriented collagen fibers. Few vertical collagen fibers *(more at right)* crossed over the subjacent layers and reached the subchondral bone.



Figs 12c and 12d The fibrous layer appeared more and more thickened from medial to lateral sections, and the vertical collagen fibers constituted bundles of fibers arranged in curved lines and anchored to the subchondral bone. The chondrocytes became hypertrophic, and clusters of chondrocytes were surrounded by bundles of collagen.

Group B. In all sections, the outline of the cartilage was regular when the disc exhibited minor displacement or reshaping, but in marked displacement cases, the surface was irregular and had very incongruent surfaces. As a result of disc rotation, marked cartilage alterations were observed in the lateral part of the joint, while in all animals operated upon, primary changes arose in the medial part.

Small-Displacement Group. In the lateral sections, the cartilage thickness varied in different areas, with a rough transition at the borders of the overstressed zone facing the displaced posterior band and a uniformly increased thickness in the medial sections as compared to the control group.

Progressive changes in the cartilage can be traced from medial to lateral in each joint by the comparison of 4 to 5 serial sections (Figs 12a to 12d). In the first section (Fig 12a), the disc was lightly displaced and the articular zones facing the posterior band displayed an increase in the fibrous component. The fibrous layer contained thick collagen fibers, sagittally oriented, with only occasional fibroblasts. Some collagen fibers reached the subjacent layers across the proliferative and chondroblastic layers. In the next section (Fig 12b), the fibrillation process increased in the fibrous layer and also inside the lower layers, where vertical collagen bundles divided the chondroblastic layer into separated chondrocyte columns and reached the subchondral bone. The prechondroblastic cells decreased but the chondrocyte cellular morphology was maintained. In the next section (Fig 12c), the fibrous layer inside the cartilage matrix expanded and was arranged as curved lines surrounding the major cellular population, which was made up of hypertrophic chondrocytes. In the final section (Fig 12d), the articular layer was connected and anchored in the subchondral bone by arciform bundles of thick collagen fibers crossing the cartilage matrix among less numerous clusters of chondrocytes.

The progressive histologic changes previously described for the condylar cartilage could also be observed in the cartilage covering the articular eminence. Nevertheless, taking into account all the sections, there was often a shift toward alteration in the structural state from the condyle to the temporal cartilage. As shown in Fig 13, the organization of the temporal cartilage was completely lost in lateral sections; the cartilage disappeared and left a thick, fibrous layer.

Large-Displacement Group. The cartilage alterations were more pronounced, with noticeable thickening of the zone facing the interposed bilaminar zone, which became a "neodisc" with thick oriented, horizontal collagen fibers. The round, bony-shaped contours were always modified in this group, with local V-shaped bone defects surrounding vertical collagen bundles, reactive woven bone in the condyle and the articular tubercle, horizontal splitting, and chondrocyte necrosis (Figs 14a to 14c).

Opposite Joints. The cartilage tissues revealed a thickening of the fibrous layer with thick sagittal collagen fibers. The proliferative and chondroblastic layers contained vertical and horizontal collagen fibers surrounding clusters of chondrocytes. These fibers reached the subchondral bone (Fig 15).

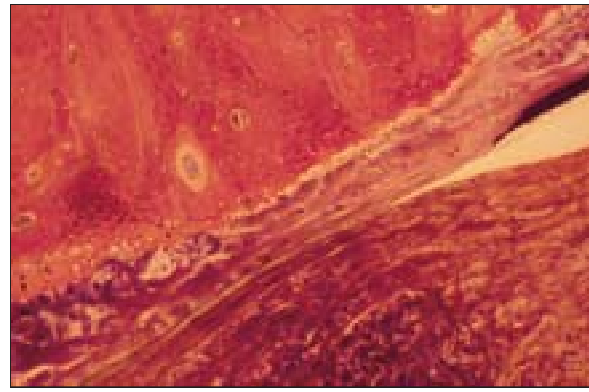


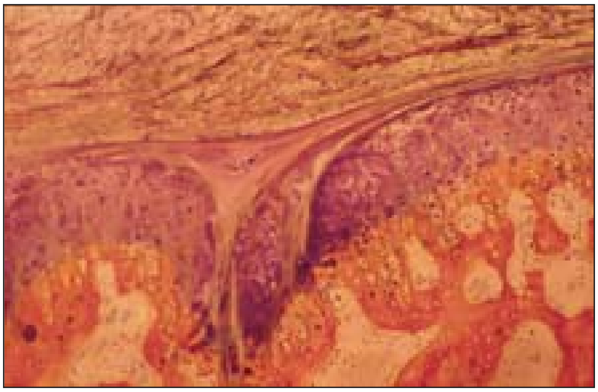
Fig 13 Mid-parasagittal section of temporal articular cartilage through an experimental joint (group B, small-displacement group). A thick, fibrous layer remained on the articular eminence after cartilage degeneration related to disc displacement (magnification ×500).

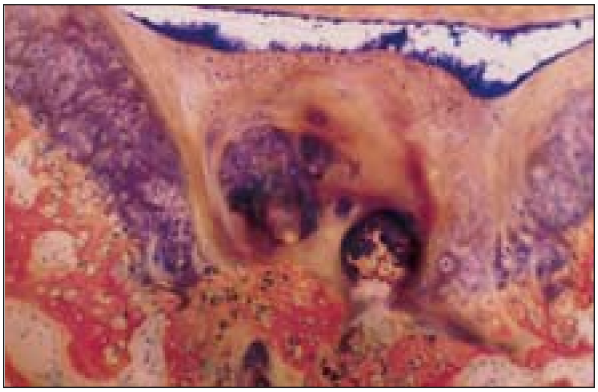
Discussion

Various rabbit models have been proposed for the study of histologic changes associated with TMJ dysfunction, especially anterior disc displacements without reduction in the rabbit craniomandibular joint. Tallents et al[7] induced disc displacement by transection of both temporal and condylar parts of the posterior attachments from medial to lateral, and then pushed the disc anteriorly between the condyle and the articular eminence. Ali and Sharawy[8] severed all discal attachments except the posterior attachments, which were left intact. Then, the disc proper was pulled anteriorly and fixed to the zygomatic arch with a suture. The position of the bilaminar zone between the condyle and the articular eminence was used as a reference position in this model. Acute disc displacement without reduction was created, and the sharp overload of the bilaminar zone explained the early histopathologic changes of the joint, which were similar to those seen in osteoarthrosis. Finally, Mills et al[9] proposed another technique to study the evolution of pathologic changes of disc displacements in the rabbit TMJ. The squamosal attachments of the disc were identified and cut to displace the disc anteriorly. The disc was drawn forward and downward to the condyle and attached via a suture to the condylar process. This last technique was less destructive, but the disc was unable to move over the condyle.

In the present study, we proposed a new rabbit model specially focused on preserving the TMJ anatomy and mimicking partial disc displacement with reduction, which is known to be the first step in internal derangement.[4,13] Theoretically, the anterior anchorage of the mechanical device into the inferior border of the orbital rim allowed disc motions over the condyle during mandibular translation when the spring became less active. Nevertheless, a major difficulty was to control the tension placed on the disc, since a large variability in the displacements occurred in this study. Yet this drawback was partly counterbalanced by the advantage of the disc rotation initiated by this procedure. The rotational movement of the disc over the condyle in the axial plane determined a positive gradient of stress from the medial to the lateral part of the joint, as the posterior band was more anteriorly displaced laterally than medially.

Figs 14a to 14c Parasagittal sections of articular cartilage through experimental joints (group B, large-displacement group) (magnification ×500).





Figs 14a and 14b Severe condylar cartilage alterations characterized by thick vertical bundles of collagen fibers, subchondral bone defects, and *(right)* chondrocyte necrosis.

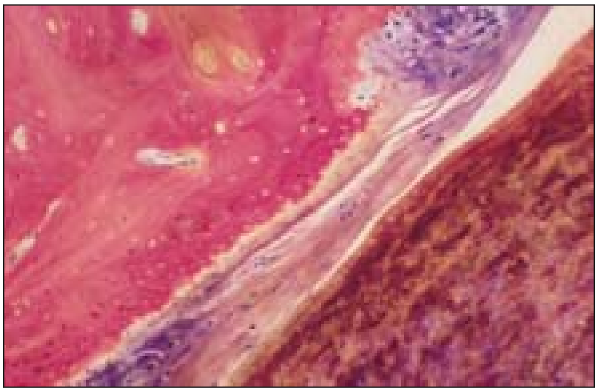


Fig 14c Horizontal splitting of the remaining fibrous layer.

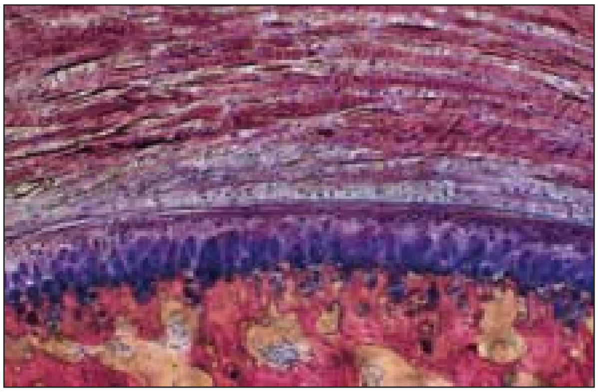


Fig 15 Mid-parasagittal section through the articular cartilage of an opposite joint. Moderate fibrillation of the cartilage is seen, with thickening of horizontal and vertical collagen fibers (magnification ×500).

Considering this mediolateral displacement gradient, the relationship between stress and tissue response was established in this study for each joint. Whatever the tension developed by the mechanical device, the medial displacement was always used as an internal control of minimal stress state and alteration of the joint.

All experimental rabbits with partial anterior disc displacement showed histologic changes in all TMJ structures. However, the clear differences observed between group A and B joints demonstrate the relationship between the tissue responses and the mechanical environment.

It is well known that the disc displacement represents 1 of the major factors implied in loading variations by concentrating stress on local areas.[15] The transduction of these mechanical stimuli into histologic changes may be investigated in our model. In group A, the force applied to the disc by the resorbable suture was time-limited and not strong enough to pull the posterior band between the articular surfaces. Nevertheless, the strain stretched the disc and artificially increased the tribology on the articular surfaces. The structural changes observed were related more to the lack of disc-condyle coordination during mandibular movement than to local overloading. They were characterized by a thinning and a lengthening of the disc intermediate zone, a limited fibrillation of the sagittal fibers of the articular layer, and a thickening of the cartilage layers, especially in the zones facing the posterior band. These variations have been described in different studies using human cadavers and have been considered to reflect an adaptive mechanism.[16]

The tissue responses of group B joints were different mainly because the forces exerted by the spring to tract the disc posterior band between the articular surfaces were higher. Despite the fact that the 1 N spring tension was controlled and measured in each animal, the displacement of the disc varied between animals, and it can be noted that the more the disc was anteriorly displaced, the more pronounced the tissue response. This explained why no clear-cut time dependence of the histologic changes was found, as the strain variability was more important than the time factor. Adaptive changes could be observed 24 weeks after surgery in rabbits with light disc displacement and osteoarthrosis was seen 12 weeks after surgery when the disc was markedly displaced. The analysis of the serial sections from lateral to medial in each specimen demonstrated an obvious correlation between loading and tissue modifications.

The anatomic sagittal sections obtained in rabbits having small disc displacements fit well with sagittal MRI images of partial anterior disc displacement with reduction obtained in humans. Due to the rotation and also the flexibility of the disc, the stress on the posterior band was less in the medial part of the joint. Consequently, the posterior band became flat without any trace of collagen thickening or chondrocyte proliferation, compared to what happened in the lateral part of the joint. The thickening and light fibrillation of the cartilage remained in the range of physiologic remodeling, and there was no evidence that such changes in the cell number and organization of the extracellular matrix, if not reversible, would systematically lead to subsequent osteoarthrosis.

De Bont et al[17] have previously described the spatial distribution of the collagen fibrils in human condylar cartilage, with fibers arranged in thin bands parallel to the surface in the articular layer and dispersed in a radial orientation in the inner layers. The organization of the collagen network is adapted to load-bearing of the joint surface, and the correlation between increased load and collagen thickening demonstrated in this model is not surprising. It is considered that the arrangement of collagen fibers is related to the force pattern acting on the articular cartilage.[18] The so-claimed "remarkable adaptive potential of the TMJ" resides in the capacity of the fibrocartilage to drop octopus-like collagen anchors into the subchondral bone under overloading conditions to protect from bone-cartilage interface splitting. This adaptive potential can be studied only when the joint is progressively loaded. Models that do not take into account the adaptive process can only result in arthrosis. It is not surprising that in such drastic conditions no difference can be found between hyaline cartilage and fibrocartilage. When compared to these models, our study demonstrated major differences, such as the presence of a perichondrium made of type I collagen, the thickening of which was the first structural response to overloading. This specific response protected the cartilage matrix and the chondrocytes from being exposed to the joint cavity and being degraded, as in a hyaline cartilage.[19] When the stress increased, type I collagen fibers crossed the chondroblastic layer and reached the bone. This could be related to the immunostaining shift from collagen type II to type I described by Ali and Sharawy.[20] Increased stresses resulted in mostly acellular fibrillation invading the cartilage matrix and decreasing the number of chondrocytes. These changes can be considered a tissue adaptation, since no cartilage splitting and no alteration of subchondral bone morphology were associated with this process. It can be noted that cartilage splitting occurring at the osteochondral junction was found in our study only in the most advanced cases. One may suspect that the splitting found when decalcified histologic techniques are used may be artifactual and that only preparation without demineralization will demonstrate the occurrence of such defects.

Different histologic features were observed in 1 joint and classified according to strain exposure. Since these evolutions were found regardless of the time of implantation, one cannot conclude that tissues submitted to mild changes will later evolve. It may be hypothesized that the strain has been absorbed by the tissues and that this organization will be stable for a long time.

On the other hand, the changes observed in group B joints with larger disc displacements fit with the description of the various osteoarthrotic features found in the human TMJ with internal derangement[21,22] and in all rabbit models, leading to disintegration of the collagen fiber network. In this group, it is clear that the mechanical conditions exceeded the adaptive potential of the tissue.

On the opposite joints, the changes were similar to those observed in the experimental joints when a resorbable suture was used. It is not surprising that a contralateral effect occurred after an internal derangement was created, even though the mandible of the rabbit possesses a fibrous sympheseal joint. This observation questions the traditional use of the contralateral joint as a control, at least for long experimental periods.

Our results have illustrated that the articular soft tissues adapt themselves to maintain the function of the TMJ in the case of a minor disc-condyle derangement. But, as demonstrated in this study and as previously mentioned, the limits between adaptation and disease are not straightforward, and the boundaries between remodeling, repair, and osteoarthritis are always difficult to define.[23] Complex relationships mediated by biochemical signals exist between composition, structure, and mechanical function. The same biochemical signals may occur in both degenerative or adaptive changes, but the method of interpreting possible differences remains unclear. The frontier between these changes responds to biochemical limit.[24–26] Biochemical markers may perhaps answer this question in the future, but since adaptive and degenerative changes may act together in the same joint, it will remain difficult to know precisely the biologic status of the joint.

In summary, this study has demonstrated that the nature of the histologic changes was determined by the amount of stress applied to the tissues; partial disc displacement induced adaptive or degenerative responses of the articular tissues according to the amount of displacement; and any disc displacement always resulted in progressive changes in the cartilage.

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