

The development of traumatic temporomandibular joint bony ankylosis: A course similar to the hypertrophic nonunion?

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ABSTRACT

The traumatic temporomandibular joint (TMJ) bony ankylosis has generated great interest in the cranio-maxillofacial surgeons yet remains an enigma, due to its unknown pathogenesis. Organization and ossification of hematoma is the classical hypothesis concerning the underlying pathophysiology, but it could not explain all the unique characters of TMJ bony ankylosis. The previous imaging descriptions about bony ankylosis tend to over-emphasize the obliteration of joint space and the overgrowth of new bone around the joint. Our recent study has found that the radiolucent zone in the bony fusion area indicating impaired bone healing is one of the most important imaging features of bony ankylosis, and this imaging feature is similar to that of hypertrophic nonunion of long bone. We also observe that there is close relationship between the mouth opening and the degree of calcification of radiolucent zone. Therefore, we hypothesize that the development of traumatic TMJ bony ankylosis may be the course of bone healing of two injured articular surfaces under the interference of opening movement, which is similar to the hypertrophic nonunion. Our hypothesis could help to explain some unintelligible characters of bony ankylosis, and deserves further studies.

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Introduction

Temporomandibular joint (TMJ) ankylosis refers to a chronic, persistent, and progressive inability to open the jaw, resulting from the fusion of the condyle with the glenoid fossa [1]. It can be classified into fibrous, fibro-osseous, and bony ankylosis according to the tissue involved in the joint space [2]. The most common cause of TMJ ankylosis is trauma, mainly condylar fracture [2–4].

So far, the pathogenesis of traumatic TMJ bony ankylosis remains ill-defined. Based on the plain films, the previous imaging descriptions about TMJ bony ankylosis tend to over-emphasize the obliteration of joint space and the overgrowth of new bone around the joint [5,6]. According to these imaging features, the classical hypothesis believes that the organization and ossification of the intra-capsular hematoma [6] or extracapsular hematoma [7] leads to bony ankylosis secondary to condylar fractures.

However, owing to problems of image distortion and superimposition [8], plain films could not accurately display the lesion characteristics of TMJ bony ankylosis. The analysis of CT features of bony ankylosis demonstrates that the bony fusion area is not calcified

completely in most patients [7,9,10]. On the contrary, there is a vague radiolucent zone in the bony fusion area [7,9,10]. These evidences question the classical hypothesis because the organization and ossification of hematoma is difficult to explain why the bony fusion area is not fully calcified during such a long course.

The similarities between the TMJ bony ankylosis and hypertrophic nonunion

Although it is generally agreed among clinicians that prolonged immobilization of the jaw after condylar fracture can increase the risk of ankylosis [11], complete immobilization is not a prerequisite for the development of ankylosis because most patients with traumatic TMJ ankylosis do not receive treatment of their original TMJ trauma by intermaxillary fixation [7]. On the contrary, the fact that the overwhelming majority of patients with ankylosis can open their mouth [12] shows that opening movement always exists in the whole course of ankylosis. Our recent study further found that there was close relationship between the mouth opening and the degree of calcification of radiolucent zone for patients with bony ankylosis. This finding suggests that the radiolucent zone indicating the inhibition of bone formation in the joint space may be caused by opening movement.

It is well recognized that stable mechanical environment is one of prerequisites for normal fracture healing, and that excessive

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motion at a fracture site will delay or prevent fracture union [13]. When comparing the clinical features of the traumatic bony ankylosis with that of hypertrophic nonunion, remarkable similarities can be discovered:

- (1) Medical history: nonunion is diagnosed when nine months has elapsed since the traumatic event, and no visible signs of progressive healing for a minimum of three months [14], whereas bony ankylosis occurs several months to years after TMJ trauma [6].
- (2) Aetiology: insufficient stabilization and persisting micromotion of fragment ends are generally accepted as one of the main causes of hypertrophic nonunion [15,16]. Whereas during the development of bony ankylosis, repeated opening movement is obviously comparable to the excessive micromotion of fragment ends and may be the cause of radiolucent zone in the bony fusion area which indicates the inhibition of bone formation between the two traumatic articular surfaces.
- (3) Imaging features: the typical manifestation of hypertrophic nonunion in X-ray appearance is elephant's foot or horse's hoof [13], in which the cortical expansion adjacent to the nonunion site indicates potential biological activity and the radiolucent zone located between the two fragment ends demonstrates the nonunion [13] (Fig. 1A). Similarly, for the bony ankylosis, the enlarged condyle and new bone formation in the root of zygomatic arch are closely similar to the cortical expansion in the hypertrophic nonunion, and the radiolucent zone in bony fusion area can be also considered as the indicator of nonunion (Fig. 1B).
- (4) Histology: the intervening tissue at the hypertrophic nonunion site is composed of fibrous tissue and cartilage [17], whereas tissue at the joint gap of ankylosis corresponding to the radiolucent zone on CT scan is also fibrous tissue and cartilage [6,18,19].
- (5) Turnover of disease: For the hypertrophic nonunion, the nonunion site is ready to unite and the biological process to union is inhibited by the lack of mechanical stability

[15,16], therefore, simple stabilization of the nonunion site without resection of nonunion tissue is enough for the healing of most hypertrophic nonunions [20]. During the formation of bony ankylosis, although there are no exogenous factors to stabilize the condyle, its movement is severely restricted along with the disease progress. Finally, the bony fusion occurs in the relative stable mechanical environment.

Hypothesis

Our hypothesis is that the development of TMJ bony ankylosis may be the course of bone healing of two traumatic articular surfaces under the interference of opening movement, which is similar to the hypertrophic nonunion.

The critical conditions for the traumatic TMJ bony ankylosis are equivalent to establish the microenvironment for the bone healing of the two articular surfaces

An outstanding feature of TMJ ankylosis which triggers widespread interest is that although condylar fracture is the leading cause, the incidence of ankylosis secondary to condylar fracture is only 0.4%–2% [11,21]. The questions derived from this phenomenon are why few injured joints ankylose and most do not, and what are the critical conditions inducing the traumatic TMJ ankylosis.

A great deal of clinical observations have revealed the risk factors for traumatic TMJ ankylosis including young individuals [11,22], severe TMJ trauma [11], special types of condylar fractures [23,24], prolonged immobilization of the mandible [11], and disc displacement [11,25,26]. Animal experiments have demonstrated that discectomy and severe injury to both articular surfaces are very important for the formation of traumatic ankylosis [19,27], and that bone graft in the joint or restricted jaw movement can accelerate the process of ankylosis [28,29].

These evidences from clinical observations and animal experiments reveal that disc displacement and severe injury to articular surfaces are the critical conditions for the development of

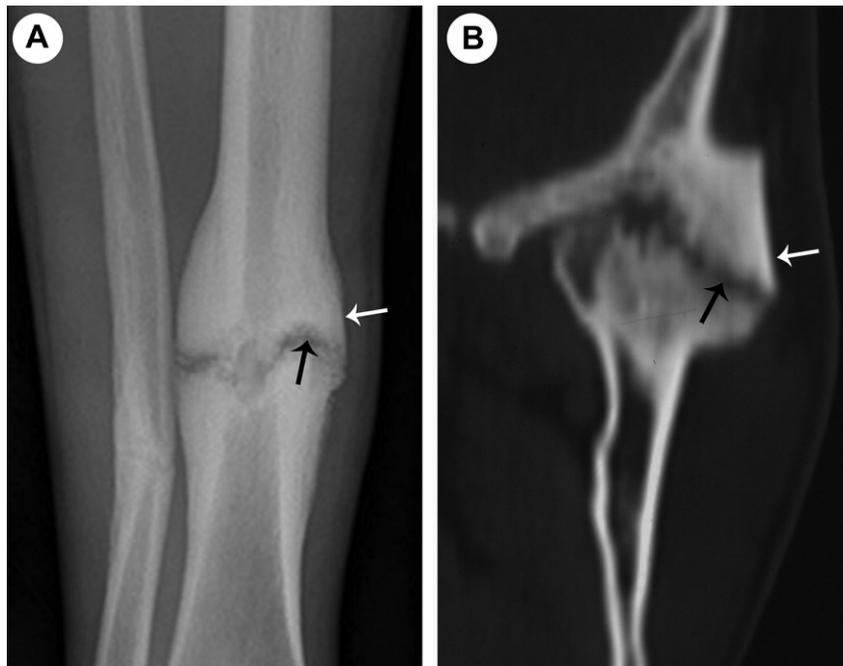


Fig. 1. The similarity of imaging features between hypertrophic nonunion and TMJ bony ankylosis. (A) hypertrophic nonunion, white arrow indicates the cortical expansion adjacent to the nonunion site, black arrow indicates the radiolucent zone. (B) TMJ bony ankylosis, white arrow indicates the overgrowth of new bone in the zygomatic arch, and black arrow indicates the radiolucent zone in bony fusion area.

traumatic TMJ ankylosis [11,19,27]. We consider that these critical conditions are to establish the microenvironment for the bone healing of the two articular surfaces: the two severe injured articular surfaces are similar to the fragment ends when fracture occurs, and the disc displacement can make the traumatic articular surfaces contact directly, which provides a comparable condition for bone healing.

The view that considers the formation of traumatic TMJ ankylosis to be a course of bone healing can easily explain the phenomenon that few injured joints ankylose and most do not. Namely only injured joints which meet the microenvironment for the bone healing of the two articular surfaces can develop into ankylosis.

The bone healing of the two traumatic articular surfaces may be inhibited by the opening movement

Since we consider the development of ankylosis to be a course of bone healing, it is reasonable to hypothesize that the repeated opening movement may inhibit the bone formation in the joint space. This view can be supported by animal experiments and clinical observations.

A number of different animal species have been used for the study of TMJ ankylosis, and discectomy with severe injury to articular surfaces is the general method to induce ankylosis [18]. However, almost all models result in only fibrous or fibro-osseous ankylosis instead of bony ankylosis [18]. The difficulty in establishing an animal model of bony ankylosis indicates the inhibitive effect of opening movement on the bone formation of the joint space.

Clinically, the previous imaging descriptions about TMJ bony ankylosis tend to over-emphasize the obliteration of joint space and the overgrowth of new bone around the joint [5,6], but little attention was paid to the radiolucent zone in the bony fusion area [9]. Our recent study found that the vague radiolucent zone in the bony fusion area was one of the most important imaging features of bony ankylosis, and that there were close relationship between the mouth opening and the degree of calcification of radiolucent zone [10]. These findings suggest that the radiolucent zone indicating the inhibition of bone formation in the joint space may be caused by opening movement.

Perren's strain theory is suitable to explain the formation of TMJ bony ankylosis

The "interfragmentary strain theory" which was first proposed by Perren more than 30 years ago elegantly describes the link between fracture mechanics and bone healing. The principles of this theory hold true today and are supported by modern evidence in many ways [30]. The theory believes that the repair tissues between the fragment ends can always withstand the mechanical strain without destruction, and if the strain exceeds the tolerance level of this tissue, namely strain tolerance of this tissue, it can not be produced [31]. The strain tolerance of bone is less than 2%, the strain tolerance of cartilage is 2%–10%, and the strain tolerance of fibrous tissue is larger than 10% [31].

We consider that Perren's strain theory is also suitable to explain the formation of TMJ bony ankylosis. When condylar fracture with disc displacement and severe injury to the glenoid fossa occurs, the traumatic articular surfaces can directly contact, which provides a favorable condition for bone healing. However, the complex stress in the joint space resulting from the repeated opening movement will lead to different amounts of tissue deformation in different regions. According to the Perren's strain theory, cartilage will produce in the region where the strain $>2\%$ and $\leq 10\%$, and fibrous tissue produce in the region where the strain $>10\%$. The mixture of cartilage and fibrous tissue in the joint space will limited the opening movement, which leads to the strain $\leq 2\%$ in

some small areas, for example, in the lateral part of the joint where bony fusion mostly locates [6,32]. Then endochondral ossification occurs, further restricting the opening movement. Under the relative stable mechanical environment, the region of endochondral ossification extends gradually and forms the bony fusion area. And the remnant regions without calcification in the bony fusion area manifests as vague radiolucent zone in the imaging examination.

Testing

Although the clinical risk factors for fracture nonunion are well known, the pathological processes and pathogenesis remain unclear. Recent studies demonstrated that the reduced bone forming activity in nonunion may attribute to the deficiency of key growth factors regulating normal fracture healing [33–35] and/or the decreased capacity of osteogenesis of mesenchymal progenitor cells from the nonunion site [34,36,37]. These above-mentioned mechanisms in the nonunion may also play the same role in the development of TMJ bony ankylosis.

Our team has successfully established a model of TMJ bony ankylosis in growing sheep by mimicking the traumatic microenvironment of sagittal condylar fracture [38]. To testify our hypothesis, based on the animal model and clinical specimens, we will design the following experiments. On one hand, we intend to verify whether bone forming activity in the joint space of bony ankylosis reduces or not, by examining expression of a series of genes regulating cartilage formation, bone formation, endochondral ossification, and bone remodeling in bony ankylosis compared with the standard condylar fracture healing. On the other hand, we will dissociate mesenchymal stem cells from the joint space of bony ankylosis and from the gap of standard condylar fracture healing. After identifying both mesenchymal stem cells, we will detect the cell viability and osteoblast differentiation to confirm whether the capacity of osteogenesis of mesenchymal progenitor cells from the joint space of bony ankylosis changes or not.

Significance of the hypothesis

This hypothesis is actually a supplement to the classical hypothesis of organization and ossification of hematoma. Due to taking into account the role of the opening movement in the development of bony ankylosis, it can easily explain some unintelligible characteristics of bony ankylosis, such as the long clinical course and the radiolucent zone in the bony fusion area. The view that considers bony ankylosis to be a course similar to the hypertrophic nonunion would contribute to grasp the nature of this disease. The results of experiments trying to test this hypothesis would provide more evidences for the pathophysiology of TMJ ankylosis.

Conflicts of interest statement

The authors indicate no potential conflicts of interest.

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