

Temporomandibular Joint Growth Adaptation and Articular Disc Positional Changes in Functional Orthopedic Treatment: Magnetic Resonance Imaging Investigation

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Functional orthopedic appliances have been proposed for the correction of Class II malocclusion due to a retrognathic mandible. The aim of using this appliance is to stimulate mandibular growth by forward positioning of the mandible in order to achieve normal jaw relationship. However, the modes of action using this appliance are still inconclusive. Also the effects of this therapy on the temporomandibular joint (TMJ) are still subject to doubts and discussion. Magnetic resonance imaging (MRI), the gold standard for assessing the soft tissue and position of the TMJ articular disc, therefore, was used to help clarify the effect of this appliance on the TMJ.

The aims of this article are to provide a literature review of the methods that are used to assess changes in the TMJ, as seen on MRIs, from functional orthopedic appliances which include condylar and glenoid fossa remodeling assessment, condyle-fossa relationship assessment and articular disc assessment and to review clinical studies using MRI to investigate the effects of functional orthopedic treatment on the TMJ.

Keywords: Functional orthopedic appliance, Temporomandibular joint (TMJ), Magnetic resonance imaging (MRI)

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Functional orthopedic appliances have been recommended for the correction of Class II malocclusion associated with a retrognathic mandible⁽¹⁾. There are a variety of mechanisms by which the functional appliances are known to act⁽²⁾, such as dentoalveolar changes, redirection of condylar growth, restriction of forward growth of the midface, altered expression of mandibular growth, adaptive redirection of the glenoid fossa growth pattern and adaptive changes in neuromuscular functional anatomy that would induce bone remodeling. However, to date, there is still controversy regarding their modes of action^(3,4).

Numerous studies using functional orthopedic appliances have evaluated the effects on TMJ using, for example, roentgenograms and computed tomography. However, these tools have a limitation for

imaging the articular disc or cartilage, which are the structures of interest when studying TMJ growth adaptation prompted by functional appliances. Therefore, magnetic resonance imaging (MRI), which allows a valid and reproducible assessment of articular joint cartilage morphology⁽⁵⁾, has superior sensitivity for the detection of unmineralized tissue. This imaging technique has been used to demonstrate condylar and glenoid fossa remodeling in patients treated with functional appliances, for a better understanding of the effect on the TMJ.

MRI in TMJ evaluation

MRI allows excellent demonstration of the TMJ anatomy because of the use of surface coils⁽⁶⁾ and its high resolution and tissue contrast. MRI has become the gold standard for examination of the TMJ area. It has the advantage of constructing the image without using ionizing radiation and without pain. This imaging technique can differentiate the cortex, bone marrow, hyaline cartilage, muscle, fluid and fibrous tis-

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sue⁽⁷⁾. With the development of faster imaging techniques and dual-coil imaging, it can help in bilateral examination of the TMJ in the functional or static conditions of the joint⁽⁸⁾.

TMJ imaging techniques

Imaging of the TMJ can be performed in any plane of space. With bilateral small surface coils, simultaneous bilateral imaging of the TMJ is possible and high quality images can be obtained. The condyles are oriented about 30° medially on the axial view; hence the image planes are oblique sagittal or oblique coronal⁽⁹⁾. Oblique sagittal images are taken perpendicular to the horizontal long axis of the mandibular condyle, whereas the coronal oblique images are taken parallel with the long axis of the condyle. The latter view is useful to evaluate medial or lateral disc displacement. Variations in protocol have been proposed for evaluating the TMJ but certain basic parameters are necessary for examination with optimal image quality and efficiency⁽⁹⁾. A T1-weighted protocol (short repetition time and short echo time) is used to determine disc position, internal morphology and mobility. A T2-weighted protocol (long repetition time and long echo time) is routinely used to determine joint effusion and inflammation. Proton density-weighted images (long repetition time and short echo time) are used to evaluate joint effusion, morphology and signal intensity of the articular disc.

TMJ anatomy in MR imaging

The TMJ is formed by the mandibular condyle and glenoid (articular) fossa of the temporal bone. The articular eminence of the temporal bone and the condyle of the mandible demonstrate the high signal intensity of fatty marrow, whereas the cortical bone shows a dark signal and displays a uniform surface on the condylar head, glenoid fossa and the articular eminence.

The articular disc of the TMJ is a biconcave fibrocartilaginous disc with an anterior and posterior band and a thin intermediate zone. It is located between the low signal intensity cortical surfaces of the articular eminence and condylar head. The disc shows low signal intensity on T1- and T2-weighted images, whereas synovium in the superior or inferior joint spaces defines intermediate signal intensity. The central portion of the posterior band of the disc can show intermediate signal intensity while the thick posterior band blends with a vascularized bilaminar zone in the retrodiscal tissue complex, which is anchored to the temporal bone.

Methods to analyze changes in TMJ in functional appliance therapy using MRI

Condylar and glenoid fossa remodeling assessment

In this assessment, proton density-weighted MRIs were used to identify possible areas of remodeling. Signs of remodeling were identified by increased signal intensity (bright areas). Possible remodeling processes of the condyle and glenoid fossa were analyzed by visual inspection of MRIs⁽¹⁰⁾. The principle of interpreting proton density-weighted MR images is that the contrast in the image demonstrates the differences in the proton densities between the tissues. Therefore, tissues which have a high proton density show a high signal and appear bright. On the other hand, tissues with a low proton density show a low signal and appear dark on the MR image.

Besides the visual assessment mentioned earlier, Chintakanon et al⁽¹¹⁾ described the use of the sagittal MR image of the central part of the condyle in the metrical evaluation of glenoid fossa remodeling by measuring the steepness of the articular eminence, defined as the angle formed by a line tangential to the posterior slope of the eminence relative to the posterior condylar line (PC-line) and the Frankfurt Horizontal line (FH-line) (Fig. 1). This angle is called the 'eminence angle'. Wadhawan et al⁽¹²⁾ also described another assessment called the 'glenoid fossa angle' which is also measured on the sagittal MR image of the central part of the condyle. This angle is formed between the anterior and posterior slopes of the glenoid

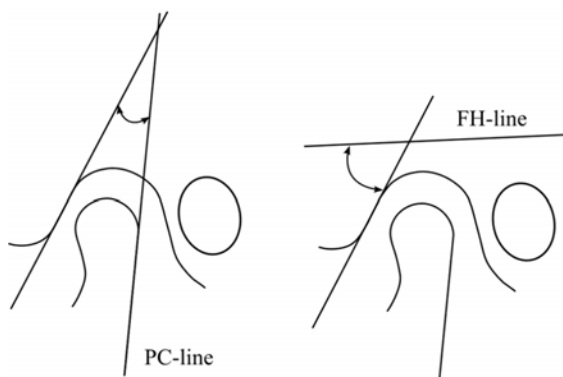


Fig. 1 Method of measuring eminence angle: the left picture shows the angle between the line tangent to the posterior slope of the articular eminence and posterior condylar line (PC-line); the right picture shows the angle between the line tangent to the posterior slope of articular eminence and Frankfurt Horizontal line (FH-line). (cited in Chintakanon et al⁽¹¹⁾)

fossa (Fig. 2).

The linear measurement for observing the remodeling of the post-glenoid spine (PGS) is another assessment using the sagittal MRI of the central slice

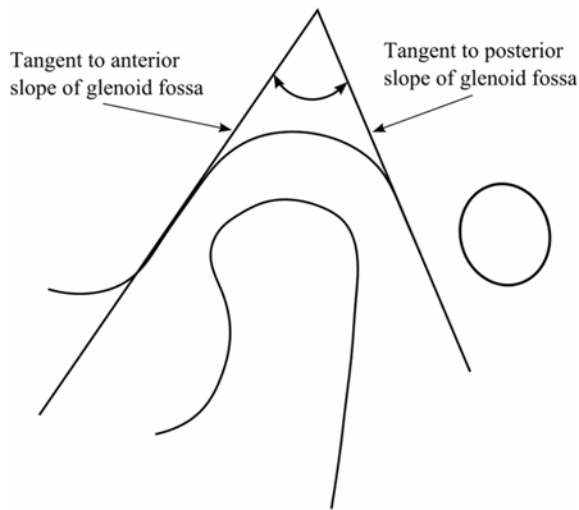


Fig. 2 Method of glenoid fossa angle measurement (cited in Wadhawan et al⁽¹²⁾)

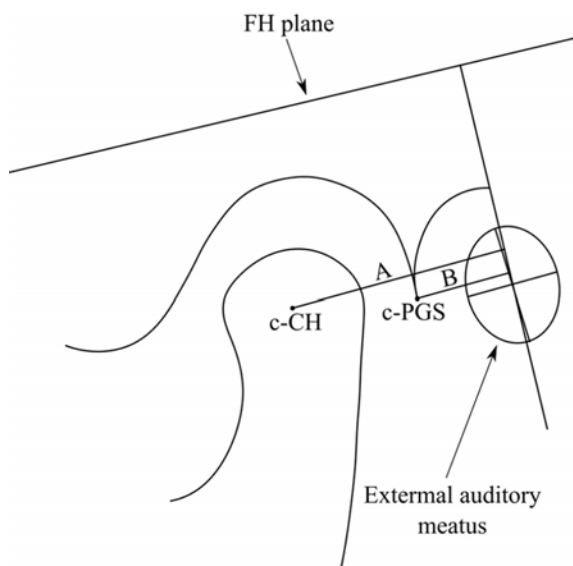


Fig. 3 Assessment of the linear metric measurement to evaluate the sagittal position of the condyle and post-glenoid spine in relation to the FH perpendicular: A = linear distance between FH perpendicular to the center of the external auditory meatus and the center of the condylar head(c-CH); B = linear distance between the FH perpendicular to the center of the external auditory meatus and the crest of the post-glenoid spine(c-PGS) (cited in Wadhawan et al⁽¹²⁾)

of the condyle, described by Wadhawan et al⁽¹²⁾ in 2008. This assessment uses the center of the external auditory meatus (c-EAM) as a reference. Another line used is a line perpendicular to the transferred FH plane through the constructed c-EAM. Then two other marked points are used, one at the crest of the post-glenoid spine (c-PGS), the other at the center of condylar head (c-CH) (Fig. 3). The linear distances of the c-CH and the c-PGS from the c-EAM, are assessed as the shortest linear distances from the constructed FH perpendicular.

Condyle-fossa relationship assessment

To assess the condyle-fossa relationship in functional appliance treatment, the condylar position in relation to the glenoid fossa was evaluated⁽¹¹⁻¹⁵⁾. The condylar position was assessed metrically on the central slice of the closed-mouth parasagittal MRIs by using the methods described by Mavreas and Athanasiou⁽¹⁶⁾ or the similar method described by Kamelchuk et al⁽¹⁷⁾. To assess the positional relationship between the mandibular condyle and the fossa, the shortest distance between the condylar head and the articular eminence was measured as the anterior joint space and the shortest distance between the condylar head and the PGS was measured as the posterior joint space (Fig. 4). Then the anterior (ant) and posterior (post) joint spaces were calculated as a Joint Space Index (JSI) as follows:

$$JSI = [(post-ant)/(post + ant)] \times 100$$

A positive value indicates anterior condylar displacement or ventral position of the condyle within the glenoid fossa and a negative value demonstrates posterior condylar displacement or dorsal position of the condyle within the glenoid fossa. While the zero value shows the centric condylar position. The normative values of JSI which correspond to a physiologic range of the condylar position range from -32.5% to 21.1%⁽¹⁸⁾.

Articular disc assessment

Most of the MRI studies on the effect of functional appliances^(11,12,15,19-24) mainly analyzed the disc-condyle relationship. Disc positions were analyzed both in sagittal and coronal positions.

The sagittal position of the articular disc was assessed both in closed mouth and open mouth positions.

In the closed-mouth position, the posterior band location and the intermediate zone location were evaluated. Drace and Enzmann⁽²⁵⁾ described a method in which the position of the posterior band was mea-

sured in relation to the 12 o'clock position of the condyle within the glenoid fossa (Fig. 5). A positive angle value defined an anterior position of the disc; a negative angle value defined a posterior position of the disc. Standard values which corresponded to a physiological relationship between the disc and condyle, range from -25.7° to 18.7° . Bumann et al⁽²⁶⁾ recommended the method that evaluated the location of the intermediate zone (IZ) of the disc. It was the measurement of the distance (mm) between the midpoint of the articular disc and a line connecting the midpoint of the condyle and the tuberculum articulare. This distance was measured after perpendicular projection of the midpoint of the disc to a tangent on the articular eminence (Fig. 6). A positive value showed anterior positioning of the disc; a negative value indicated posterior positioning of the disc. The normal range of the IZ location was -1.1 to 1.7 mm, according to Vargas Pereira⁽¹⁸⁾.

In the open mouth position, the disc position

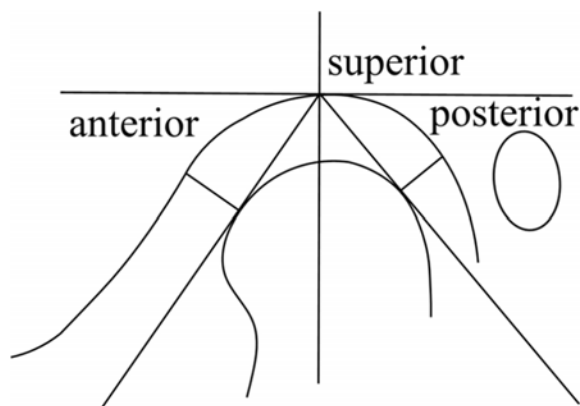


Fig. 4 Assessment of anterior and posterior joint space (mm) (cited in Kamelchuk et al⁽¹⁷⁾)

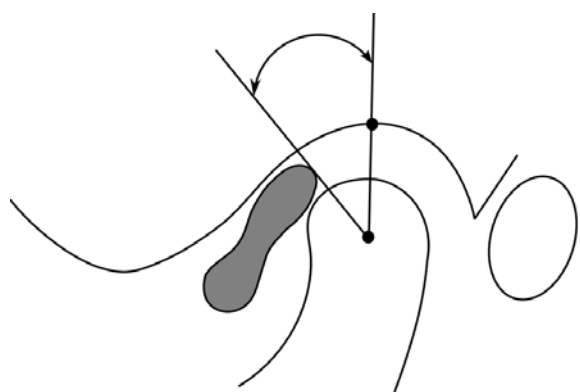


Fig. 5 Assessment of sagittal position of the posterior band of the articular disc in relation to the mandibular condyle (cited in Draze and Enzmann⁽²⁵⁾)

was considered normal if the IZ of the disc was interposed between the tuberculum articulare and the mandibular condyle throughout all slices (medial, central, and lateral slices).

Chintakanon et al⁽¹¹⁾ described a method that evaluated coronal disc position on closed mouth coronal MRIs. A reference line along the long axis of the condylar head and neck was constructed. Another line across the maximum width of the condylar head was also constructed and then divided into tenths (Fig. 7). The disc position was recorded in relation to the 1/10 divisions of the condylar width. Negative values de-

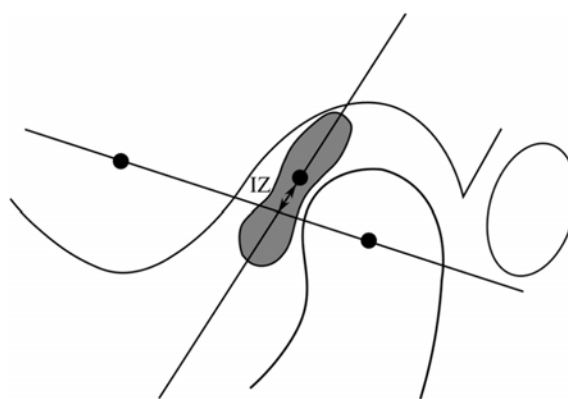


Fig. 6 Assessment of sagittal position of the intermediate zone (IZ) of the articular disc in relation to the mandibular condyle. (cited in Bumann et al⁽²⁶⁾)

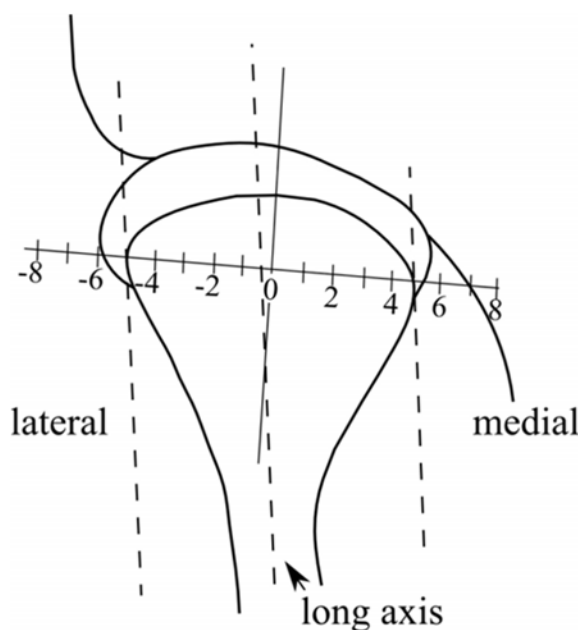


Fig. 7 Method of measuring coronal disc position (cited in Chintakanon et al⁽¹¹⁾)

defined lateral disc positioning and positive values defined medial disc positioning.

TMJ adaptation and changes in articular disc position treated by the functional orthopedic appliance: MRI investigation

To find out the effects of functional orthopedic appliances on TMJ adaptation and articular disc position, the clinical studies with MRI were reviewed (Table 1).

From these clinical studies, three adaptive processes in the TMJ from functional appliances are thought^(10,12,13) to contribute to forward positioning of the mandible:

Condyle remodeling

The use of MRI to demonstrate condylar remodeling during functional appliance therapy was first reported by Ruf and Pancherz^(10,13). In those studies, there were 15 adolescent subjects with a mean age of 13.5 years treated with the Herbst appliance. Ruf and Pancherz reported that after using the Herbst appliance for six to 12 weeks, signs of remodeling were observed in 29 of the 30 investigated TMJs in the form of distinct areas of increased signal intensity (bright areas) on the posterior-superior region of the condyle in proton density weighted parasagittal MRI.

Similar findings were reported in a study of Twin-Block and Bionator appliances from India⁽¹²⁾; visual evidence was found of changes in the shape of the condylar head after at least six months of functional appliance therapy. Eight of twelve cases (ages between 10 and 14 years old) demonstrated the visual observation of a convexity on the posterior-superior surface of the condylar head. Furthermore, in the present study, a previously unreported reduction in the prominence of the notch on the anterior surface of the condylar head was shown. Although there was evidence of changes in the condylar head, areas of increased signal intensity were not detected in that study, which may be because a different MRI sequence was used or because of a different specific time after treatment at which the MRIs were recorded. Therefore, the changes were too far advanced to detect. If the periodic MRIs were recorded at shorter intervals, an increase in MRI signal intensity might have been detected.

Another study by Chintakanon et al⁽¹¹⁾ also did not report evidence of increased MRI signal intensity after six months of Twin-Block therapy in subjects in the same age range as in the sample in the present

study mentioned above⁽¹²⁾. The reasons for not seeing the increase in MRI signal might be the same as in Wadhawan and coworkers' study⁽¹²⁾.

In contrast to most functional appliance studies, which focused on active growing subjects, the present study of the Herbst appliance by Ruf and Pancherz in 1999⁽¹⁰⁾ studied both adolescents and young adults. They studied 25 adolescents (mean age 12.8 years) and 14 young adult patients (mean age 16.5 years) with Class II malocclusions treated with the Herbst appliance. Adolescents or young adults referred to the skeletal age determined according to the methods described by Hagg and Taranger⁽²⁷⁾. The results showed that signs of condylar remodeling were seen in the posterior-superior of the condyle of both adolescents (48 of the 50 TMJs) and young adults (26 of the 28 TMJs). That study verified that growth adaptation of the TMJ could be achieved by the Herbst appliance, even in patients with Class II malocclusions whose growth had ended.

Glenoid fossa remodeling

Ruf and Pancherz^(10,13) reported that the signs of glenoid fossa remodeling could be observed visually in MR images of patients treated with the Herbst appliance. These signs could be seen in both adolescents and young adults⁽¹⁰⁾. The adaptive processes were found located on the anterior surface of the PGS in all subjects; however, the MRI appearance which was interpreted as remodeling of the glenoid fossa differed between individuals⁽¹³⁾. In most subjects, the signs of glenoid fossa remodeling were detected later than those of condylar remodeling. The explanation for this delayed manifestation might be the difference between the adaptive processes of the glenoid fossa (periosteal ossification) and of the condyle (endochondral ossification). Because periosteal ossification is not associated with a huge increase in water content of the tissue, the marked change in MRI signal intensity is not seen. Thus the newly formed bone at the PGS is observed in MRI when it has consolidated.

According to the expected horizontal mandibular growth following the use of functional appliances in patients with Class II malocclusions, a shallower eminence angle which represents glenoid fossa remodeling is anticipated. However, Chintakanon et al⁽¹¹⁾ found the eminence angle was not statistically significantly changed following six months of Twin-Block therapy. This finding is similar to the results of Wadhawan et al⁽¹²⁾, who also did not find any statistically significant changes in eminence angle following

Table 1. Clinical studies of the effects of functional orthopedic appliances on the TMJ based on magnetic resonance imaging (MRI)

Authors	Year of publication	Sample size	Functional Appliance used	Design	Finding (s)
Ruf and Pancherz ⁽¹³⁾	1998	15 t	Herbst	Prospective	-Remodeling of condylar and glenoid fossa -No significant changes in condylar position -No adverse effects on TMJ in long-term -Remodeling of the condyle and glenoid fossa
Ruf and Pancherz ⁽²⁹⁾	1998	20 t	Herbst	Retrospective	
Ruf and Pancherz ⁽¹⁰⁾	1999	25 t adolescents, 14 t young adults	Herbst	Prospective	
Pancherz et al ⁽¹⁹⁾	1999	15 t	Herbst	Prospective	-No significant changes in condylar position -No adverse effects on disc position -No adverse effects on TMJ
Ruf and Pancherz ⁽¹⁵⁾	2000	62 t	Herbst	Prospective	
Chintakanon et al ⁽¹¹⁾	2000	19 t 21 nt	Twin-Block	Prospective	-No clear evidence of remodeling of glenoid fossa -No adverse effects on disc position -Anterior condylar position -No adverse effects on disc position -No adverse effects on disc position -No adverse effects on TMJ
Arat et al ⁽²⁸⁾	2001	9 t 9 nt	Andresen activator	Prospective	
Franco et al ⁽²⁰⁾	2002	28 t 28 nt	Frankel II	Prospective	
Ruf et al ⁽²¹⁾	2002	30 t	Activator	Prospective	
Kinzinger et al ⁽²²⁾	2006	15 t	FMA	Prospective	-No adverse effects on TMJ
Kinzinger et al ⁽¹⁴⁾	2006	20 t	Herbst, FMA	Prospective	-No significant changes in condylar position
Kinzinger et al ⁽²³⁾	2006	20 t	Herbst, FMA	Prospective	-No adverse effects on disc position
Aidar et al ⁽²⁴⁾	2006	20 t	Herbst	Prospective	-No significant changes in disc position
Wadhawan et al ⁽¹²⁾	2008	12 t	Twin-Block, Bionator	Prospective	-Remodeling and forward relocation of PGS -No significant changes in condylar position -No significant changes in disc position

t = treatment; nt = no treatment; FMA= functional mandibular advancer; PGS= post-glenoid spine

Twin-Block or Bionator appliance therapy for six months. Both findings helped support the results from Ruf and Pancherz⁽¹³⁾ that in most subjects, the amount of glenoid fossa remodeling was smaller than that of condylar remodeling.

Besides evaluating the visual changes in the glenoid fossa and measuring the eminence angle, linear measurement of the remodeling of the PGS was also evaluated in the present study of Wadhawan et al⁽¹²⁾. The results showed that there was a forward remodeling or displacement of the PGS along the FH-plane following Twin-Block or Bionator therapy⁽¹²⁾.

Condyle-fossa relationship changes

Ruf and Pancherz⁽¹³⁾ examined the JSI pre- and post- Herbst appliance treatment to evaluate changes in condyle position in relation to the glenoid fossa. They found that the pre-treatment index showed the condyles of Class II subjects had a tendency toward anterior position (posterior JSI value) and the post-treatment index showed the condylar position of this phase was more anteriorly positioned than pre-treatment. However, the average change of the index during the treatment was not significant. This meant that condylar position was not affected by the Herbst appliance. The results of that study then was supported by another study using the Herbst appliance⁽¹⁵⁾ that observed the condylar position on MRI before treatment, immediately after treatment and one year after treatment and in which the results also showed that there was no significant change in condylar position after Herbst appliance treatment.

The effect of other functional appliances on condylar position was assessed. Ruf and coworkers⁽²¹⁾ reported a slightly anterior position of the condyle within the fossa following Activator treatment. Additionally, Arat et al⁽²⁸⁾ reported a similar change in condylar position during Andresen activator treatment. The anterior position of the condyle in both studies was reported in a physiological range. The effect of Twin-Block^(11,12) and Bionator⁽¹²⁾ treatment on the position of the condyle was also studied. The results showed that condyles were situated in a slightly anterior position within the fossa at pre-treatment in most of the subjects. After treatment for six months, anterior positioning of condyle was found with more anterior positioning compared to pre-treatment. However, the position during the functional orthopedic treatment was still in a physiologic position relative to the fossa. Furthermore, Wadhawan and co-workers⁽¹²⁾ assessed the condylar position after completion of 2-phase treatment (phase I treatment

with Twin-Block or Bionator). They found the condyles demonstrated a tendency to return to their original positions as before treatment with functional appliances. Kinzinger et al⁽¹⁴⁾ studied the effect of the fixed functional orthopedic appliance called Functional Mandibular Advancer (FMA) and found similar changes in the condylar position at the end of treatment.

Besides TMJ adaptation, changes in articular disc position following functional appliance therapy were also studied to verify if functional orthopedic treatment cause changes in the internal structures of the TMJ.

Sagittal articular disc position

In studies of fixed functional appliances^(15,19), the sagittal disc position in closed-mouth parasagittal MRIs during the Herbst treatment (when the appliance was placed) there was a slight tendency towards retrusive positioning, but when the appliance was removed the disc returned to its pre-treatment position, whereas open-mouth parasagittal MRIs showed an average disc retrusion with or without the appliance in place. Similar changes in the sagittal disc position were observed in studies reported in 2006 by Aidar et al⁽²⁴⁾ and Kinzinger et al⁽²²⁾.

The changes in sagittal disc position during treatment with removable functional appliances, such as Twin-Block^(11,12), Bionator⁽¹²⁾ and Frankel⁽²⁰⁾ appliances were the same as those with fixed functional appliances.

Interestingly, Kinzinger et al^(22,23) reported significant improvement of the disc position in joints which initially had partial or total disc displacement.

Coronal articular disc position

Changes in coronal disc position were observed in studies using Twin-Block and Bionator appliances^(11,12). The results showed that there were no significant differences in the coronal disc position. This might be imply that functional orthopedic therapy has little effect on coronal disc position.

Conclusion

From the clinical studies using MRI mentioned above, the effects of functional appliance therapy on TMJ morphology can be assessed by the evaluation of condylar and glenoid fossa remodeling, evaluation of condylar position and evaluation of articular disc position. Additionally, the results of this appliance on TMJ morphology can be concluded as follows:

- The adaptive processes of the TMJ follow-

ing the use of the Herbst appliance probably result from remodeling of the condyle and glenoid fossa. These changes can be found both in adolescents and young adults, while the effects of using other types of functional appliances on TMJ adaptation are still unclear.

- Changes in condylar position relative to the glenoid fossa following the use of either fixed or removable functional appliances are minor and not clinically significant because the position of the condyle is still in the physiological range.

- Neither fixed nor removable functional appliances result in any adverse effects on the articular disc position or induce temporomandibular disorders in a short-term period.

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Potential conflicts of interest

None.

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การปรับการเจริญเติบโตของข้อต่อขากรรไกรและการเปลี่ยนแปลงตำแหน่งของแผ่นรองข้อต่อขากรรไกร ในการรักษาด้วยเครื่องมือฟังก์ชันนอล: การตรวจสอบด้วยแมกเนติกเรโซแนนซ์ อิมเมจจิง

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เครื่องมือฟังก์ชันนอลที่ใช้เปลี่ยนความสัมพันธ์ของขากรรไกรเป็นเครื่องมือที่ใช้ในการแก้ไขการสบฟัน ผิดปกติแบบที่สอง ในผู้ป่วยที่มีโครงสร้างขากรรไกรล่างถอยไปข้างหลัง โดยวัตถุประสงค์ของการใช้เครื่องมือชนิดนี้ คือเพื่อกระตุ้นให้ขากรรไกรล่างมีการเจริญเติบโตไปทางด้านหน้าเพื่อให้ได้ความสัมพันธ์ของขากรรไกรที่ปกติ แต่อย่างไรก็ตามยังไม่มีข้อสรุปที่แน่ชัดของกลไกการทำงานของเครื่องมือชนิดนี้ รวมไปถึงผลของการใช้เครื่องมือนี้ ต่อข้อต่อขากรรไกรก็ยังเป็นประเด็นที่ยังคงเป็นที่โต้แย้งกันอยู่ ดังนั้นจึงมีการนำแมกเนติกเรโซแนนซ์อิมเมจจิง ซึ่งจัดเป็นเครื่องมือที่ดีที่สุดที่ใช้ในการดูส่วนของเนื้อเยื่ออ่อน และตำแหน่งของแผ่นรองข้อต่อขากรรไกรมาช่วยให้เข้าใจผลของเครื่องมือฟังก์ชันนอลต่อข้อต่อขากรรไกรได้มากขึ้น

วัตถุประสงค์ของบทความปริทัศน์นี้ เพื่อรวบรวมวิธีการประเมินการเปลี่ยนแปลงของข้อต่อขากรรไกร ซึ่งเป็นผลมาจากการใช้เครื่องมือฟังก์ชันนอลจากภาพแมกเนติกเรโซแนนซ์อิมเมจจิง ซึ่งประกอบไปด้วยการประเมิน การปรับรูปของคอนดายล์และแอ่งข้อต่อขากรรไกร การประเมินความสัมพันธ์ของคอนดายล์และแอ่งข้อต่อขากรรไกร และการประเมินแผ่นรองข้อต่อขากรรไกร และเพื่อรวบรวมวรรณกรรมที่เกี่ยวข้องทางคลินิกในการใช้แมกเนติกเรโซแนนซ์อิมเมจจิง มาประเมินผลการรักษาของเครื่องมือที่มีผลต่อข้อต่อขากรรไกร
