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Physiological effects of anterior repositioning splint on temporomandibular joint disc displacement: a quantitative analysis

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SUMMARY Anterior repositioning splints (ARS) are used primarily for the management of temporomandibular joint (TMJ) anterior disc displacement with reduction (ADDwR). However, the exact physiological effects of ARS are still unclear. This study investigated the short and long-term effects of ARS on disc and condyle angles/positions by metric analysis. Twenty-two subjects diagnosed with ADDwR were recruited. Maxillary full-coverage ARS were fabricated, and MRI of TMJs was obtained before splint treatment, immediate post-insertion and 6 months after splint treatment. Disc–condyle relationship was determined by disc–condyle angle measurement. Disc and condyle positions were described as X-Y coordinates with the summit of glenoid fossa as the origin of the coordinates. Thirty-two TMJs were classified as ADDwR and 12 were normal. Upon ARS insertion, all TMJs with ADDwR got normal disc–condyle relationships. The condyles moved significantly forward and downward, while the discs moved significantly backward and upward. MRI at 6 months after treatment (without ARS insertion) indicated that only 40·6% (13/32) of the joints were maintained in the normal disc–condyle relationship. The majority of condyles returned to their pre-treatment positions, while the discs generally moved anteriorly again. The use of ARS resulted in forward and downward condyle movement, and a concurrent backward movement of the disc resulting in ideal spatial disc–condyle relationship. The stability of this relationship, however, could not be maintained in the majority of TMJs upon ARS removal. Findings explain the good short-term clinical outcomes with ARS and their relatively lower efficacy in the long term.

KEYWORDS: **anterior repositioning splint, temporomandibular disorders, anterior disc displacement, condyle position, disc position**

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Introduction

Temporomandibular disorders (TMD) represent a cluster of musculoskeletal and neuromuscular conditions involving the temporomandibular joints (TMJs), masticatory muscles and/or associated structures. The signs and symptoms of TMD include headaches, facial pain, joint sounds, jaw function difficulties, limited and abnormal jaw movements as well as catching/locking of the jaws. TMD can be broadly classified into TMJ and masticatory muscle disorders (1). Anterior disc displacement (ADD) is the most common type of TMJ arthropathy and involves abnormal disc–condyle relationships (2). ADD can be further

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subdivided into disc displacement with (ADDwR) and without reduction (ADDwoR). In the latter, the disc is in an anterior position relative to the condyle when the mouth is closed and cannot be reduced with mouth opening. In the acute stage, it is often associated with limited mandibular opening.

Anterior repositioning splints (ARS) are used primarily for the management of ADDwR and were first described by Farrar in 1970s (3). They aim to re-establish normal disc–condyle–fossa relationships through the use of therapeutic mandibular positions that are forward to maximum intercuspation. The mandible is guided into the protrusive jaw positions by means of occlusal indentations and reverse guidance inclines integrated into the ARS. The exact physiological effects of ARS are still unclear and subjected to much debate. Two main theories exist pertaining to their usefulness in reducing TMJ pain, clicking and dysfunction (4). The first proposed that ARS reposition condyles anteriorly to catch or 're-capture' displaced discs, establishing normal disc–condyle relationships in the mandibular fossae. The disc–condyle complexes are subsequently 'walked back' along the posterior slope of the articular eminence by periodic modification of the ARS (5, 6). The second theory asserted that ARS allow for the displaced discs to slip back into their normal positions in the therapeutic mandibular positions (7).

Clinical studies have reported the superiority of ARS over other occlusal splint designs for the management of TMJ ADDwR (4, 8, 9). More recently, the use of ARS had been shown to facilitate regenerative remodelling of condyles in patients with both ADDwR and ADDwoR (10). 'Double-contour' images suggesting condylar bone remodelling were observed in about 80% of subjects with cone-beam computerised tomography. Despite their short-term reliability, the long-term efficacy of ARS remains equivocal especially when they are removed. While some studies have conveyed high rates of long-term 're-capturing' of discs (11, 12), others have reported that disc 're-capture' is permanent in only a small percentage of patients and advocated the need for more enduring change of mandibular position through occlusal rehabilitation (4, 5, 13, 14).

This study aims to provide new understanding of the immediate and long-term physiological effects of ARS in patients with ADDwR. While previous magnetic resonance imaging (MRI) studies on ARS and ADDwR were largely qualitative in nature (7, 11, 14), metric analysis was performed on disc and condyle angles/positions in this study. The null hypothesis was that ARS do not change disc–condyle angles and positions upon immediate post-insertion nor 6 months after splint therapy. Findings may help explain the short-term and long-term clinical outcomes associated with ARS.

Materials and method

Ethics approval was obtained from the Biomedical Institutional Review Board of Peking University School of Stomatology prior to conducting the study (PKUSSIRB-2012001). Subjects were recruited from patients seeking care at the Center for TMD & Orofacial Pain of Peking University School & Hospital of Stomatology. Thirty-one consecutive patients were enrolled based on the following inclusion criteria: Subjects (a) aged 15 to 30 years, (b) without any systematic diseases, (c) with clinical diagnosis of ADDwR based on DC/TMD (1), (d) with MRI confirmation of ADDwR, (e) without radiographic signs of TMJ degeneration, and (f) with informed consent for ARS treatment. Exclusion criteria were as follows: subjects (a) older than 30 years, (b) who are pregnant, (c) with congenital abnormalities or dentofacial deformities, (d) who sustained recent oro-facial or cervical trauma, (e) with major psychological disorders, (f) with complete or partial dentures and (g) who had received prior TMD treatment. Of the 31 subjects, seven were omitted as they did not complete ARS treatment, and two were excluded due to pregnancies after initiation of therapy. The 22 eligible subjects had a mean age 23·32 years (range from 15 to 27 years) and comprised of 13 females and nine males.

Splint procedures

Maxillary full-coverage acrylic ARS (denture base polymer QC-20, Dentsply, USA) with occlusal indentations and anterior reverse inclines were fabricated for the subjects. To obtain the therapeutic protrusive jaw position, subjects were instructed to open their mouths fully beyond the clicking point and to close in a protruded position with the incisors in an edge-to-edge relation (15). This technique had been reported to facilitate clinical 're-capturing' of anteriorly displaced discs (Fig. 1). All ARS were fabricated in this

Fig. 1. Maxillary full-coverage ARS fabricated in the therapeutic protrusive jaw position (a–c). Pre-treatment occlusion was re-established after stopping daytime ARS wear (d–f). [Colour figure can be viewed at wileyonlinelibrary.com]

therapeutic jaw position by one dental technician and adjusted/issued by the authors. Subjects wore the ARS continuously for 3 months and were only allowed to remove the splints when brushing their teeth (8, 16). They were reviewed monthly to ensure splint acceptance/compliance and to monitor subjective/objective treatment progress. At the end of 3 months, the splints were worn only during sleep. Subjects were first asked whether their back teeth were contacting, then followed by checking with 40-μm-thick articulating paper* to ascertain the re-establishment of occlusion. The original occlusal conditions were gradually re-established over 1 to 2 weeks upon stopping daytime splint wear (Fig. 1). The subjects were recalled at 6 months and clinically assessed for signs and symptoms.

MRI procedures

MRI was performed using a 1·5-Tesla MRI scanner† with TMJ surface coils. Subjects were placed supine with their heads positioned with the Frankfurt plane perpendicular to the floor. The centre beam was then lined up with the sagittal plane. The MRI protocol consisted of an initial low-resolution T1-weighted (TR 300 ms; TE 10 ms) axial localising scan, followed by Proton-weighted (TR 1760 ms, TE 15 ms) oblique sagittal scan vertical to the long axis of each condyle. The field of view was 12 × 12 cm, and matrix size was 512 × 512. Slice thickness and interslice spacing were set at 2 mm and 1 mm, respectively.

Subjects were assigned two imaging visits. During the first visit, before treatment, MRI was acquired with the subjects' mouth closed in maximum intercuspation and opened fully. This was followed by an immediate post-splint insertion MRI with the mouth closed in the therapeutic protrusive jaw position. After 6 months, a second imaging visit was scheduled, where after treatment, MRI was taken again in the closed and opened mouth positions without the ARS. Disc and condyle angles/positions were assessed using two central and sagittal MRI images of the TMJs by a single evaluator.

Disc and condyle measurement procedures

Disc–condyle angles were used to describe disc–condyle relationships and were determined using the methodology proposed by Drace-Enazmann (17). Point C is the centric point of condyle head, while point D is the mid-point of posterior margin of the disc posterior band (Fig. 2a). Line 1 was drawn from point C perpendicular to the Frankfort horizontal plane. Line 2 was drawn through point C to point D.

*Progress, Bausch Articulating Papers Inc., Koln, Germany.
†NOVUS, Siemens, Munich, Germany.

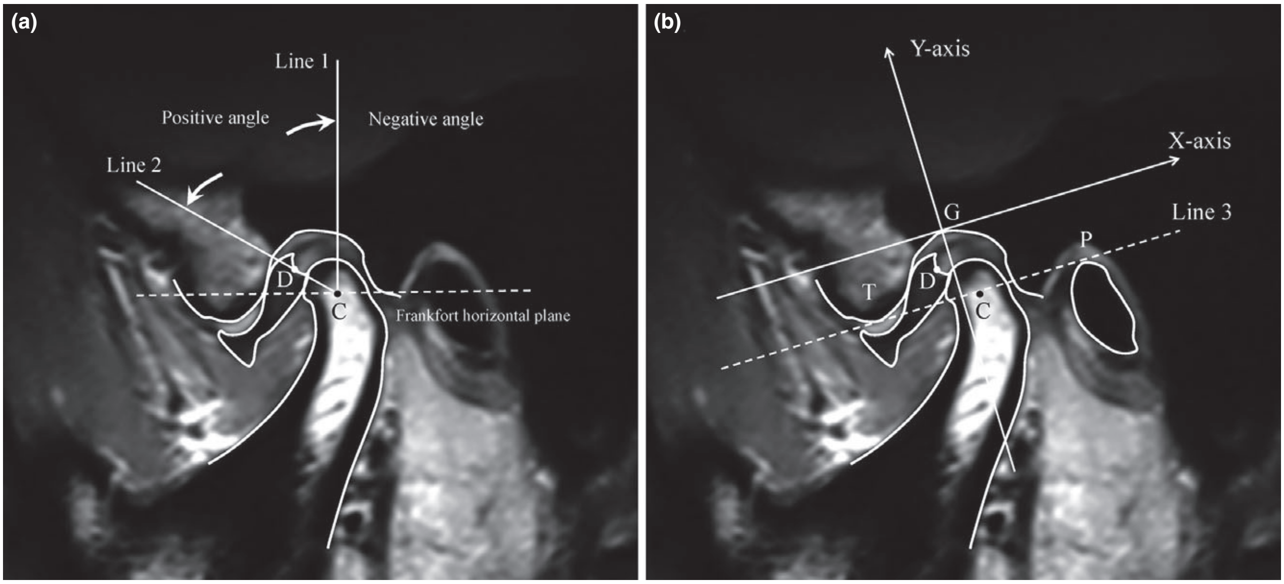

Fig. 2. (a) Drace-Enazmann's determination of disc–condyle angle. (b) Coordinate measurements for disc and condyle positions.

The angle between Line 1 and Line 2 is defined as the disc–condyle angle θ. The normal range for disc–condyle angles is between $-15°$ and $+15°$, and $\theta > +15°$ specify the occurrence of anterior disc displacements (18). Images from the MRI scanner were acquired, and disc–condyle angles were computed and quantified using Adobes Photoshop 7.0 Analysis[‡] at the three MRI phases.

Disc and condyle positions were described as X-Y coordinates (Fig. 2b). A tangent from lowest part of the articular tubercle (point T) to the highest edge of the porus acusticus externus (point P) was drawn (Line 3). The *X*-axis was drawn through the highest point of glenoid fossa (point G) parallel to Line 3. The *Y*-axis was drawn from point G perpendicular to the *X*-axis. Point G was taken as the origin of coordinates. The condyle and disc positions were expressed as point C and D in the X-Y coordinates, respectively. The MRI data were evaluated by one trained radiologist blinded to clinical information. Intra-class correlation coefficients (ICC) were used to determine the intra- and interobserver reliability. A mean intra-observer ICC of >0·95 was established for all variables (the radiologist made all measurements twice with a one-week interval). Interobserver ICC ranged from 0·85 to 1 for the different variables. The latter was determined with the assistance of another independent radiologist who was also blinded to patients' clinical data (19). Quantitative values (coordinates of point C and D) were determined in millimetres at the three MRI phases by using Adobes Photoshop 7.0 Analysis[‡] based on the measurement scale indicated in the magnetic resonance images.

Statistical analysis

Statistical analysis was performed by using SPSS version 20.0[§]. Normality of data was established with the Kolmogorov–Smirnow test. Homogeneity of variance was ascertained with Levene's test. Independence student's *t* test was used to analyse the differences in disc–condyle angles between normal joints and those with ADDwR. Double factor variance analysis was used to analyse changes of disc and condyle positions at three imaging phases (before treatment, immediate post-insertion and after treatment) at significance level $P < 0{\cdot}05$.

Results

Changes in disc–condyle angles

Twenty-six joints from the 22 subjects had symptoms of joint clicking and/or intermittent locking and were

[‡]Adobe, San Jose, CA, USA.

[§]SPSS IBM, Chicago, IL, USA.

clinically diagnosed with ADDwR. Among these 26 joints, two joints of two subjects had pain symptoms when joint moving. Four joints of four patients had tenderness on the lateral pole of the joint, two joint of two subjects had tenderness on master or temporalis muscles, respectively. The remaining 18 joints were considered normal before treatment based on the DC/TMD. Upon MRI examination, 32 TMJs were classified as ADDwR (θ>+15°) and only 12 were normal (−15°θ≤+15°). Mean disc–condyle angle of TMJs with ADDwR was 52·10 ± 4·80°, while that of normal joints was 2·90 ± 4·07°. Disc-condyle angles of joints with ADDwR were significantly greater than normal ones.

With ARS wear, the symptoms of joint clicking and/or intermittent locking disappeared, and all joints (32/32) with ADDwR were found to have normal disc–condyle relationships with a mean disc–condyle angle of −17·93 ± 3·45°, and it had no significant difference with the normal joints (−21·92 ± 5·83°). Mean disc–condyle angle was significantly reduced with ARS insertion. Six months after treatment, no subject had symptom or sign of pain, relapse of joint clicking was observed in seven of 26 joints clinically. According to MRI measurements, only 40·6% (13/32) of joints with ADDwR were maintained in the normal disc–condyle relationship with the splint removed (Figs 3 and 4). Mean disc–condyle angle was 19·92 ± 4·42° and was again significantly greater than normal joints (−1·93 ± 4·67°).

Changes in condyle positions

C points represented the condyle positions in the X-Y coordinates (Fig. 2b) and were compared before treatment, immediate post-insertion and after splint

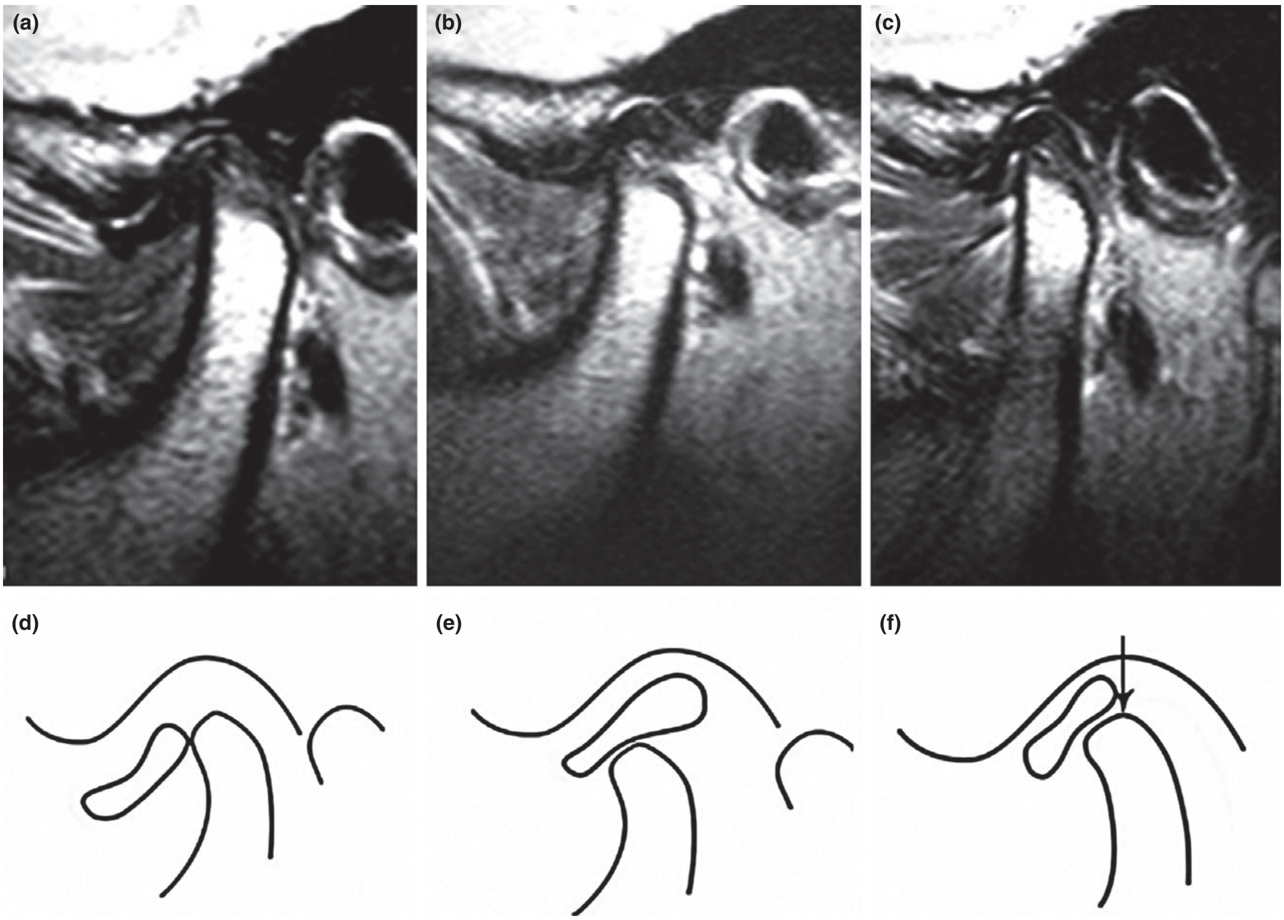

Fig. 3. MRI depicting successful disc reduction in a joint with ADDwR. (a) disc was displaced anteriorly in maximum intercuspation before splint treatment; (b) disc was fully reduced with ARS insertion; (c) disc–condyle relationship was normal in maximum intercuspation after splint treatment. (d–f) are diagrammatic representations of (a), (b) and (c), respectively.

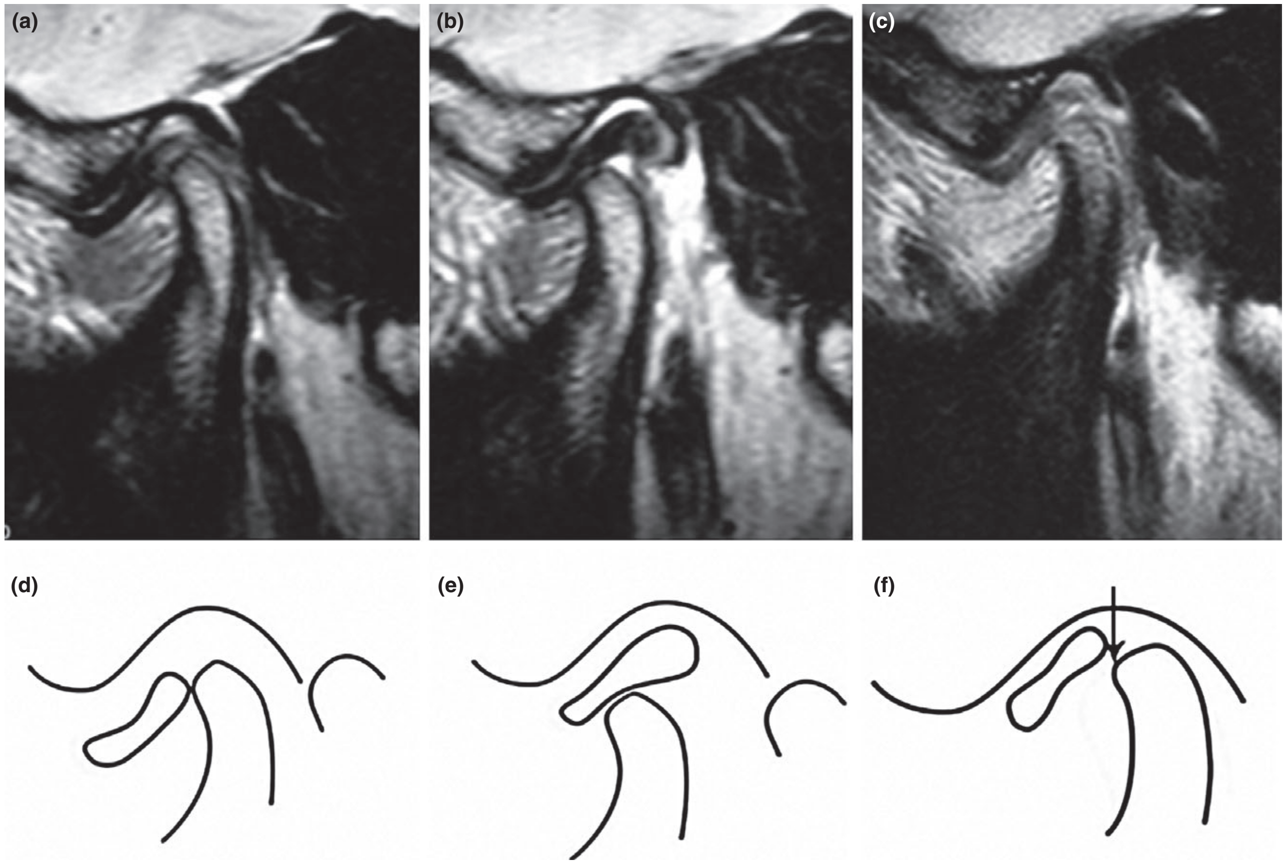

Fig. 4. MRI depicting partial disc reduction in a joint with ADDwR. (a) disc was displaced anteriorly in maximum intercuspation before splint treatment; (b) disc was fully reduced with ARS insertion; (c) disc was anteriorly displaced in maximum intercuspation after splint treatment. (d–f) are diagrammatic representations of (a), (b) and (c), respectively.

treatment. For joints with ADDwR, splint insertion moved the condyles significantly both forward ($-3{\cdot}91 \pm 2{\cdot}02$ mm in X-axis) and downward ($-2{\cdot}68 \pm 1{\cdot}37$ mm in Y-axis). Similarly, the condyles of normal joints also moved significantly both forward ($-3{\cdot}24 \pm 1{\cdot}24$ mm in X-axis) and downward ($-2{\cdot}03 \pm 1{\cdot}36$ mm in Y-axis). At 6 months after splint treatment, the condyles of both normal and disc-displaced joints generally returned to their initial pre-treatment positions (Table 1).

Changes in disc positions

D points represented the disc positions in the X-Y coordinates (Fig. 2b) and were also assessed at the three MRI phases. For joints with ADDwR, splint insertion moved the discs significantly both backward ($3{\cdot}28 \pm 1{\cdot}36$ mm in X-axis) and upward ($0{\cdot}60 \pm 1{\cdot}53$ mm in Y-axis). At 6 months after splint treatment, discs in joints with ADDwR were significantly forward ($-1{\cdot}07 \pm 2{\cdot}17$ mm in X-axis) and upward ($0{\cdot}49 \pm 1{\cdot}10$ mm in Y-axis) when compared to immediate post-splint insertion. The discs, however, moved significantly both backward ($2{\cdot}21 \pm 2{\cdot}11$ mm in X-axis) and upward ($1{\cdot}11 \pm 1{\cdot}52$ mm in Y-axis) when contrasted to before treatment (Table 2). Discs in the normal joints did not change significantly between the three MRI phases in both X and Y-axes (Table 2). The D point that indicated the posterior margin of the disc was largely located about 0 to 1 mm behind the vertex of glenoid fossa (point G).

Discussion

In the present study, changes in disc–condyle angles, condyle and disc positions were measured quantitatively before ARS treatment, immediate post-splint insertion and after splint treatment. Upon ARS insertion, all joints with displaced discs were found to have

Table 1. Mean condyle coordinates at three imaging phases for normal joints and those with ADDwR

	Normal (X, Y)	ADDwR (X, Y)
Before splint treatment	(0·21 ± 1·59 −6·82 ± 1·76)	(0·97 ± 0·51, −6·69 ± 1·05)
Immediate post-splint insertion	(−3·03 ± 1·88*, −8·85 ± 1·07*)	(−2·94 ± 0·22*, −9·37 ± 2·44*)
After splint treatment	(−0·10 ± 1·60, −7·81 ± 1·18)	(−0·14 ± 0·41*, −8·08 ± 2·31*)

*$P < 0·05$, when compared to before treatment.

Table 2. Mean disc coordinates at three imaging phases for normal joints and those with ADDwR

	Normal (X, Y)	ADDwR (X, Y)
Before splint treatment	(0·65 ± 0·85, −1·68 ± 0·44)	(−3·06 ± 1·37†, −3·83 ± 1·34†)
Immediate post-splint insertion	(0·61 ± 1·38, −2·67 ± 0·79)	(0·22 ± 1·16*, −3·23 ± 1·27*)
After splint treatment	(0·91 ± 1·29, −2·08 ± 1·09)	(−0·85 ± 1·78*,†, −2·72 ± 0·85*)

*$P < 0·05$, when compared to before treatment.
$^{\dagger}P < 0·05$, when compared to the normal joints.

normal disc–condyle relationships and significantly reduced mean disc–condyle angles. The condyles moved significantly forward and downward, while the discs moved significantly backward with splint therapy. At 6 months after treatment (without ARS insertion), the majority of condyles returned to their initial pre-treatment positions, while the discs generally moved anteriorly again. As ARS influenced disc–condyle angles and positions immediately post-insertion and in about 40% of joints with ADDwR post-treatment, the null hypothesis was rejected.

The ability of ARS to re-establish correct disc–condyle relationships in joints with ADDwR is well established. Ordinarily, the smallest mandibular protrusion needed to eliminate clinical signs is selected as the therapeutic jaw position for ARS. While disc reduction rate is reported to range from 50 to 70% based on clinical assessment, it increased more than 90% with MRI (20). In an earlier MRI study, only 54·8% displaced discs achieved normal disc–condyle relationships in the least protruded position. Success rates, however, increased to 93·5% if ARS were fabricated with incisors in the edge-to-edge relation (15). This therapeutic mandibular position was thus selected. Moreover, it allowed for some degree of protocol standardisation and was largely well tolerated by patients. The use of this therapeutic jaw position explained the high success rate (100%) of disc 're-capture' upon ARS insertion. MRI showed that all joints with ADDwR had normal disc–condyle relationship and symptoms of joint clicking and/or intermittent locking resolved. No significant difference in disc–condyle angles was observed between normal joints and those with ADDwR immediately post-splint insertion. The possibility of disc 're-capture' is reported to depend on disc–condyle position and configuration, integrity of the posterior attached and the degree of degenerative changes in the TMJ (14). Subjects with TMJ osteoarthritis were thus excluded.

Details of the MRI metric analysis developed for measuring disc and condyle positions had been described by Liu and co-workers (19). With this method, changes in disc and condyle positions at various time periods can be established by computing the numerical differences of coordinate values. The technique represents an advancement over previous practices as it allowed for more direct measurements and visualisation (21, 22). Theories relating to the effectiveness of ARS had already been featured. Walking back of the 're-captured' normal disc–condyle complexes along the posterior slope of the articular eminence necessitates the periodic judicious modification of the occluding surfaces of the ARS (5, 6, 23, 24). The latter was, however, not implemented owing to negative findings of earlier long-term clinical studies (4). The alternate theory contended that ARS permit displaced discs to slip back into their normal positions. This theory was supported by our study, as anteriorly displaced discs were quantitatively found to move backward and upward upon ARS insertion. Kurita and co-workers assessed 45 joints with ADDwR for disc 're-capture' and change of disc positions with insertion of ARS using MRI (7). They reported that all condyles moved forward, and the majority of discs (25/45) moved posteriorly, while 4/45 discs moved anteriorly and 16/45 discs had no change. While condyle movements were comparable, the amount of posterior disc movement was found to be negligible unlike the present study. The apparent discrepancy in results may be attributed to differences in case selection and degree of TMJ arthropathy.

Despite the high occurrence of long-term TMJ pain reprieve, the return of joint sounds was reported in most previous studies (4, 8, 24). This signified that disc 're-capture' was only temporal in the majority patients. Findings in our study paralleled those of earlier ones (4). Although all displaced discs were successfully reduced with splint insertion, normal disc–condyle relationship was only observed in 40·6% of joints when the ARS were removed after treatment. The majority (59·4%) of the reduced discs were again displaced anteriorly when the condyles moved back to their pre-treatment positions in the fossa. Further research pertaining to predictive factors for permanent disc 're-capture' is warranted. This should ideally involve both 2D and 3D metric analyses in addition to 3D structural reconstruction, superimposition and examination (25).

Condyles are normally located in the centre of their corresponding joint fossae. Nonetheless, in TMJs with disc displacements, condyles are usually posteriorly positioned in their joint fossae (26–29). TMJ spaces are typically well distributed with functional and ARS therapy (30). While condyle concentricity was not explicitly assessed, analysis of X-Y coordinates showed that condyles with ADDwR were $0{\cdot}97 \pm 0{\cdot}51$ mm behind point G in the maximum intercuspal position pre-treatment when compared to $0{\cdot}21 \pm 1{\cdot}59$ mm for normal joints (Table 1). These measurements indicated that condyles with ADDwR were located more posteriorly in their fossae than normal joints. After 6 months of ARS treatment, the condyles frequently moved backward to their initial pre-treatment positions in the fossae when the splints were not worn. The posterior positioning of the condyles in their fossae might contribute to displacement of the 're-captured' discs (Fig. 4) and the lower long-term success of ARS treatment.

Conclusion

The effects of ARS on disc–condyle angles and disc/condyle positions were explored using MRI metric analysis. MRI findings were more dependable for identifying TMJ disc displacements than clinical criteria. Upon ARS insertion, all TMJs with ADDwR were found to achieve ideal spatial disc–condyle relationships. The latter was achieved by significant forward and downward movement of the condyles and concurrent backward movement of the discs. The stability of this relationship could not be maintained in the majority of TMJs upon ARS removal, 6 months after splint treatment. Normal disc–condyle relationships were observed in only 40·6% of joints with ADDwR. The majority of condyles returned to their posterior pre-treatment positions while the discs generally moved anteriorly again. Findings provided new insights into the short-term and longer-term effectiveness of ARS.

Ethical approval

This study was approved by and conducted according to the recommendations of the Biomedical Institutional Review Board of Peking University School of Stomatology (PKUSSIRB-2012001).

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Competing interests

The authors have stated explicitly that there are no conflict of interests in connection with this article.

References

1. Schiffman E, Ohrbach R, Truelove E, Look J, Anderson G, Goulet JP *et al.* Diagnostic criteria for temporomandibular disorders (DC/TMD) for clinical and research applications: recommendations of the International RDC/TMD Consortium Network and Orofacial Pain Special Interest Group. J Oral Facial Pain Headache. 2014;28:6–27.
2. Manfredini D, Guarda-Nardini L, Winocur E, Piccotti F, Ahlberg J, Lobbezoo F. Research diagnostic criteria for temporomandibular disorders: a systematic review of axis I epidemiologic findings. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2011;112:453–462.
3. Farrar WB. Diagnosis and treatment of anterior dislocation of the articular disc. N Y J Dent. 1971;41:348–351.
4. Zamburlini I, Austin D. Long-term results of appliance therapies in anterior disk displacement with reduction: a review of the literature. Cranio. 1991;9:361–368.

5. Lundh H, Westesson PL, Kopp S, Tillstrom B. Anterior repositioning splint in the treatment of temporomandibular joints with reciprocal clicking: comparison with a flat occlusal splint and an untreated control group. Oral Surg Oral Med Oral Pathol. 1985;60:131–136.
6. Control or Reduction of Contributory or Predisposing Factors. Chapter 22, Clinical management. In: Zarb GA, ed. Temporomandibular joint and masticatory muscle disorders. 2nd ed. St Louis (MO): Mosby; 1994:541–542.
7. Kurita H, Kurashina K, Ohtsuka A, Kotani A. Change of position of the temporomandibular joint disk with insertion of a disk-repositioning appliance. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 1998;85:142–145.
8. Tecco S, Festa F, Salini V, Epifania E, D'Attilio M. Treatment of joint pain and joint noises associated with a recent TMJ internal derangement: a comparison of an anterior repositioning splint, a full-arch maxillary stabilization splint, and an untreated control group. Cranio. 2004;22:209–219.
9. Tecco S, Caputi S, Teté S, Orsini G, Festa F. Intra-articular and muscle symptoms and subjective relief during TMJ internal derangement treatment with maxillary anterior repositioning splint or SVED and MORA splints: a comparison with untreated control subjects. Cranio. 2006;24:119–129.
10. Liu MQ, Chen HM, Yap AU, Fu KY. Condylar remodeling accompanying splint therapy: a cone-beam computerized tomography study of patients with temporomandibular joint disk displacement. Oral Surg Oral Med Oral Pathol Oral Radiol. 2012;114:259–265.
11. Summer JD, Westesson PL. Mandibular repositioning can be effective in treatment of reducing TMJ disk displacement. A long-term clinical and MR imaging follow-up. Cranio. 1997;15:107–120.
12. Simmons C 3rd. Temporomandibular joint orthopedics with anterior repositioning appliance therapy and therapeutic injections. J Calif Dent Assoc. 2014;42:537–547.
13. Tallents RH, Katzberg RW, Macher DJ, Roberts CA. Use of protrusive splint therapy in anterior disk displacement of the temporomandibular joint: a 1- to 3-year follow-up. J Prosthet Dent. 1990;63:336–341.
14. Eberhard D, Bantleon HP, Steger W. The efficacy of anterior repositioning splint therapy studied by magnetic resonance imaging. Eur J Orthod. 2002;24:343–352.
15. Chen HM, Fu KY, Li YW, Zhang ZK. Positional changes of temporomandibular joint disk and condyle with insertion of anterior repositioning splint. Hua Xi Kou Qiang Yi Xue Za Zhi. 2009;27:408–412.
16. Davies SJ, Gray RJM. The pattern of splint usage in the management of two common temporomandibular disorders. Part III: the anterior repositioning splint in the treatment of disc displacement with reduction. Br Dent J. 1997;183:199–203.
17. Drace JE, Enzmann DR. Defining the normal temporomandibular joint: closed-, partially open-, and open-mouth MR imaging of asymptomatic subjects. Radiology. 1990;177:67–71.
18. Ahmad M, Hollender L, Anderson Q, Kartha K, Ohrbach R, Truelove EL *et al.* Research diagnostic criteria for temporomandibular disorders (RDC/TMD) development of image analysis criteria and examiner reliability for image analysis. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2009;107:844–860.
19. Liu MQ, Lei J, Han JH, Yap AU, Fu KY. Metrical analysis of disc-condyle relation with different splint treatment positions in patients with TMJ disc displacement. J Appl Oral Sci. (accepted for publication).
20. Simmons HC. Guidelines for anterior repositioning appliance therapy for the management of craniofacial pain and TMD. Cranio. 2005;23:300–305.
21. Gokalp H. Magnetic resonance imaging assessment of positional relationship between the disc and condyle in asymptomatic young adult mandibular prognathism. Angle Orthod. 2003;73:550–555.
22. Fayed MM, El-Mangoury NH, El-Bokle DN, Belal AL. Occlusal splint therapy and magnetic resonance imaging. World J Orthod. 2004;5:133–140.
23. Moloney F, Howard JA. Internal derangements of the temporomandibular joint III. Anterior repositioning splint therapy. Aust Dent J. 1986;31:30–39.
24. Okeson JP. Long-term treatment of disk-interference disorders of the temporomandibular joint with anterior repositioning occlusal splints. J Prosthet Dent. 1988;60:611–616.
25. Kinzinger G, Kober C, Diedrich P. Topography and morphology of the mandibular condyle during fixed functional orthopedic treatment – a magnetic resonance imaging study. J Orofac Orthop. 2007;68:124–147.
26. Gateno J, Anderson PB, Xia JJ, Horng JC, Teichgraeber JF, Liebschner MA. A comparative assessment of mandibular condylar position in patients with anterior disc displacement of the temporomandibular joint. J Oral Maxillofac Surg. 2004;62:39–43.
27. Rammelsberg P, Jäger L, Duc JM. Magnetic resonance imaging-based joint space measurements in temporomandibular joints with disk displacements and in controls. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2000;90:240–248.
28. Kurita H, Ohtsuka A, Kobayashi H, Kurashina K. A study of the relationship between the position of the condylar head and displacement of the temporomandibular joint disc. Dentomaxillofac Radiol. 2001;30:162–165.
29. Major PW, Kinniburgh RD, Nebbe B, Prasad NG, Glover KE. Tomographic assessment of temporomandibular joint osseous articular surface contour and spatial relationships associated with disc displacement and disc length. Am J Orthod Dentofacial Orthop. 2002;121:152–161.
30. Ma Z, Xie Q, Yang C, Zhang S, Shen Y, Cai X. Changes in the temporomandibular joint space after functional treatment of disk displacement with reduction. J Craniofac Surg. 2015;26:e78–e81.

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