Innovations

Magnetic resonance T2 mapping in Temporomandibular Joints: comparison among different age groups- an observational study

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Abstract

Introduction : *Magnetic resonance imaging is a technique used to produce slice images of the human body with high contrast between various soft tissues, structures and/or organs. T2 relaxation time is a quantitative MR imaging parameter regularly used to detect degenerated cartilage in the knee and lumbar intervertebral disks. This study assessed the T2 character of normal TMJ disc and compared the T2 MRI mapping among different age groups.* ***Materials and method:*** *Thirty volunteers meeting the clinical inclusion criteria and morphologically normal TMJ images based on a conventional MR examination were recruited for this study. The imaging was performed using a 3.0T system using turbo spin echo sequences oriented in the oblique sagittal and oblique coronal planes, perpendicular and parallel to the transverse axis of the mandibular condyle in closed-mouth positions. Global and zonal region of interests were manually determined for each TMJ disc. Mean T2 values of the global and zonal ROIs of all the TMJ disks were determined.* ***Results :*** *The mean values of the disk (global disc area, superior, inner and inferior) were compared across the groups for both right and left sides using one way ANOVA. Turkey post Hoc test was applied to compare the mean values between individual groups. The T2 relaxation time increased as the age increased on an overall comparison but there was no significant difference between group B(30-39yrs) and group C(20-29yrs).* ***Conclusion :*** *The results of this study confirmed the preliminary findings that after age 40, there is an elevation in MRI T2 values in the TMJ. Given the dependency of cartilage T2 on anisotropy of the type II collagen matrix, these findings suggest that senescent changes of cartilage collagen begin near the articular surface and progress to the deeper cartilage with advancing age.*

Keywords: 1.*Temporomandibular joint,* ***2.****Magnetic resonance imaging,* ***3.*** *T2 mapping, Aging*

Introduction

A non-invasive diagnostic technique, Magnetic Resonance Imaging (MRI) provides excellent soft-tissue contrast with delineation of disc morphology and position. Additionally, the bony articular structures of the Temporomandibular Joint (TMJ), as well as joint effusion, can be evaluated. Highfield-strength MR systems operating at 3.0 T have been available for several years and have been increasingly used to

evaluate the TMJ. In a study of healthy TMJs, Stehling et al demonstrated that the use of 3.0 T scanners allowed for an improved analysis of the small joint structures. [1]

T2 weighted images are useful for detecting degenerative periarticular changes and the presence of a joint effusion. T2 mapping is a physiological cartilage mapping technique that has been used in studies of the hyaline cartilage of large joints and menisci. T2 mapping has a potential to quantitatively identify normal cartilage and the early stages of cartilage matrix degeneration that precedes visible morphological changes and can be used as a non-invasive detector of early changes in cartilage. Though there are literature evidences on age changes in temporomandibular joint, there are no much documentation on MR T2 mapping of normal TMJ in different age groups. Therefore, the T2 character of the TMJ disc needs to be explored. Our present study is aimed at determining the T2 character of normal TMJ disc and comparing T2 MRI mapping among different age groups.

Materials and methods

Thirty healthy volunteers (60 temporomandibular joints) who met the inclusion criteria were screened in the Outpatient Department of Oral Medicine and Radiology. The ethical approval for this prospective study was obtained from the institutional review board (SRMDC/IRB/2014/MDS/NO: 903). The following clinical inclusion criteria were used:(1) no history of a sign and/or symptom of TMD; (2) no history of trauma, infection, or surgery of the TMJ; (3) neither rheumatoid arthritis, tumor, nor other systemic disease that could affect the TMJ; (4) normal psycho-logical status assessed by the Research Diagnostic Criteria (RDC)/TMD axis II criteria (5) neither a sign nor symptom of TMD according to RDC/TMD axis I criteria. Patients who are not willing to participate and who are not eligible to undergo MRI examination were excluded from the study. The volunteers were grouped into three groups of different ages.

1) GROUP A: consisted of subjects between the age groups 40-50 years,

2) GROUP B: consisted of subjects between the age group of 30-39 years,

3) GROUP C: consisted of subjects in the age group of 20-29 years.

The sixty TMJ disks of thirty subjects who met the clinical inclusion criteria were referred for conventional MR imaging, which was performed using a 3.0-T SIEMENS MRI Scanner. Images were acquired using proton density–weighted turbo spin echo sequences oriented in the oblique sagittal and oblique coronal planes, perpendicular and parallel to the transverse axis of the mandibular condyle in closed mouth positions. The T2 images were evaluated by an experienced musculoskeletal radiologist who was blinded of the volunteer's clinical histories. The imaging parameters used in this study were: 1. TE:36 ms; 2. TR: 3400 ms; 3. Number of echoes, 11; 4. Slice thickness, 3–4 mm; 5. Slice gap, 1 mm; 6. FOV, 130x130,224x320 .

The source imaging data for T2 mapping were transferred to an advantage workstation of a 3.0-T system for off-line ROI selection and T2 value calculation. Global and zonal ROIs were manually determined for each TMJ disk by one experienced observer who was blinded to the volunteers. The global ROI was traced to include the whole disk area. The zonal ROIs were determined in two ways: first, the whole disk area was divided into superior, inner, and inferior layers with equal widths and thicknesses, and second, anterior, middle, and posterior bands were divided according to the TMJ disk's anatomical configuration. Caution was practiced to exclude intensity at the articulating surfaces of the disc. Mean T2 values (msec) of each ROI were calculated, and for visualization, graded colors were assigned to the ROIs. For each disc,

ROI selections were performed on three randomly selected slices of T2 images from the medial, middle, and lateral portions of the disc.

Statistical analysis: T2 values of the global and zonal ROIs of all the TMJ discs were determined. To compare the mean values between groups one way ANOVA was applied followed by Turkey's HSD post hoc tests for multiple pair wise comparisons. To compare mean values between left and right sides paired t-test was applied. SPSS version 22.0 is used to analyse the data. Significance level was fixed as 5% (α = 0.05).

Results

Preliminary determinations of T2 values for the bands and layers of normal TMJ discs were calculated. The T2 characters of both top-down spatial variation and anterior-posterior spatial variation was documented. The mean values of the disk (global disc area, superior, inner and inferior) were compared across the groups (A, B, C) for both right and left sides. There was a significant difference between the mean T2 values across the different age groups and within the group which is tabulated in TABLE1, 2, 3 and 4. Turkey post Hoc test was applied to compare the mean values between individual groups, were in Group A(4050yrs) had significant difference with Group C(20-29yrs.). But no significant difference with Group B(30-39yrs). Similarly, Group B (30-40yrs) had significant difference with Group C(20-29yrs). But no significant difference with Group A(40-50yrs). The data of comparison is presented in table 5 and 6.

One way ANOVA to compare mean values between Groups

Table 1: RT Side

Variables	Group	N	Mean	Std. Dev	F-Value	P-Value
Global Disc Area: Rt Side	Group -A	10	45.120	2.0826	22.961	<0.001
	Group -B	10	44.410	5.0234		
	Group -C	10	34.910	3.5906		
	Total	30	41.480	5.9659		
Superior: Rt Side	Group -A	10	47.620	2.7880	36.311	<0.001
	Group -B	10	41.340	4.8254		
	Group -C	10	33.850	2.8648		
	Total	30	40.937	6.7053		
Inner: Rt Side	Group -A	10	44.210	2.2093	21.886	<0.001
	Group -B	10	42.360	4.8576		
	Group -C	10	33.620	3.9214		
	Total	30	40.063	5.9728		
Inferior: Rt Side	Group -A	10	46.630	2.8087	19.473	<0.001
	Group -B	10	43.900	5.2751		
	Group -C	10	34.930	4.6911		
	Total	30	41.820	6.6146		
Anterior: Rt Side	Group -A	10	44.120	3.7691	8.838	0.001
	Group -B	10	45.640	3.3623		
	Group -C	10	37.900	5.6190		
	Total	30	42.553	5.4143		
Mid: Rt Side	Group -A	10	46.040	2.2257	12.636	<0.001
	Group -B	10	41.570	4.2421		
	Group -C	10	35.010	7.0801		
	Total	30	40.873	6.6262		
Posterior: Rt Side	Group -A	10	45.210	2.5645	16.020	<0.001
	Group -B	10	42.450	4.4528		
	Group -C	10	33.540	6.5769		
	Total	30	40.400	6.8755		

Table 2

Variables	Sum of Squares		df	Mean Square	F-Value	P-Value
Global Disc Area: Rt Side	Between Groups	649.994	2	324.997	22.961	<0.001
	Within Groups	382.174	27	14.155		
	Total	1032.168	29			
Superior: Rt Side	Between Groups	950.505	2	475.252	36.311	<0.001
	Within Groups	353.385	27	13.088		
	Total	1303.890	29			
Inner: Rt Side	Between Groups	639.861	2	319.930	21.886	<0.001
	Within Groups	394.689	27	14.618		
	Total	1034.550	29			
Inferior: Rt Side	Between Groups	749.346	2	374.673	19.473	<0.001
	Within Groups	519.502	27	19.241		
	Total	1268.848	29			
Anterior: Rt Side	Between Groups	336.355	2	168.177	8.838	0.001
	Within Groups	513.760	27	19.028		
	Total	850.115	29			
Mid: Rt Side	Between Groups	615.585	2	307.792	12.636	<0.001
	Within Groups	657.694	27	24.359		
	Total	1273.279	29			
Posterior: Rt Side	Between Groups	743.982	2	371.991	16.020	<0.001
	Within Groups	626.938	27	23.220		
	Total	1370.920	29			

Table 3

Variables	Group	N	Mean	Std. Dev	F-Value	P-Value
Global Disc Area: Lt Side	Group -A	10	45.480	3.5826	26.998	<0.001
	Group -B	10	42.890	5.0125		
	Group -C	10	32.430	3.8839		
	Total	30	40.267	7.0274		
Superior: Lt Side	Group -A	10	44.170	4.9829	14.870	<0.001
	Group -B	10	41.370	4.0738		
	Group -C	10	33.270	4.8187		
	Total	30	39.603	6.4932		
Inner: Lt Side	Group -A	10	44.550	3.2171	27.849	<0.001
	Group -B	10	40.800	4.4858		
	Group -C	10	32.180	3.5870		
	Total	30	39.177	6.4183		
Inferior: Lt Side	Group -A	10	45.060	3.2972	22.819	<0.001
	Group -B	10	40.910	4.9102		
	Group -C	10	33.280	3.4576		
	Total	30	39.750	6.2600		
Anterior: Lt Side	Group -A	10	44.580	4.7840	9.905	0.001
	Group -B	10	43.030	5.9841		
	Group -C	10	34.200	6.0218		
	Total	30	40.603	7.1479		
Mid: Lt Side	Group -A	10	43.800	5.8965	8.262	0.002
	Group -B	10	41.850	4.5339		
	Group -C	10	34.570	5.5321		
	Total	30	40.073	6.5566		
Posterior: Lt Side	Group -A	10	43.640	4.4207	13.011	<0.001
	Group -B	10	41.460	3.0134		
	Group -C	10	34.850	4.4370		
	Total	30	39.983	5.4261		

Table 4

Variables	Sum of Squares		df	Mean Square	F-Value	P-Value
Global Disc Area: Lt Side	Between Groups	954.741	2	477.370	26.998	<0.001
	Within Groups	477.406	27	17.682		
	Total	1432.147	29			
Superior: Lt Side	Between Groups	640.867	2	320.433	14.870	<0.001
	Within Groups	581.803	27	21.548		
	Total	1222.670	29			
Inner: Lt Side	Between Groups	804.613	2	402.306	27.849	<0.001
	Within Groups	390.041	27	14.446		
	Total	1194.654	29			
Inferior: Lt Side	Between Groups	714.026	2	357.013	22.819	<0.001
	Within Groups	422.429	27	15.646		
	Total	1136.455	29			
Anterior: Lt Side	Between Groups	627.053	2	313.526	9.905	0.001
	Within Groups	854.617	27	31.652		
	Total	1481.670	29			
Mid: Lt Side	Between Groups	473.313	2	236.656	8.262	0.002
	Within Groups	773.366	27	28.643		
	Total	1246.679	29			
Posterior: Lt Side	Between Groups	419.029	2	209.514	13.011	<0.001
	Within Groups	434.793	27	16.103		
	Total	853.822	29			

Tukey HSD post hoc tests for multiple pair wise comparisons

Table 5:

Variable	Group		Mean Difference	P-Value
Global Disc Area: Rt Side	Group -A	Group -B	.7100	0.907
		Group -C	10.2100	<0.001
	Group -B	Group -C	9.5000	<0.001
Superior: Rt Side	Group -A	Group -B	6.2800	0.002
		Group -C	13.7700	<0.001
	Group -B	Group -C	7.4900	<0.001
Inner: Rt Side	Group -A	Group -B	1.8500	0.533
		Group -C	10.5900	<0.001
	Group -B	Group -C	8.7400	<0.001
Inferior: Rt Side	Group -A	Group -B	2.7300	0.359
		Group -C	11.7000	<0.001
	Group -B	Group -C	8.9700	<0.001
Anterior: Rt Side	Group -A	Group -B	-1.5200	0.719
		Group -C	6.2200	0.010
	Group -B	Group -C	7.7400	0.001
Mid: Rt Side	Group -A	Group -B	4.4700	0.125
		Group -C	11.0300	<0.001
	Group -B	Group -C	6.5600	0.016
Posterior: Rt Side	Group -A	Group -B	2.7600	0.418
		Group -C	11.6700	<0.001
	Group -B	Group -C	8.9100	0.001

Tukey HSD post hoc tests for multiple pair wise comparisons

Table: 6

Variable	Group		Mean Difference	P-Value
Global Disc Area: Lt Side	Group -A	Group -B	2.5900	0.367
		Group -C	13.0500	<0.001
	Group -B	Group -C	10.4600	<0.001
Superior: Lt Side	Group -A	Group -B	2.8000	0.381
		Group -C	10.9000	<0.001
	Group -B	Group -C	8.1000	0.002
inner: Lt Side	Group -A	Group -B	3.7500	0.088
		Group -C	12.3700	<0.001
	Group -B	Group -C	8.6200	<0.001
Inferior: Lt Side	Group -A	Group -B	4.1500	0.066
		Group -C	11.7800	<0.001
	Group -B	Group -C	7.6300	0.001
Anterior: Lt Side	Group -A	Group -B	1.5500	0.813
		Group -C	10.3800	0.001
	Group -B	Group -C	8.8300	0.004
Mid: Lt Side	Group -A	Group -B	1.9500	0.697
		Group -C	9.2300	0.002
	Group -B	Group -C	7.2800	0.014
Posterior: Lt Side	Group -A	Group -B	2.1800	0.455
		Group -C	8.7900	<0.001
	Group -B	Group -C	6.6100	0.003

Discussion

Van Lehner et al and Rubenstein et al demonstrated the spatial variation of T2 values in healthy articular cartilage to be related to the different orientations of collagen fibres in different histologic layers of the cartilage or the magic-angle effect. Xia et al[12] in 2005 explained Magic angle effect. In articular cartilage with different histologic organization layers, cartilage layers with highly ordered collagen result in restricted motion of water protons binding to collagenous tissue, and this restriction effect tends to enhance the dipolar interaction of 2 spins and shorten T2 values. This dipolar interaction diminishes when the angle between the orientation of the static magnetic field (B0) and the prevailing orientation of the collagen fibres of the cartilage is equal to [13].74° (the magic angle). This is the so-called magic-angle effect. Thus, the magic-angle effect predicts certain spatial variations of T2 values in cartilage with different collagen anisotropies and collagen orientations at the standard perpendicular orientation of the cartilage surface relative to the B0.

Another finding of our study is that the T2 character of the TMJ disk has an anterior-posterior spatial variation. As described previously, in the thin superior and inferior surface histologic zones and the histologic zone between the inner zone and the thin surface zone, the collagen fibres are similarly arranged from anterior to posterior. In the thick inner zone of the disk (although the fibres are well organized), they have different orientations in the anterior, middle, and posterior bands.[14,15] In the anterior and posterior bands, the collagen fibres run primarily mediolaterally, whereas in the middle

band, the collagen fibres run primarily anteroposteriorly. [14,15] Different collagen orientations are believed to have different T2 values under the influence of the magic-angle effect.[16]

Thus, the anterior-posterior T2 spatial variation of the disk may be related to the collagen orientation variation in the thick inner layer of the anterior, middle, and posterior bands. Further in vitro studies that investigate the association between T2 spatial variations and the histologic bands of the discs are needed.

Of interest was the statistically significant smaller deformation of articular disc observed in the older cohorts, suggesting stiffer disc. Our Study was the first of its kind to compare the T2 values of the disc among different age groups. A potential cause of the increased cartilage stiffness is accumulation of advanced glycation end products and cross-linking of the collagen fibrils that occur with age which increase the stiffness of the collagen matrix and make the fibrils more prone to fatigue failure.[17,18] When comparing groups of younger cohorts, we did not observe a difference in cartilage deformation which is consistent with the results obtained by Mosher et al[19]. Because cartilage T2 values increase with increasing water content, a senescent decrease in the water content would not produce the observed increase in the cartilage T2 values in the older subjects. It is also possible that senescent loss of proteoglycans contributes to the greater variability in cartilage T2 values we observed in the subjects older than 40 years.

There is strong evidence to indicate that elevations in the cartilage T2 values are secondary to structural changes in the type II collagen matrix. With restricted water mobility, anisotropy of the collagen matrix provides an efficient mechanism for T2 relaxation, resulting in relatively short T2 times. Because of residual dipole interactions between collagen fibrils and cartilage water, the cartilage T2 time is very dependent on the orientation of the collagen fibre matrix relative to the applied magnetic field[20,21].Water located in highly anisotropic environments can be selectively detected using double-quantum–filtered spectroscopic imaging. In cartilage, strong quadrupolarsplitting resulting from this interaction is observed in the deep radial zone, with a smaller degree of splitting at the articular surface.[20]

Several studies have demonstrated a strong inverse correlation between cartilage T2 values and collagen fiber anisotropy identified with polarized light microscopy. Nieminen and coworkers[22] demonstrated an inverse correlation between T2 values and cartilage zones demonstrating optical birefringence. Xia et al have also established a strong inverse correlation between findings of polarized light microscopy and findings of spatially resolved cartilage T2 microscopy, and have shown that both techniques demonstrate similar changes during skeletal maturation. Grunder et al[23]has shown that the regional T2 response of cartilage to compressive loading is strongly correlated with regional changes in collagen fiber orientation as observed with polarized light microscopy. The strong dependency of cartilage T2 values on the highly ordered structure of the collagen matrix makes cartilage T2 mapping a sensitive, noninvasive technique for studying structural changes in the collagen matrix, providing information analogous to that provided with polarized light microscopy.

The findings of our study showing elevated T2 values in the TMJ of age group 40–50 years, are consistent with the results of previous histologic studies. The ability to monitor these changes noninvasively over time provides a method for identifying important cofactors that may influence collagen denaturation. Cartilage T2 mapping techniques such as those described here have been used with 3T clinical scanners and standard clinical hardware, with relatively minor software modifications. Because of the high sensitivity to structural changes in type II collagen, cartilage T2 mapping may be a

particularly useful technique for evaluating the efficacy of therapy targeted toward inhibition of collagen breakdown, such as matrix metalloproteinase inhibitors.

In future studies, it would be useful to compare the results of MRI T2 mapping with the findings of immuno histologic studies and serum biochemical markers of type II collagen degradation and cleavage.

Conclusion

In conclusion, the results of this study confirm our preliminary findings that after age 40, there is an elevation in MRI T2 values in the TMJ. The T2 relaxation time increased as the age increased on an overall comparison but there was no significant difference between group B(30-39yrs) and group C(20-29yrs). Given the dependency of cartilage T2 on anisotropy of the type II collagen matrix, these findings suggest that senescent changes of cartilage collagen begin near the articular surface and progress to the deeper cartilage with advancing age.

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