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Correlation Between Osseous Degenerative Changes on CBCT and Disc Displacement on MRI in Temporomandibular Joint Osteoarthritis

Korelacija između koštanih degenerativnih promjena na CBCT-u i dislokacije diska na MR-u u slučaju osteoartritisa temporomandibularnoga zgloba

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Abstract

Objective of work: Osteoarthritis (OA) of the temporomandibular joint (TMJ) is a degenerative condition affecting both osseous and soft-tissue structures. Cone beam computed tomography (CBCT) offers detailed visualization of osseous changes, while magnetic resonance imaging (MRI) provides superior assessment of soft tissues, particularly the articular disc. The relationship between bony degeneration and disc abnormalities remains poorly defined. This study examined the correlation between CBCT-identified osseous radiological features of TMJ OA and MRI-detected disc displacement patterns. **Materials and Methods:** A cross-sectional analysis was performed on 198 TMJs from 99 patients clinically diagnosed with TMJ OA, where both MRI and CBCT were performed in the same patient to enable direct comparative analysis. MRI was used to classify disc position as normal, partial displacement with reduction, complete displacement with reduction (DDR), or complete displacement without reduction (DDWR). CBCT scans were assessed for degenerative bone changes, including subchondral cysts, erosions, generalized sclerosis, osteophytes, and loose calcified bodies. OA severity was graded using the Ahmad and Schiffman criteria. Statistical evaluation was conducted using Fisher's Exact Test. **Results:** A statistically significant correlation was found between OA severity and disc displacement type ($p < 0.001$). DDWR was most frequently associated with Grade 2 OA (26.8%). Subchondral cysts ($p = 0.004$), erosions ($p < 0.001$), generalized sclerosis ($p < 0.001$), and osteophytes ($p < 0.001$) occurred with significantly higher prevalence in patients presenting with DDWR. Loose calcified bodies showed no significant association with disc position ($p = 0.191$). **Conclusions:** There is an association between degenerative osseous changes and disc displacement patterns in TMJ OA, and DDWR represents a more advanced stage of internal derangement accompanied by pronounced bone remodeling. These results support the combined use of CBCT and MRI for the comprehensive assessment of TMJ OA.

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Introduction

Temporomandibular joint (TMJ) disorders encompass a heterogeneous group of conditions affecting the joint complex, surrounding tissues, and associated anatomical structures. Among these, osteoarthritis (OA) represents a significant degenerative pathology characterized by progressive articular damage, resulting in pain, functional impairment, and restricted mandibular motion (1,2). While clinical examination provides valuable diagnostic information, comprehensive assessment of osteoarthritic changes and associated joint pathologies often necessitates advanced radiological imaging techniques (2,3,4).

Magnetic resonance imaging (MRI) is widely recognized as the gold standard modality for evaluating soft tissue components of the TMJ, particularly for assessing disc position, morphology, and associated soft tissue abnormalities (5,6). Standardized MRI protocols in open- and closed-mouth position allow assessment of disc-condyle relationships, which is crucial in the diagnosis of the most common intra-articular TMJ abnormality known as the internal derangement (7,8).

Conversely, cone beam computed tomography (CBCT) offers superior visualization of osseous structures, making it particularly valuable for detecting osteoarthritic bone changes, including erosions, osteophyte formation, subchondral cysts, generalized sclerosis, and loose calcified bodies (5,9). Emerging evidence suggests significant correlations between CBCT-detected degenerative changes and MRI-identified internal derangement, particularly anterior disc displacement (10).

Anterior disc displacement represents a common feature of TMJ disorders and has been implicated in the onset and progression of osteoarthritis. Displacement of the articular disc from its physiological position disrupts normal joint biomechanics, potentially leading to increased mechanical stress on bony components and accelerating the degenerative process characteristic for osteoarthritis (11,12). Joint effusion, frequently indicating synovial inflammation, may further complicate the clinical picture and serve as an early indicator of degenerative joint changes (13,9).

MRI demonstrates not only disc malposition but also marrow signal alterations and joint effusion that may reflect active degenerative or inflammatory processes (7,8).

Understanding the relationship between imaging findings across modalities holds substantial clinical importance for the diagnosis and management of TMJ OA. The integration of both CBCT and MRI provides clinicians with a comprehensive and accurate assessment of joint status, facilitating enhanced diagnostic precision and improved therapeutic decision-making (12,14). Although the precise cause-and-effect relationship between disc displacement and OA development continues to be investigated, current evidence strongly suggests that internal derangement significantly increases the risk of developing degenerative TMJ changes, with prevalence increasing with the duration and persistence of disc displacement (7,8,9,13).

The growing number of publications, questions remain regarding the strength and specificity of associations be-

Uvod

Poremećaji temporomandibularnog zgloba (TMZ) obuhvaćaju heterogenu skupinu stanja koja zahvaćaju zglobni kompleks, okolna tkiva i pripadajuće anatomske strukture. Među njima je osteoartritis (OA) značajna degenerativna patologija obilježena progresivnim oštećenjem zgloba, što rezultira bolovima, funkcionalnim oštećenjem i ograničenim kretanjama mandibule (1, 2). Iako klinički pregled pruža dragocjene dijagnostičke informacije, sveobuhvatna procjena osteoartritičnih promjena i povezanih patologija zgloba često zahtijeva primjenu naprednih tehnika radiološkog oslikavanja (2, 3, 4).

Magnetska rezonancija (MR) općeprihvaćena je kao zlatni standard u procjeni mekkih tkivnih komponenti TMZ-a, osobito za analizu položaja i morfologije diska te povezanih abnormalnosti mekih tkiva (5, 6). Standardizirani MR protokoli u položaju otvorenih i zatvorenih usta omogućuju procjenu odnosa diska i kondila, što je ključno za dijagnozu najčešće intraartikularne abnormalnosti TMZ-a poznate kao unutarnji poremećaj (engl. *internal derangement*) (7, 8).

Suprotno tomu, konusna kompjutorizirana tomografija (CBCT) omogućuje vrhunsku vizualizaciju koštanih struktura, što je čini posebno vrijednom za detekciju osteoartritičnih promjena na kostima, uključujući erozije, formiranje osteofita, subhondralne ciste, generaliziranu sklerozu i slobodna kalcificirana zglobna tijela (5, 9). Noviji dokazi upućuju na značajnu korelaciju između degenerativnih promjena otkrivenih CBCT-om i unutarnjih poremećaja identificiranih MR-om, posebice anteriorne dislokacije diska (10).

Anteriorna dislokacija diska često je obilježje poremećaja TMZ-a te se povezuje s pojavom i progresijom osteoartritisa. Pomak zglobnoga diska iz njegova fiziološkog položaja narušava normalnu biomehaniku zgloba, što potencijalno potiče povećano mehaničko opterećenje koštanih komponenti i ubrzava degenerativni proces karakterističan za osteoartritis (11, 12). Zglobni izljev, koji često upozorava na sinovijalnu upalu, može dodatno komplicirati kliničku sliku i služiti kao rani indikator degenerativnih promjena zgloba (13, 9).

MR ne prikazuje samo malpoziciju diska, nego i promjene signala koštane srži te zglobni izljev, što može odražavati aktivne degenerativne ili upalne procese (7, 8).

Razumijevanje odnosa između nalaza na različitim modalitetima oslikavanja od velike je kliničke važnosti za dijagnostiku i liječenje OA TMZ-a. Integracija CBCT-a i MR-a omogućuje kliničarima sveobuhvatnu i preciznu procjenu stanja zgloba jer olakšava dijagnostičku točnost i poboljšava donošenje terapijskih odluka (12, 14). Iako se precizan uzročno-posljedični odnos između dislokacije diska i razvoja OA-a i dalje istražuje, sve brojniji dokazi snažno sugeriraju da unutarnji poremećaj značajno povećava rizik od nastanka degenerativnih promjena TMZ-a, pri čemu prevalencija raste s trajanjem i stupnjem dislokacije diska (7, 8, 9, 13).

Unatoč sve brojnijim publikacijama, povezanost između pojedinih modela dislokacije diska i specifičnih degenerativnih koštanih promjena u kontekstu cjelokupnog stupnjevanja težine OA-a nije potpuno razjašnjena. Nadalje, klinička korisnost kombiniranih modaliteta oslikavanja u rutinskoj

tween particular disc displacement patterns and specific degenerative bone changes in the context of complete OA severity grading. Furthermore, the clinical utility of combined imaging modalities in routine TMJ OA assessment warrants further investigation. This study, therefore, aims to examine correlations between CBCT-detected bony structural changes and MRI-identified soft tissue abnormalities, particularly disc displacement patterns, in patients with clinically diagnosed TMJ OA.

Unlike previous correlation studies examining disc displacement and individual degenerative features, this study incorporates a systematic assessment of osteoarthritis severity using validated grading criteria, specifically examining the novel relationship between disc displacement patterns and OA grades.

We hypothesize that complete anterior disc displacement without reduction (DDWR) will demonstrate the strongest association with higher OA grades and the highest prevalence of specific degenerative bone changes reflecting the biomechanical consequences of altered joint loading patterns.

Enhanced understanding of these relationships is essential for improving diagnostic accuracy, treatment selection, and long-term management strategies for TMJ osteoarthritis.

Materials and Methods

Participants and Study Design

This cross-sectional observational study analyzed imaging data from 198 TMJs in patients clinically diagnosed with TMJ OA. Patients were recruited from the Department of Mobile Prosthetics, Faculty of Dental Medicine, University of Zagreb, and the Department of Diagnostic and Interventional Radiology, University Hospital Center 'Sisters of Charity' between 2013 and 2023. The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Ethics Committee [Approval No.: 05-PA-5-28/2024, date: 15.5.2024.]. Informed consent was obtained from all participants.

The study population comprised 99 patients (98 female patients and 1 male patient) with a mean age of 49.03 ± 2.3 years (range: 46.73–51.33 years). Patients with bilateral TMJ imaging ($n = 99$) contributed 198 joints to the analysis (99.0% female, 1.0% male) (Table 1). Bilateral TMJs from individual patients were analyzed independently at the joint level. Statistical analyses accounted for the potential clustering of observations from the same individual.

Inclusion criteria comprised: (1) clinical diagnosis of TMJ OA based on the presence of pain, joint sounds (clicking, crepitus), and/or limited mouth opening; (2) availability of both MRI and CBCT imaging of adequate diagnostic quality acquired in the same patient for direct comparative analysis; (3) age ≥ 18 years. Exclusion criteria included: (1) history of TMJ trauma or surgery; (2) systemic inflammatory arthropathies (e.g., rheumatoid arthritis, psoriatic arthritis); (3) previous TMJ infection; and (4) incomplete imaging datasets. Complete imaging datasets from both CBCT and MRI were required for inclusion; no missing data were present in the final study cohort.

procjeni OA-a TMZ-a zahtijeva daljnje istraživanje. Zato je cilj ovog istraživanja bio ispitati korelacije između koštanih strukturalnih promjena detektiranih CBCT-om i mekotkivnih abnormalnosti identificiranih MR-om, posebice modela dislokacije diska, kod pacijenata s klinički dijagnosticiranim OA-om TMZ-a.

Za razliku od dosadašnjih korelacijskih studija koje su ispitivale dislokaciju diska i pojedinačna degenerativna obilježja, u ovo istraživanje uključena je sustavna procjena težine osteoartrisa koristeći validirane kriterije stupnjevanja, specifično istražujući novu korelaciju između uzoraka dislokacije diska i stupnjeva OA.

Hipoteza je da će potpuna anteriorna dislokacija diska bez redukcije (DDWR) pokazati naj snažniju povezanost s višim stupnjevima OA-a i najvišom prevalencijom specifičnih degenerativnih koštanih promjena koje odražavaju biomehaničke posljedice izmijenjenih modela opterećenja zglobova.

Bolje razumijevanje tih odnosa ključno je za poboljšanje dijagnostičke točnosti, odabir liječenja i strategije dugoročnog upravljanja OA TMZ-a.

Materijali i metode

Sudionici i dizajn istraživanja

U ovoj opservacijskoj studiji presječnoga tipa analizirani su radiološki podatci 198 TMZ-ova kod pacijenata s kliničkim OA TMZ-om. Ispitanici su pacijenti u Zavodu za mobilnu protetiku Stomatološkog fakulteta Sveučilišta u Zagrebu te Kliničkog zavoda za dijagnostičku i intervencijsku radiologiju KBC-a Sestre milosrdnice od 2013. do 2023. godine. Istraživanje je provedeno u skladu s Helsinškom deklaracijom i odobrilo ga je Etičko povjerenstvo (broj odobrenja: 05-PA-5-28/2024, datum: 15. 5. 2024.). Svi sudionici potpisali su informirani pristanak. Studijska populacija obuhvatila je 99 pacijenata (98 žena i 1 muškarca) prosječne dobi $49,03 \pm 2,3$ godine (raspon: 46,73 – 51,33 godine). Budući da je svima učinjena obostrana dijagnostika TMZ-a, u analizu je uključeno ukupno 198 zglobova (99,0 % žena, 1,0 % muškaraca) (Tablica 1.). Lijevi i desni zglobovi svakog pacijenta analizirani su neovisno na razini zglobova, a statistička obrada uzela je u obzir potencijalni efekt grupiranja podataka istog pojedinca.

Kriteriji za uključenje bili su: (1) klinička dijagnoza OA-a TMZ-a temeljena na bolovima, zglobnim zvukovima (škljocanje, krepitacije) i/ili ograničenom otvaranju usta; (2) dostupnost MR i CBCT snimki odgovarajuće dijagnostičke kvalitete istog pacijenta radi izravne usporedbe i (3) dob ≥ 18 godina.

Kriteriji za isključenje bili su: (1) povijest traume ili kirurških zahvata na TMZ-u; (2) sistemske upalne artropatije (npr., reumatoidni artritis, psorijatični artritis); (3) prethodne infekcije TMZ-a i (4) nepotpuna radiološka dokumentacija. Za uključivanje su bili potrebni potpuni skupovi podataka s CBCT-a i MR-a, u konačnoj studijskoj kohorti nije bilo nedostajućih podataka.

MRI and CBCT scans of the TMJs were reviewed from the electronic archive at the Department of Diagnostic and Interventional Radiology, University Hospital Centre 'Sisters of Charity'. The images were stored in DICOM format on CD media and accessed via the ISSA system (ISSA Network Station Version 3.1, VAMSTEC d.o.o., Zagreb, Croatia) and Syngo fast View® (Siemens, Erlangen, Germany). Both systems are DICOM-compatible and support image viewing, analysis, and quantitative measurements.

Radiological images of the TMJ (a total of 198 joints imaged by CBCT and MRI) were analyzed for greater reliability by two independent readers (radiologists experienced in TMJ interpretation) who evaluated the images using pre-defined criteria. In case of disagreement in the interpretation, the images were re-evaluated, and discrepancies were resolved by consensus discussion.

Procedures

MRI Protocol

MRI examinations were performed using MAGNETOM Siemens Avanto 1.5T and Siemens MAGNETOM Aera 1.5T systems (Siemens, Germany) equipped with a dedicated TMJ surface coil. Both systems employed identical TMJ protocols to minimize technical variability. The imaging protocol included parasagittal view of the TMJ in the closed- and open-mouth position in different spin-echo sequences (T_1 -weighted images: echo time (TE) 9.4-15 milliseconds (ms), repetition time (TR) 380 - 410 ms, the field of view (FoV) 180×180 pixels/cm, and the matrix 410×512 pixels; T_2 -weighted images: TE 13 - 15 ms, TR 460 - 770 ms, FoV 180×180 pixels/cm, the matrix 224×320 and 128×256 pixels; proton density (PD): TE 90 ms, TR 2800 ms, FoV 160×160 pixels/cm, the matrix 320×320 pixels) as well as axial and coronal plane imaging (TE: 2.91 ms, FoV 240×240 pixels/cm matrix, TR 7 ms with a matrix of 384×512 pixels.)

MRI Assessment and Disc Displacement Classification

MRI scans were evaluated by 2 radiologists experienced in TMJ MRIs to determine disc position relative to the condyle. Disc position was classified according to established criteria (4,15) into the following categories:

- Normal disc position: The posterior band of the disc is aligned with the superior aspect of the condyle in the closed-mouth position, with the intermediate zone positioned between the condyle and articular eminence in the open-mouth position.
- Partial disc displacement with reduction: The disc is malpositioned within the mediolateral plane but reduces to a more normal position during mouth opening (16).
- Complete anterior disc displacement with reduction (DDR): The posterior band is displaced anterior to the 12 o'clock position relative to the condyle in the closed-mouth position, but the disc reduces to normal position during mouth opening.
- Complete anterior disc displacement without reduction (DDWR): The disc remains anteriorly displaced in both closed-mouth and open-mouth positions, failing to reduce during mandibular translation.

Sve radiološke snimke uzete su i pregledane iz elektroničkog arhiva KBC-a Sestre milosrdnice. Podatci pohranjeni u formatu DICOM analizirani su sustavima ISSA (VAMSTEC d.o.o., Zagreb, Hrvatska) i Syngo fast View® (Siemens, Erlangen, Njemačka). Oba sustava su DICOM-kompatibilna i podržavaju pregled slika, analizu i kvantitativna mjerenja.

Radiološke slike TMZ-a (ukupno 198 zglobova snimljenih CBCT-om i MR-om) analizirane su radi veće pouzdanosti od strane dva neovisna očitača (radiologa s iskustvom u interpretaciji TMZ-a) koji su analizirali slike koristeći unaprijed definirane kriterije. U slučaju neslaganja u interpretaciji, snimke su ponovno analizirane, a neslaganja su riješena konsenzusom.

Postupci

Protokol magnetske rezonancije (MR)

MR pregledi obavljani su na uređajima MAGNETOM Siemens Avanto 1,5T i Siemens MAGNETOM Aera 1,5T (Siemens, Njemačka), uz primjenu namjenske površinske zavojnice za TMZ. U primjeni obaju sustava bili su identični protokoli kako bi se tehnička varijabilnost svela na minimum. Protokol snimanja uključivao je parasagitalni prikaz TMZ-a u položaju zatvorenih i otvorenih usta u različitim spin-echo sekvencijama: T_1 -mjerene slike: vrijeme eha (TE) 9,4 – 15 ms, vrijeme ponavljanja (TR) 380 – 410 ms, vidno polje (FoV) 180 × 180 piksela/cm, matrica 410 × 512 piksela; T_2 -mjerene slike: TE 13 – 15 ms, TR 460 – 770 ms, FoV 180 × 180 piksela/cm, matrica 224 × 320 i 128 × 256 piksela. *Proton-density* (PD): TE 90 ms, TR 2800 ms, FoV 160 × 160 piksela/cm, matrica 320 × 320 piksela. Aksijalna i koronalna ravnina: TE 2,91 ms, FoV 240 × 240 piksela/cm, TR 7 ms uz matricu 384 × 512 piksela.

MR procjena i klasifikacija dislokacije diska

MR snimke analizirala su dva radiologa s iskustvom u očitavanju slikovnih nalaza TMZ-a kako bi odredili položaj diska u odnosu prema kondilu. Položaj diska klasificiran je prema utvrđenim kriterijima (4, 15) u sljedeće kategorije:

- Normalan položaj diska: stražnji rub diska poravnat je s vrhom kondila (položaj 12 sati) u položaju zatvorenih usta, a intermedijarna zona nalazi se između kondila i zglobne kvržice u položaju otvorenih usta.
- Djelomična dislokacija diska s redukcijom: disk je nepravilno postavljen u mediolateralnoj ravnini, ali vraća se u normalan položaj tijekom otvaranja usta (16).
- Potpuna anteriorna dislokacija s redukcijom (DDR): stražnji rub diska pomaknut je anteriorno u odnosu prema položaju 12 sati pri zatvorenim ustima, ali disk se vraća u fiziološki položaj tijekom otvaranja usta.
- Potpuna anteriorna dislokacija bez redukcije (DDWR): disk ostaje anteriorno pomaknut i u zatvorenom i u otvorenom položaju usta, bez redukcije tijekom mandibularne translacije.

Cone Beam Computed Tomography Protocol

CBCT imaging was performed on all participants using the J. Morita 3D Accuitomo system. Standard imaging protocol was deployed using a field of view (FOV) of 170.25 x 170.25 x 121 mm. Voxel size was 0.250 mm in all three planes, enabling the volumetric analysis. In terms of exposure parameters, tube current was 5.5 mA, and tube voltage was 90.0 kV. Average scan time was 121 ms. Dedicated reconstruction algorithm used 1 mm thick slices at 0.5 mm intervals.

CBCT Assessment of Degenerative Changes

CBCT images were systematically analyzed by 2 qualified radiologists for the presence of degenerative bone changes affecting the mandibular condyle and articular eminence. The following osseous abnormalities were documented (17,18):

- Subchondral cysts: well-defined radiolucent cavities located beneath the articular cortical bone.
- Erosions: discontinuity or irregularity of the cortical surface.
- Generalized sclerosis: increased bone density and thickening of cortical and trabecular bone, appearing as increased radiodensity on CBCT.
- Osteophytes: marginal bony outgrowths or protrusions extending from the articular surface.
- Loose calcified bodies: free-floating calcified fragments within the joint space, representing detached osteochondral or cartilaginous elements.

Osteoarthritis Grading

TMJ osteoarthritis was graded according to the classification system established by Ahmad and Schiffman (19):

- Grade 0: No degenerative changes evident.
- Grade 1: Mild OA characterized by osteophytes <2 mm, single erosion <2 mm in depth or width, and/or single subchondral pseudocyst <2 mm.
- Grade 2: Moderate to severe OA with osteophytes ≥2 mm, multiple erosions, erosions ≥2 mm, multiple subchondral cysts, and/or cysts ≥2 mm.

Statistical Analysis

Statistical analyses were performed using IBM SPSS v27.0. Descriptive statistics were calculated for demographic and clinical variables. Fisher's Exact Test was employed to assess associations between categorical variables, specifically examining correlations between disc displacement patterns and individual radiological features. Given the bilateral nature of TMJ analysis from individual patients (potential clustering effect), Fisher's Exact Test was selected as the appropriate non-parametric test. Statistical significance was set at $p < 0.05$.

Results

Correlation Between Osteoarthritis Grade and Disc Displacement

Out of 198 imaged joints (from 99 patients with bilateral imaging), grade 0 OA was found in 27 joints, grade 1

Protokol konusne kompjutorizirane tomografije

CBCT snimanje obavljeno je sustavom J. Morita 3D Accuitomo. Korišten je standardni protokol uz vidno polje (FOV) od 170,25 x 170,25 x 121 mm. Veličina vokseli iznosila je 0,250 mm u svim trima ravninama, što je omogućilo volumetrijsku analizu. Parametri ekspozicije bili su: struja cijevi 5,5 mA, napon cijevi 90,0 kV. Prosječno vrijeme skeniranja iznosilo je 121 ms. Za rekonstrukcijski algoritam upotrijebljeni su slojevi debljine 1 mm s razmacima od 0,5 mm.

CBCT procjena degenerativnih promjena

Dva iskusna radiologa sustavno su analizirala CBCT snimke kako bi detektirali degenerativne koštane promjene kondila i zglobne kvrčice. Dokumentirane su sljedeće koštane abnormalnosti (17, 18):

- Subhondralne ciste: jasno ograničena radiolucentna područja smještena ispod zglobne kortikalne kosti.
- Erozijske: prekid kontinuiteta ili nepravilnost kortikalne površine.
- Generalizirana skleroza: povećana gustoća kosti i zadebljanje kortikalne i trabekularne kosti, vidljivo kao pojačana radiogustoća na CBCT-u.
- Osteofiti: rubni koštani izdanci koji se šire sa zglobne površine.
- Slobodna kalcificirana zglobna tijela: slobodni kalcificirani fragmenti unutar zglobnog prostora koji čine odvojene osteohondralne ili hrskavične elemente.

Stupnjevanje osteoartritisa

OA TMZ-a stupnjevan je prema klasifikacijskom sustavu Ahmada i Schiffmana (19):

- Stupanj 0: nema vidljivih degenerativnih promjena.
- Stupanj 1: blagi OA karakteriziran osteofitima < 2 mm, pojedinačnom erozijom dubine ili širine < 2 mm i/ili pojedinačnom subhondralnom pseudocistom < 2 mm.
- Stupanj 2: umjereni do teški OA s osteofitima ≥ 2 mm, višestrukim erozijama, erozijama ≥ 2 mm, višestrukim subhondralnim cistama i/ili cistama ≥ 2 mm.

Statistička analiza

Statistička obrada obavljena je u programu IBM SPSS v27.0. Izračunata je deskriptivna statistika za demografske i kliničke varijable. Fisherov egzaktni test korišten je za procjenu povezanosti između kategoričkih varijabli, specifično za analizu korelacija između uzoraka dislokacije diska i pojedinih radioloških obilježja. S obzirom na bilateralnu analizu zglobova kod pojedinih pacijenata (potencijalni efekt grupiranja), Fisherov egzaktni test odabran je kao odgovarajući neparametarski test. Razina statističke značajnosti postavljena je na $p < 0,05$.

Rezultati

Korelacija između stupnja OA-a i dislokacije diska

Od 198 analiziranih zglobova (kod 99 pacijenata s obostranim oslikavanjem zglobova), OA stupnja 0 ustanovljen je u 27 zglobova, OA stupnja 1 u 86, a OA stupnja 2 u 85 zglobova.

Table 1 Baseline Demographic, Clinical and Imaging Characteristics
Tablica 1. Demografske, kliničke i radiološke značajke

Sample size • Veličina uzorka	Number of patients • Broj pacijenata	99
	Number of joints • Broj zglobova	198
Age distribution (in years) • Dobna distribucija (u godinama)	Mean age (95% confidence interval) • Prosječna dob (95 % interval pouzdanosti)	49.03 ± 2.3
	Lower bound • Donja granica	46.73
	Upper bound • Gornja granica	51.33
Sex distribution • Distribucija prema spolu	Female • Ženski	98 (196 joints • zglobova)
	Male • Muški	1 (2 joints • zglobova)
Inclusion criteria • Kriteriji za uključivanje	1. clinical diagnosis of TMJ OA; 2. both MRI and CBCT acquired in the same patient; 3. age ≥18 years. • 1. klinička dijagnoza OA TMZ-a; 2. učinjeni i MR i CBCT istom pacijentu; 3. dob ≥ 18 godina.	
Exclusion criteria • Kriteriji za isključivanje	1. history of TMJ trauma or surgery; 2. systemic inflammatory arthropathies; 3. previous TMJ infection; 4. incomplete imaging datasets • 1. trauma ili kirurški zahvat TMZ-a u anamnezi; 2. sistemske upalne artropatije; 3. prethodna infekcija TMZ-a; 4. nepotpuni radiološki podatci.	
OA Grade Distribution • Distribucija stupnja OA-e	Grade 0 • Stupanj 0	27 joints • zglobova (13.6%)
	Grade 1 • Stupanj 1	86 joints • zglobova (43.4%)
	Grade 2 • Stupanj 2	85 joints • zglobova (42.9%)
Disc Displacement Distribution • Uzorak pomaka diska	No displacement • Nema dislokacije	52 joints • zglobova (26.3%)
	Partial with reduction • Parcijalna dislokacija s redukcijom	29 joints • zglobova (14.6%)
	Complete with reduction (DDR) • Potpuna dislokacija s redukcijom (DDR)	42 joints • zglobova (21.2%)
	Complete without reduction (DDWR) • Potpuna dislokacija bez redukcije (DDWR)	75 joints • zglobova (37.9%)

Table 2 Association between osteoarthritis grade and disc displacement pattern. Data presented as joint-level analysis (n=198 TMJs from 99 patients). Bilateral TMJ pairs are presented independently. Percentages calculated relative to total joint count (N=198). Values reflect bilateral contributions.

Tablica 2. Povezanost stupnja osteoartritisa i uzorka dislokacije diska; podatci su prikazani na razini zglobova (N = 198 zglobova kod 99 pacijenata); lijevi i desni zglobovi analizirani su neovisno; postotci su izračunati u odnosu na ukupan broj zglobova (N = 198); vrijednosti odražavaju doprinos obaju zglobova svakog ispitanika

Disk Displacement • Dislokacija diska	Grade 0 • Stupanj 0	Grade 1 • Stupanj 1	Grade 2 • Stupanj 2	Stat. Significance (p) • Stat. značajnost (p)
None • Nema	12 (6.1%)	36 (18.2%)	4 (2.0%)	Fisher=68.097, p=0.000
Partial displacement with reduction • Parcijalni pomak s redukcijom	8 (4.0%)	11 (5.6%)	10 (5.1%)	
Complete displacement with reduction • Potpuni pomak s redukcijom	7 (3.5%)	17 (8.6%)	18 (9.1%)	
Complete displacement without reduction • Potpuni pomak bez redukcije	0 (0.0%)	22 (11.1%)	53 (26.8%)	
Total • Ukupno	27 (13.6%)	86 (43.4%)	85 (42.9%)	

Fisher's Exact Test • Fisherov egzaktni test: Fisher = 68.097, $p = 0.000$

OA was found in 86 joints, and grade 2 OA was found in 85 joints. Disc displacement without reduction (DDWR) was found in 75 joints, complete disc displacement with reduction (DDR) was found in 42 joints, partial disc displacement was found in 29 joints, and in 52 joints there was no disc displacement (Table 1).

A statistically significant correlation was observed between the degree of osteoarthritis and the pattern of disc displacement (Fisher = 68.097, $p < 0.001$) (Table 2). Complete anterior disc displacement without reduction (DDWR) was most frequently associated with Grade 2 OA, present in 53 joints (26.8% of the total sample) (Figure 1). Only four joints with grade 2 OA (2.0%) showed no displacement (Figure 2). Grade 1 OA showed heterogeneous distribution across disc displacement patterns and was most commonly observed in joints with either no disc displacement (36 joints, 18.2%) or DDWR (22 joints, 11.1%) (Figure 3). Most joints with grade 0 OA

bova. Dislokacija diska bez redukcije (DDWR) zabilježena je u 75 zglobova, potpuna dislokacija s redukcijom (DDR) u 42, djelomična dislokacija u 29 zglobova, a u 52 zglobova nije bilo dislokacije diska (Tablica 1.). Uočena je statistički značajna korelacija između stupnja OA-a i modela dislokacije diska (Fisher = 68,097, $p < 0,001$) (Tablica 2.). Potpuna anteriorna dislokacija diska bez redukcije (DDWR) najčešće je bila povezana s OA-om stupnja 2, što je zabilježeno u 53 zglobova (26,8 % ukupnog uzorka) (slika 1.). Samo četiri zglobova s OA-om stupnja 2 (2,0 %) nisu pokazivala dislokaciju (slika 2.). OA stupnja 1 pokazao je heterogenu distribuciju na temelju uzoraka dislokacije diska, a najčešće je uočen u zglobovima bez dislokacije diska (36 zglobova, 18,2 %) ili s DDWR-om (22 zglobova, 11,1 %) (slika 3.). Većina zglobova s OA-om stupnja 0 nije imala dislokaciju (12 zglobova, 6,1 %) (slika 4.). DDWR nije zabilježen ni u jednom zglobovu s OA-om stupnja 0.

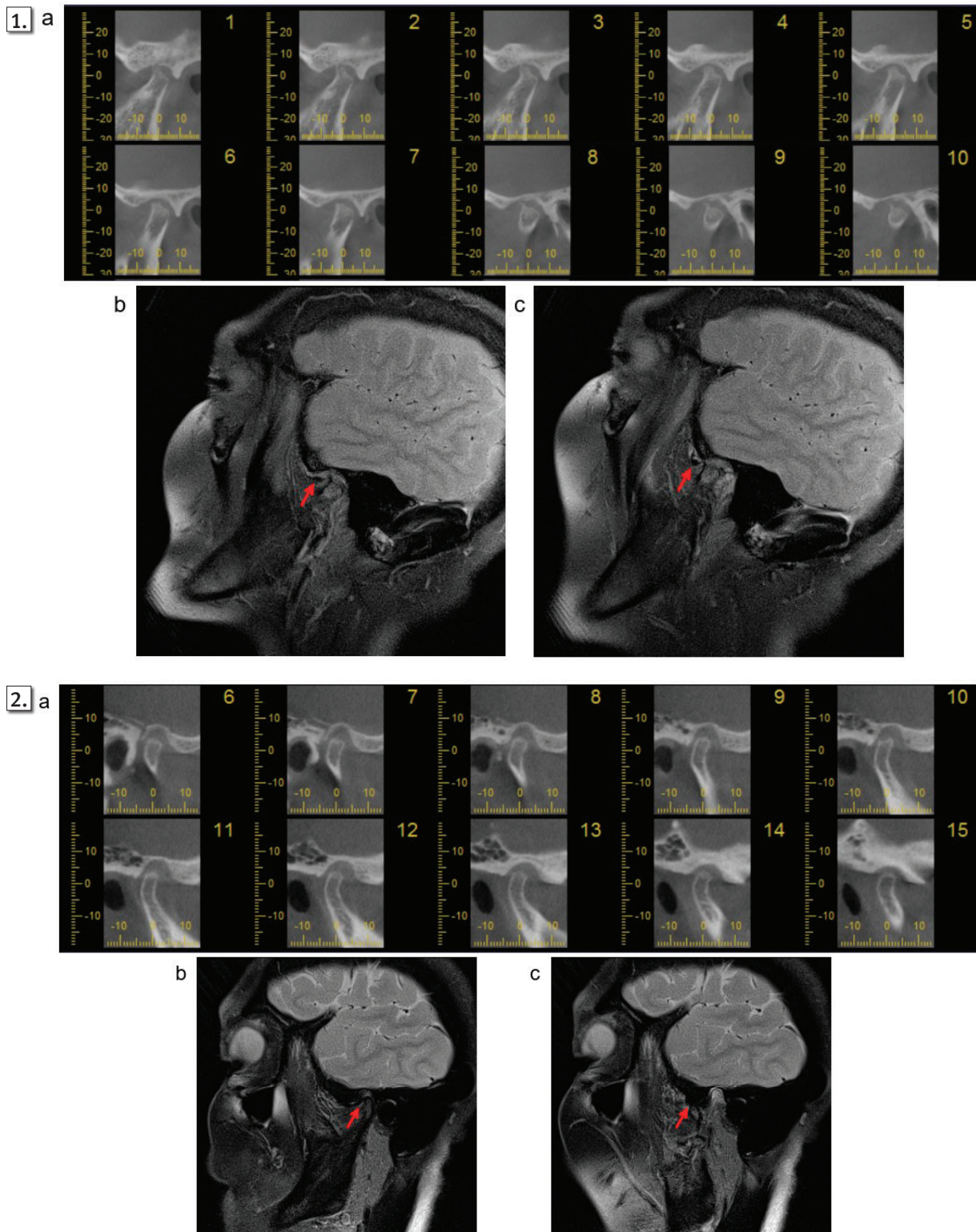


Figure 1 Grade 2 osteoarthritis (OA) and disc displacement without reduction (DDWR): a) CBCT showing marked osteophyte, subchondral sclerosis and condylar head erosion representing advanced degenerative changes; b) MRI proton density (PD) sequence in closed mouth and c) open mouth position demonstrates anteriorly displaced disk (red arrow).

Slika 1. Osteoarthritis (OA) stupnja 2 i dislokacija diska bez redukcije (DDWR): a) CBCT prikazuje izraženi osteofit, subhondralnu sklerozu i eroziju glave kondila, što je uznapredovala degenerativna promjena; b) MR sekvencija *proton density* (PD) u položaju zatvorenih usta i c) otvorenih usta prikazuje anteriorno dislocirani disk (crvena strelica)

Figure 2 Grade 2 osteoarthritis (OA) without disc displacement: a) CBCT showing significant degenerative changes with erosion of the condylar head greater than 2 mm; b) MRI proton density (PD) sequence in closed mouth and open mouth (c) position demonstrates normal position of the disk (red arrow).

Slika 2. Osteoarthritis (OA) stupnja 2 bez dislokacije diska: a) CBCT prikazuje značajne degenerativne promjene uz eroziju glave kondila veću od 2 mm; b) MR sekvencija PD u položaju zatvorenih usta i c) otvorenih usta prikazuje pravilan (fiziološki) položaj diska (crvena strelica)

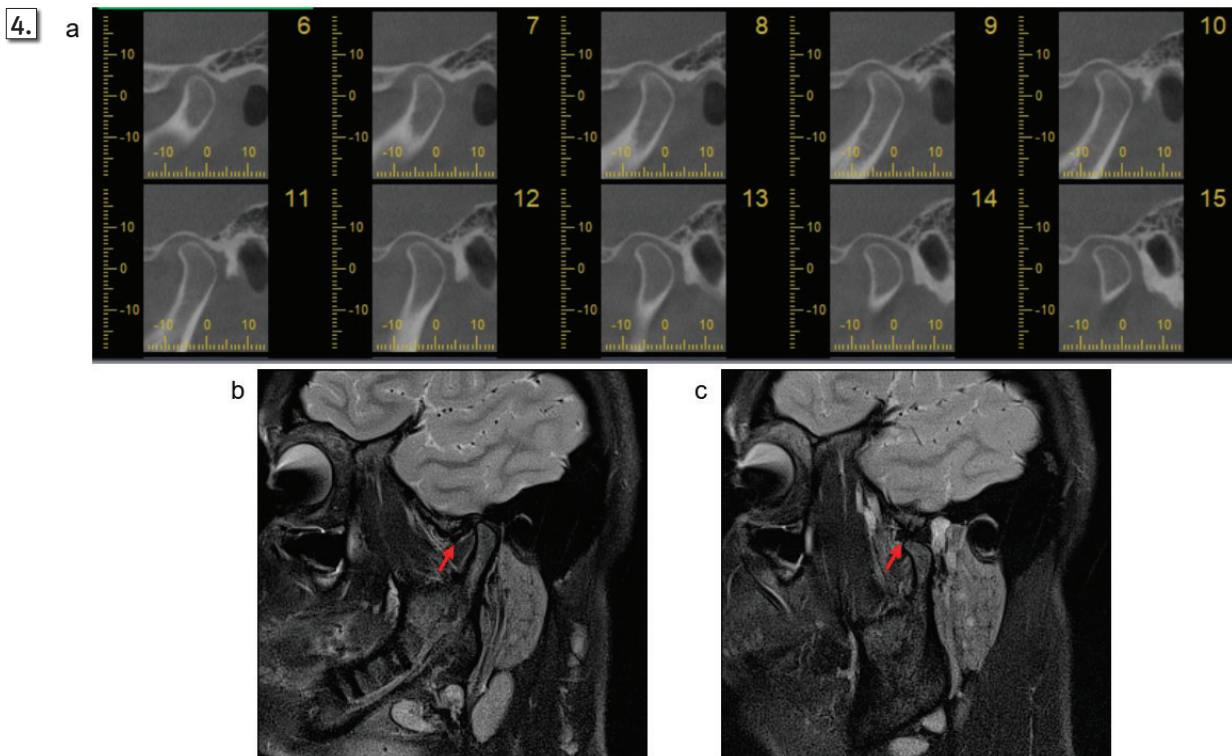
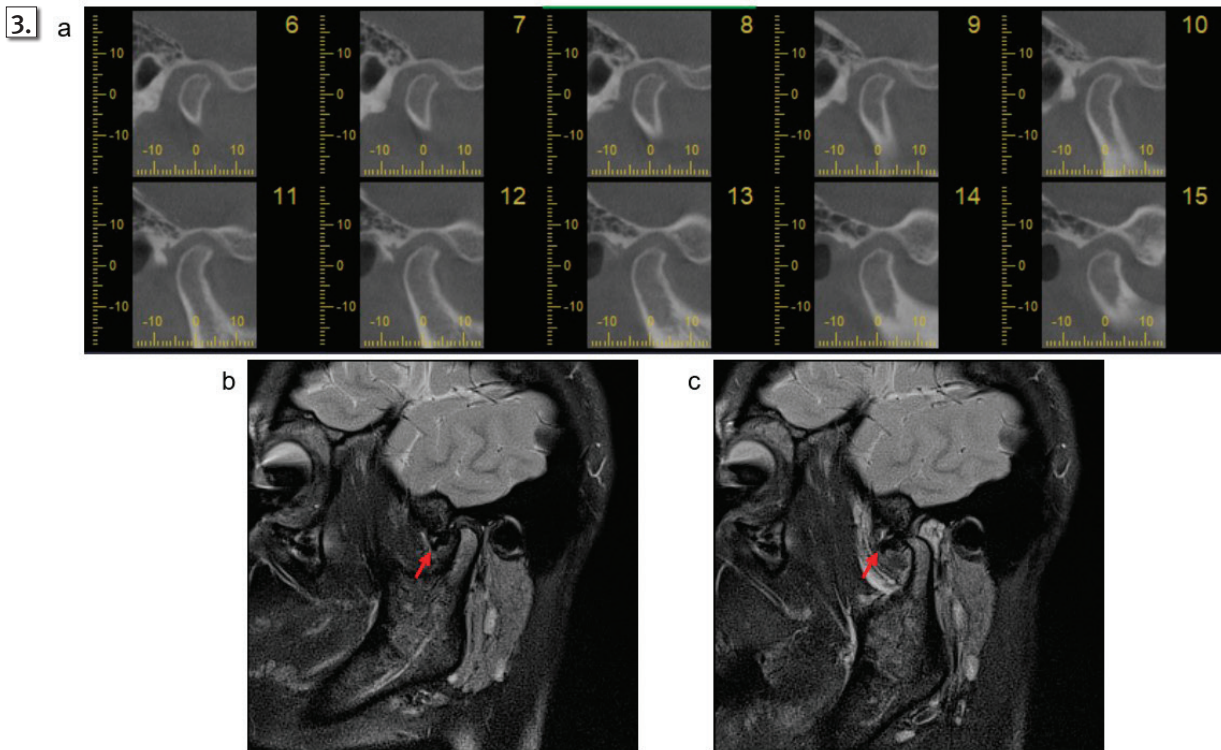


Figure 3 Grade 1 osteoarthritis (OA) and disc displacement without reduction (DDWR): a) CBCT showing mild degenerative changes with irregular contour of the condylar head representing small erosion; b) MRI proton density (PD) sequence in closed mouth and c) open mouth position demonstrates anteriorly displaced disk (red arrow).

Slika 3. Osteoarthritis (OA) stupnja 1 i dislokacija diska bez redukcije (DDWR): a) CBCT prikazuje blage degenerativne promjene uz iregularnu konturu glave kondila koja pokazuje manju eroziju; b) MR sekvencija PD u položaju zatvorenih usta i c) otvorenih usta prikazuje anteriorno dislocirani disk (crvena strelica)

Figure 4 Grade 0 osteoarthritis (OA) and disc displacement with reduction (DDR): a) CBCT showing normal appearance of the TMJ bony structures, without degenerative changes; b) MRI proton density (PD) sequence in closed mouth demonstrates anteriorly displaced disk (red arrow) that returns in normal position in open mouth position (c).

Slika 4. Osteoarthritis (OA) stupnja 0 i dislokacija diska s redukcijom (DDR): a) CBCT prikazuje uredan nalaz koštanih struktura TMZ-a, bez vidljivih degenerativnih promjena; b) MR sekvencija PD u položaju zatvorenih usta prikazuje anteriorno dislocirani disk (crvena strelica) koji se vraća u pravilan položaj pri otvorenim ustima (c)

showed no displacement (12 joints, 6.1%) (Figure 4). Complete anterior disc displacement without reduction (DDWR) wasn't described in any of the joints with grade 0 OA.

Note: All percentages were calculated based on joint-level analysis (N=198 joints) reflecting bilateral contributions from 99 patients.

Correlation Between Disc Displacement and Specific Bone Features of TMJ OA

Out of the degenerative bone changes, generalized sclerosis was the most frequent abnormality, present in 134 joints (67.7 %). The second most common finding, osteophytes, were present in 106 joints (53.5%), followed by subchondral cysts (68 joints, 34.3%), erosions (67 joints, 33.8%), and loose calcified bodies (5 joints, 2.5%).

Detailed analysis revealed significant associations of almost all individual radiological features with disc displacement patterns (Table 3). All of the specific radiologic features of OA were more commonly found in DDWR than in any other disc position category.

Subchondral cysts were significantly more prevalent in joints with DDWR (36 joints, 18.2%) compared to those with no displacement (9 joints, 4.5%), partial displacement with reduction (9 joints, 4.5%), or complete displacement with reduction (14 joints, 7.1%) (Fisher = 13,221, $p < 0.004$).

Erosions demonstrated a similar pattern, with markedly higher prevalence in DDWR (38 joints, 19.2%) compared to other displacement categories (Fisher = 17,923, $p < 0.001$).

Generalized sclerosis was most commonly observed in joints with DDWR (66 joints, 33.3%), showing a strong statistical association with this displacement pattern (Fisher = 27,695, $p < 0.001$).

Osteophytes exhibited the strongest correlation with disc displacement, being present in 57 joints (28.8%) with

Napomena: Podatci prikazani na razini zglobova (N = 198); bilateralni parovi TMZ-a analizirani su neovisno. Ukupni iznosi odražavaju bilateralne doprinose.

Korelacija između dislokacije diska i specifičnih koštanih obilježja OA TMZ-a

Među degenerativnim koštanim promjenama najčešća je bila generalizirana skleroza, zabilježena u 134 zgloba (67,7 %). Drugi najčešći nalaz bili su osteofiti u 106 zglobova (53,5 %), zatim subhondralne ciste (68 zglobova, 34,3 %), erozije (67 zglobova, 33,8 %) te slobodna kalcificirana zglobna tijela (5 zglobova, 2,5 %).

Tijekom detaljne analize otkrivena je značajna povezanost gotovo svih pojedinačnih radioloških obilježja s uzorcima dislokacije diska (tablica 3.). Sva specifična radiološka obilježja OA-a češće su pronađena u slučaju DDWR-a nego u bilo kojoj drugoj kategoriji položaja diska.

Subhondralne ciste bile su znatno češće u zglobovima s DDWR-om (18,2 %) u usporedbi s onima bez dislokacije (4,5 %) (Fisher = 13,221, $p < 0,004$).

Erozije su pokazale sličan obrazac s izrazito višom prevalencijom u slučaju DDWR-a (19,2 %) (Fisher = 17,923, $p < 0,001$).

Generalizirana skleroza najčešće je uočena u slučaju DDWR-a (33,3 %), uz snažnu statističku povezanost (Fisher = 27,695, $p < 0,001$).

Osteofiti su pokazali najsnažniju korelaciju s dislokacijom diska i pronađeni su u 28,8 % zglobova s DDWR-om (Fisher = 35,068, $p < 0,001$).

Suprotno tomu, slobodna kalcificirana tijela nisu pokazala statistički značajnu povezanost s uzorcima dislokacije diska (Fisher = 3,964, $p = 0,191$).

Table 3 Association between disc displacement patterns and each of the specific osseous degenerative change. Data presented as joint-level analysis (n=198 TMJs from 99 patients). Bilateral TMJ pairs are presented independently. Percentages calculated relative to total joint count (N=198). Values reflect bilateral contributions.

Tablica 3. Povezanost uzoraka dislokacije diska i specifičnih koštanih degenerativnih promjena; podatci su prikazani na razini zglobova (N = 198 zglobova kod 99 pacijenata); lijevi i desni zglobovi analizirani su neovisno; postotci su izračunati u odnosu na ukupan broj zglobova (N = 198); vrijednosti odražavaju doprinose obaju zglobova svakog ispitanika

Radiological Finding • Radiološki nalaz	No Displacement • Nema dislokacije	Partial Displacement with Reduction • Parcijalna dislokacija s redukcijom	Complete Displacement with Reduction • Potpuna dislokacija s redukcijom	Complete Displacement without Reduction • Potpuna dislokacija bez redukcije	Total • Ukupno
Subchondral cysts • Subhondralne ciste	9 (4.5%)	9 (4.5%)	14 (7.1%)	36 (18.2%)	68 (34.3%)
Total • Ukupno	52 (26.3%)	29 (14.6%)	42 (21.2%)	75 (37.9%)	198 (100%)
Erosions • Erozijske	9 (4.5%)	6 (3.0%)	14 (7.1%)	38 (19.2%)	67 (33.8%)
Total • Ukupno	52 (26.3%)	29 (14.6%)	42 (21.2%)	75 (37.9%)	198 (100%)
Generalized sclerosis • Generalizirana skleroza	30 (15.2%)	19 (9.6%)	19 (9.6%)	66 (33.3%)	134 (67.7%)
Total • Ukupno	52 (26.3%)	29 (14.6%)	42 (21.2%)	75 (37.9%)	198 (100%)
Osteophytes • Osteofiti	13 (6.6%)	12 (6.1%)	24 (12.1%)	57 (28.8%)	106 (53.5%)
Total • Ukupno	52 (26.3%)	29 (14.6%)	42 (21.2%)	75 (37.9%)	198 (100%)
Loose calcified bodies • Slobodna kalcificirana zglobna tijela	0 (0.0%)	1 (0.5%)	0 (0.0%)	4 (2.0%)	5 (2.5%)
Total • Ukupno	52 (26.3%)	29 (14.6%)	42 (21.2%)	75 (37.9%)	198 (100%)

DDWR, compared to substantially lower frequencies in other categories (Fisher = 35.068, $p < 0.001$).

In contrast, loose calcified bodies showed no statistically significant association with disc displacement patterns (Fisher = 3.964, $p = 0.191$).

Note: Data presented at joint-level (N=198); bilateral TMJ pairs analyzed independently. Totals reflect bilateral contributions.

Discussion

Association Between Disc Displacement and Osteoarthritis Severity

A significant association was observed between osteoarthritis (OA) grade and disc displacement pattern (Fisher's exact test = 68.097, $p < 0.001$). The osteoarthritis (OA) grade increased with increasing disc displacement grade.

More advanced OA was strongly associated with irreversible disc displacement. This is concordant with earlier findings by Cortés et al (20). Early stages of OA were characterized by either normal disc position or reducible displacement, whereas advanced OA was predominantly associated with complete displacement without reduction. This progression supports current understanding of the pathophysiology of TMJ OA, in which biomechanical considerations of internal derangement play a role in the development of OA.

The articular disc normally functions as a stress distributor and shock absorber, protecting the underlying bone from excessive loading during mandibular function (11). When displaced, particularly in DDWR, the altered load distribution leads to focal overload on areas of the condylar surface that are biomechanically unprepared for direct loading (13). This mechanical overload initiates a cascade of events, including chondrocyte apoptosis, disruption of the collagen type II and proteoglycan networks, and progressive loss of cartilage elasticity and integrity (17). Delpachitra and Dimitroulis emphasized that while disc displacement is not the sole etiological factor in TMJ OA, it contributes substantially to a degenerative cascade involving cartilage breakdown, subchondral bone remodeling, and synovial inflammation (12). The present findings support this multifactorial model, demonstrating that DDWR is associated with multiple concurrent degenerative changes rather than isolated pathology.

Furthermore, an important finding is that no joints with DDWR demonstrated the absence of OA. This may imply a complementary process in which ongoing degenerative changes within the joint may compromise disc integrity and mobility over time, leading to fixed disc displacement.

Specific Radiological Features and Their Correlation with Disc Displacement

The radiological markers of OA examined in this study—subchondral cysts, erosions, generalized sclerosis, and osteophytes—all demonstrated significantly higher prevalence in patients with DDWR. These findings are consistent with previous research demonstrating strong links between disc derangement severity and extent of osseous degeneration (5,9).

Napomena: Podatci prikazani na razini zglobova (N=198); bilateralni parovi TMJ-a analizirani su neovisno. Ukupni iznosi odražavaju bilateralne doprinose.

Rasprava

Povezanost dislokacije diska i stupnja OA-e

Uočena je značajna povezanost između stupnja OA-a i uzorka dislokacije diska (Fisher = 68,097, $p < 0,001$) pri čemu se stupanj OA-a povećavao s porastom stupnja pomaka diska. Uznapredovali OA bio je snažno povezan s pomakom diska bez redukcije. To je u skladu s ranijim nalazima Cortésa i suradnika (20). Rane faze OA-a obilježava ili normalni položaj diska ili pomak s redukcijom, a uznapredovali OA pretežno je bila povezana s potpunim pomakom bez redukcije. Ta progresija podupire trenutačno razumijevanje patofiziologije OA TMZ-a u kojoj su biomehanički čimbenici unutarnjeg poremećaja zgloba itekako važni u razvoju OA-e.

Artikularni disk normalno funkcionira kao distributer stresa i amortizer, štiteći podležecu kost od prekomjernog opterećenja tijekom kretanja mandibule (11). Kada je disk pomaknut, posebno u DDWR-u, izmijenjena raspodjela opterećenja rezultira fokusiranim preopterećenjem na područjima kondilarne površine koja biomehanički nisu pripremljena za izravno opterećenje (13). To mehaničko preopterećenje pokreće kaskadu događaja, uključujući apoptotsku smrt hondrocita, disruptivnost kolagena tip II i mreže proteoglikana, te progresivni gubitak elastičnosti i integriteta hrskavice (17). Delpachitra i Dimitroulis istaknuli su da, iako pomak diska nije jedini etiološki faktor u OA-u TMZ-a, značajno pridonosi degenerativnoj kaskadi koja uključuje razgradnju hrskavice, remodeliranje subhondralne kosti i sinovijalnu upalu (12). Sadašnji nalazi podupiru taj multifaktorijski model i pokazuju da je DDWR povezan s višestrukim istodobnim degenerativnim promjenama, a ne izoliranom patologijom.

Nadalje, važan nalaz jest da ni jedan zglob s DDWR-om nije prikazivao odsutnost OA-a. To može sugerirati komplementarni proces u kojemu trajne degenerativne promjene unutar zgloba mogu kompromitirati integritet i pokretljivost diska tijekom vremena te rezultirati fiksnim pomakom diska.

Specifične radiološke koštane značajke i njihova korelacija s pomakom diska

Radiološki biljezi OA-a koji su ispitivani u ovoj studij – subhondralne ciste, erozije, generalizirana skleroza i osteofiti – svi su pokazali značajno veću prevalenciju kod pacijenata s DDWR-om. Ti nalazi u skladu su s dosadašnjim istraživanjima u kojima se ističe snažna povezanost između stadija unutarnjeg poremećaja diska i opsega koštane degeneracije (5, 9). Westesson (1992.) i Rao i Bacelar (2004.) u svojim ključnim

Both Westesson (1992) and Rao & Bacelar (2004) in their pivotal works described TMJ OA as a potential consequence of longstanding internal derangement, particularly DDWR, and noted that chronic disc displacement may result in degenerative bony changes (7,8).

The most prevalent finding, generalized sclerosis, indicative of chronic mechanical stress and adaptive bone remodeling, was present in 134 (67.7%) of joints with DDWR, consistent with the observations of Roh et al. (13), who reported a fourfold increased OA risk in patients with DDWR.

Osteophyte formation exhibited the strongest correlation with DDWR joints (Fisher = 35.068, $p < 0.001$). This may confirm the previously suggested adaptive role of osteophytes as a stabilization mechanism in response to altered joint loading patterns (10).

The frequent co-occurrence of subchondral cysts and erosions with DDWR suggests an ongoing chronic degenerative process. Subchondral cyst formation likely reflects increased intraosseous pressure and synovial fluid intrusion into areas of compromised bone integrity (19). Erosions represent direct bone loss, potentially resulting from inflammatory mediators and enzymatic degradation of the bone matrix (14).

Previous investigations by Dias et al. (6) and Cortés et al. (20) reported similar associations, documenting high rates of condylar flattening, erosion, and osteophyte formation in TMJs affected by disc displacement without reduction, but no prior study analyzed the relationship with OA grade. The present study extends these observations by demonstrating statistically significant correlations across multiple specific radiological markers of degeneration, as well as the severity of OA.

The Role of Loose Calcified Bodies

Interestingly, no statistically significant correlation was observed between loose calcified bodies and disc displacement patterns (Fisher = 3.964, $p = 0.191$). This finding suggests that loose bodies may arise through alternative pathogenic mechanisms not directly related to disc displacement. Potential explanations include: (1) detachment of osteophytic fragments in advanced disease stages; (2) synovial chondromatosis, or (3) calcification of necrotic synovial tissue (18). The relative rarity of loose bodies in this cohort (2.5% overall) may also have limited statistical power to detect associations. Further research with larger sample sizes and longitudinal designs is warranted to clarify the pathogenesis of loose calcified bodies in TMJ OA.

Multimodal Imaging

Recent advances in understanding TMJ OA emphasize the importance of viewing this condition not merely as a radiographically detectable degenerative process, but as a multifactorial disorder involving complex interplay among mechanical, inflammatory, metabolic, and hormonal factors (17,19).

While CBCT provides excellent visualization of osseous structures and MRI offers insights into soft tissue status, the interpretation of findings from either modality in isolation may be incomplete. MRI can detect early soft tissue chang-

radovima opisali su OA TMZ kao potencijalnu posljedicu dugotrajne unutarnje smetnje, posebno DDWR-a, i uočili da kronični pomak diska može rezultirati degenerativnim koštanim promjenama (7, 8).

Najčešći nalaz, generalizirana skleroza koja upućuje na kronični mehanički stres i adaptivno remodeliranje kosti, bila je prisutna u 134 (67,7 %) zglobova s DDWR-om, što je u skladu s opažanjima Roha i suradnika (13) koji su izvijestili o četverostruko povećanom riziku od OA-a kod pacijenata s DDWR-om.

Formiranje osteofita pokazalo je najjaču korelaciju s DDWR zglobovima (Fisher = 35,068, $p < 0,001$). To može potvrditi prethodno sugeriranu adaptivnu ulogu osteofita kao mehanizma stabilizacije u odgovoru na izmijenjene uzorke opterećenja zgloba (10).

Česta koegzistencija subhondralnih cista i erozija s DDWR-om sugerira kontinuirani kronični degenerativni proces. Formiranje subhondralnih cista vjerojatno nastaje zbog povećanog pritiska unutar kosti i intruzije sinovijalne tekućine u područja kompromitiranoga koštanog integriteta (19). Erozijske su izravni gubitak kosti i potencijalno rezultat upalnih medijatora i enzimske degradacije koštanoga matriksa (14). Dias i suradnici (6) te Cortés i suradnici (20) u svojim su dosadašnjim istraživanjima izvijestili o sličnim asocijacijama, dokumentirajući visoke stope spljoštenja kondila, erozije i formiranja osteofita u TMZ-ovima s pomakom diska bez redukcije, ali ni u jednoj dosadašnjoj studiji nije analiziran odnos sa stupnjem OA-a. Sadašnja studija proširuje ta opažanja i pokazuje statistički značajne korelacije među višestrukim specifičnim radiološkim markerima degeneracije, kao i sa stupnjem OA-a.

Uloga slobodnih kalcificiranih zglobnih tijela

Zanimljivo je da nije uočena statistički značajna korelacija između slobodnih kalcificiranih tijela i uzoraka pomaka diska (Fisher = 3,964, $p = 0,191$). Taj nalaz sugerira da slobodna tijela mogu nastati alternativnim mehanizmima koji nisu izravno povezani s pomakom diska. Potencijalna objašnjenja uključuju: (1) odvajanje osteofitnih fragmenata u naprednijim fazama bolesti; (2) sinovijalnu osteohondromatozu, ili (3) kalcifikaciju nekrotičnoga sinovijalnog tkiva (18). Relativna rijetkost slobodnih tijela u ovoj skupini (2,5 % ukupno) također može ograničiti statističku moć za otkrivanje povezanosti. Daljnja istraživanja s većim uzorcima i longitudinalnim dizajnima potrebna su da bi se razjasnila patogeneza slobodnih kalcificiranih tijela u OA TMZ-u.

Multimodalno snimanje

Nedavni napredak u razumijevanju OA TMZ-a ističe važnost promatranja toga stanja ne samo kao radiografski detektabilnoga degenerativnog procesa, nego kao multifaktorijski poremećaj koji uključuje složenu interakciju između mehaničkih, upalnih, metaboličkih i hormonskih čimbenika (17, 19).

Dok CBCT omogućuje izvrsnu vizualizaciju koštanih struktura, MR daje uvid u stanje mekih tkiva, a izolirana interpretacija nalaza bilo kojeg modaliteta može biti nedostatna. MR-om se mogu detektirati rane promjene mekog tkiva

es such as disc displacement, deformation, and joint effusion that may precede or occur in the absence of CBCT-detectable bone changes (9). Conversely, CBCT-detected osteophytes and sclerosis may persist long after resolution of acute symptoms, representing stabilized chronic changes (10,17).

Molecular mechanisms underlying TMJ OA progression include vascular endothelial growth factor (VEGF)-mediated angiogenesis triggered by mechanical stress, which promotes vascular invasion into normally avascular cartilage while simultaneously activating matrix metalloproteinases (MMPs) and pro-degradative signaling cascades (18). These processes help explain how localized MRI abnormalities, particularly joint effusion and disc deformation, might temporally precede or exceed CBCT-detectable osseous changes in certain patients.

Sex Hormones and TMJ Osteoarthritis

The overwhelming female predominance observed in this study (99% female) reflects well-documented epidemiological patterns in TMJ disorders (3). Sex hormones, particularly estrogen, play modulatory roles in TMJ homeostasis. While estrogen appears to exert protective effects on subchondral bone density, elevated estrogen levels may paradoxically compromise cartilage integrity, potentially contributing to the higher prevalence of TMJ OA in women (12,21). The specific mechanisms underlying these sex-related differences warrant further investigation but likely involve estrogen receptor-mediated effects on cartilage metabolism, inflammatory responses, and pain perception (12).

Clinical Implications and Future Directions

The discrepancy between clinical symptoms and radiographic findings represents a major challenge in TMJ OA management. Many joints demonstrating advanced osseous changes on CBCT remain asymptomatic, while conversely, some patients with severe pain and dysfunction exhibit minimal radiographic abnormalities (16,22). This underscores the importance of multimodal imaging approaches and comprehensive clinical evaluation.

CBCT provides objective structural markers of disease chronicity and severity, while MRI detects active inflammation (joint effusion) and discal pathology that often correlate more closely with patient-reported symptoms (9,10). In cases where joint pain or otalgia (referred ear pain) does not correlate with imaging findings, referring physicians and radiologists should consider alternative etiologies of otalgia, including primary ear disorders, cervical pathology, or referred pain from other orofacial structures. Comprehensive imaging evaluation combined with a detailed history and physical examination is essential for accurate diagnosis.

Given the complexity and overlapping nature of TMJ disorders, combined CBCT and MRI imaging is recommended, particularly in patients presenting with clinical signs such as pain, joint sounds, or restricted mandibular motion (12). A multimodal imaging approach enhances diagnostic accuracy, facilitates disease staging, supports individualized treatment planning, and enables monitoring of disease progression and treatment response (12,14).

kao što su pomak diska, deformacija i zglobna efuzija koje mogu prethoditi ili se pojaviti u odsutnosti koštanih promjena detektabilnih CBCT-om (9). Istodobno, CBCT-om uočeni osteofiti i skleroza mogu postojati dugo nakon što se akutni simptomi povuku, i to su stabilizirane kronične promjene (10, 17).

Molekularni mehanizmi koji su u osnovi progresije OA TMZ-a uključuju angiogenezu posredovanu vaskularnim endotelnim faktorom rasta (VEGF) koja se pokreće mehaničkim stresom, koji potiče vaskularnu invaziju u normalno avaskularnu hrskavicu, a istodobno aktivira matriks metaloproteinaze (MMPs) i prodegradacijske signalne kaskade (18). Ti procesi pomažu objasniti kako lokalizirane MR abnormalnosti, posebno zglobna efuzija i deformacija diska, mogu vremenski prethoditi ili nadmašiti CBCT-om detektabilne koštane promjene kod određenih pacijenata.

Spolni hormoni i OA TMZ

Izražen udio žena u ovoj studiji (99 %) odražava dobro dokumentirane epidemiološke uzorke u poremećajima TMZ-a (3). Spolni hormoni, posebno estrogen, modulacijski djeluju u homeostazi TMZ-a. Dok se čini da estrogen ima zaštitne učinke na gustoću subhondralne kosti, povišene razine toga hormona mogu, paradoksalno, kompromitirati cjelovitost hrskavice i potencijalno pridonijeti višoj prevalenciji OA TMZ-a kod žena (12, 21). Specifični mehanizmi koji su u osnovi tih spolnih razlika zahtijevaju daljnja istraživanja, ali vjerojatno uključuju učinke posredovane receptorima za estrogen na metabolizam hrskavice, upalne odgovore i percepciju bolova (12).

Kliničke implikacije i buduće smjernice

Razlika između kliničkih simptoma i radiografskih nalaza velik je izazov u upravljanju OA-a TMZ-a. Mnogi zglobovi koji pokazuju uznapredovale koštane promjene na CBCT-u ostaju asimptomatski, a istodobno, kod nekih pacijenata s teškim bolovima i disfunkcijom zabilježene su minimalne radiografske abnormalnosti (16, 22). To pokazuje koliko je važan multimodalni pristup u snimanju i sveobuhvatna klinička evaluacija.

CBCT daje objektivne strukturne biljege kroničnosti i uznapredovalosti bolesti, a MR detektira aktivnu upalu (zglobna efuzija) i dislocirane patologije koje često bliže koreliraju sa simptomima na koje se pacijenti žale (9, 10). Onda kada bolovi u zglobovi ili otalgija (prenosiva bol u uhu) ne koreliraju s nalazima snimanja, kliničari i radiolozi trebaju razmotriti alternativne etiologije otalgije, uključujući primarne poremećaje uha, cervikalnu patologiju ili prenosive bolove iz drugih orofacijalnih struktura. Sveobuhvatna evaluacija snimanja u kombinaciji s detaljnom anamnezom i kliničkim pregledom ključna je za točnu dijagnozu.

S obzirom na složenost i preklapanje poremećaja TMZ-a, preporučuje se kombinirano snimanje CBCT-om i MR-om, posebno ako pacijenti pokazuju kliničke znakove kao što su bolovi, zvukovi u zglobovi ili ograničena pokretljivost mandibule (12). Multimodalni pristup snimanju poboljšava dijagnostičku točnost, olakšava procjenu stadija bolesti, podupire individualizirano planiranje liječenja te omogućuje

The findings demonstrate a clear relationship between disc displacement pattern and the severity of osteoarthritis. Although a clear association was observed, causality cannot be inferred due to the cross-sectional study design. Future research should prioritize longitudinal cohort studies to elucidate the temporal sequence of events in TMJ OA development and to identify early predictive markers of disease progression. Additionally, studies examining the relationship between imaging findings and patient-reported outcome measures will enhance understanding of the clinical relevance of radiological abnormalities.

Study Limitations

This study has several important limitations that warrant consideration:

Clustering Effect: While bilateral TMJs were analyzed independently at the joint level, observations from the same individual may share unmeasured clustering variables (e.g., genetic factors, systemic disease, occlusal characteristics), potentially inflating statistical associations. Future analyses incorporating multilevel statistical models accounting for patient-level clustering may provide more conservative estimates.

Selection Bias: This study enrolled patients with a clinical TMJ OA diagnosis from specialized dental medicine clinics, creating selection bias toward more severe or symptomatic disease compared to general population samples. Findings may not generalize to milder, asymptomatic TMJ pathology or population-based cohorts.

MRI System Variability: Imaging was performed using two different MRI systems (Siemens Avanto 1.5T and Siemens MAGNETOM Aera 1.5T). While both systems are comparable 1.5T machines using standardized TMJ protocols, potential variability in image quality, artifact patterns, and signal characteristics between systems may influence radiological assessments and reader interpretation.

Extreme Sex Distribution: The overwhelming female predominance (99% female, 1% male) reflects the known epidemiology of TMJ disorders but severely limits the generalizability of findings to male populations. Results may not be applicable to balanced sex-distributed cohorts or to males specifically.

Mitigation Factors: Strengths of the study include standardization of CBCT imaging to a single system (J. Morita 3D Accuitomo), use of validated grading criteria (Ahmad and Schiffman) to minimize subjective variation, and a two-reader consensus approach for discordant interpretations, all of which enhance the reliability and reproducibility of findings.

Conclusions

This study successfully demonstrates significant correlations between CBCT-identified radiological features of temporomandibular joint osteoarthritis and MRI-detected disc displacement patterns. The findings highlight the complex relationship between soft tissue derangement and osseous degeneration, with disc displacement without reduction

praćenje napredovanja bolesti i odgovora na liječenje (12, 14).

Nalazi pokazuju jasnu povezanost između uzoraka pomaka diska i stupnja OA-a. Iako je uočena jasna povezanost, uzročnost se ne može potvrditi zbog dizajna studije presjeka. U budućim istraživanjima trebalo bi prioritetizirati longitudinalne kohortne studije kako bi razjasnilo vremensku sekvenciju događaja u razvoju OA TMZ-a i identificirali rani prediktivni biljezi napredovanja bolesti. Također, studije u kojima se ispituje odnos između radioloških nalaza i ishoda koje prijavljuju pacijenti poboljšat će razumijevanje kliničke relevantnosti radioloških abnormalnosti.

Ograničenja studije

Ova studija ima nekoliko važnih ograničenja koja zahtijevaju razmatranje:

Klusterski efekt: iako su bilateralni TMZ-ovi analizirani neovisno na razini zgloba, opažanja dobivena od istog pojedinca mogu dijeliti neizmjerene klusterske varijable (npr., genetski čimbenici, sistemske bolesti, obilježja okluzije), potencijalno povećavajući statističke povezanosti. U budućim analizama koje će uključivati višerazinske statističke modele koji uzimaju u obzir klasteriranje na razini pacijenata mogle bi se dobiti konzervativnije procjene.

Selekcijska pristranost: u ovu studiju bili su uključeni pacijenti s kliničkom dijagnozom OA TMZ-a iz specijaliziranih stomatoloških klinika, stvarajući selekcijsku pristranost prema težim ili simptomatskim bolestima u usporedbi s uzorcima opće populacije. Nalazi se možda neće generalizirati na blaže, asimptomatske patologije TMZ-a ili kohorte zasnovane na populaciji.

Varijabilnost MR sustava: snimanje je obavljeno na dvama različitim sustavima MR-a (Siemens Avanto 1,5T i Siemens MAGNETOM Aera 1,5T). Iako su oba usporedivi uređaji zbog jakosti magnetskoga polja od 1,5T te su korišteni standardizirani protokoli za TMZ, potencijalna varijabilnost u kvaliteti slika, uzorcima artefakata i obilježjima signala između sustava može utjecati na radiološke procjene i interpretaciju.

Ekstremna distribucija spolova: neravnomjeran udio spolova (99 % žena, 1 % muškaraca) odražava poznatu epidemiologiju poremećaja TMZ-a, ali značajno ograničava generalizaciju nalaza na mušku populaciju. Rezultati se možda neće primijeniti na uravnotežene kohorte s raspodjelom spolova ili na muškarce posebno.

Čimbenici ublažavanja: snage studije uključuju standardizaciju CBCT snimanja na jedan sustav (J. Morita 3D Accuitomo) i korištenje valjanih kriterija ocjenjivanja (Ahmad i Schiffman) kako bi se smanjila subjektivna varijacija te pristup konsenzusa dvaju radiologa za neusklađene interpretacije, što sve poboljšava pouzdanost i ponovljivost nalaza.

Zaključak

U ovoj studiji uspješno je pokazana značajna korelacija između radioloških značajki OA TMZ-a identificiranih CBCT-om i uzoraka pomaka diska otkrivenih MR-om. U nalazima se ističe složena povezanost između unutarnjeg poremećaja zgloba, odnosno diska i koštane degeneracije, pri čemu je pomak diska bez redukcije (DDWR) snažno povezan

(DDWR) strongly associated with more severe degenerative bone changes, including subchondral cysts, erosions, generalized sclerosis, and osteophytes. The lack of significant association between loose calcified bodies and disc displacement warrants further investigation. MRI sensitivity to early soft tissue changes provides valuable diagnostic information that cannot be captured by CBCT alone, while CBCT remains essential for comprehensive assessment of osseous pathology. Given the complexity of TMJ OA and the variability in clinical presentation, a multimodal imaging approach combining CBCT and MRI is recommended for comprehensive joint assessment. Future longitudinal studies are needed to establish temporal relationships between imaging findings and to identify early predictive markers of disease progression.

Conflict of interest: no conflict of interest

Ethical Approval and Informed Consent: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Ethics Committee [School of Dental Medicine, University of Zagreb, Approval No.: 05-PA-5-28/2024, Date: 15.5.2024.]. Informed consent was obtained from all subjects involved in the study. [Consent for voluntary participation was obtained during the clinical and radiological work-up of the patients, so that they were given an Informed Consent Form before the start of the study (clinical examination and diagnostics, magnetic resonance imaging, and CBCT). The collection of diagnostic data from people with symptoms was approved by the Ethics Committee of the School of Dental Medicine Zagreb under the titles: Magnetic resonance in the diagnosis and therapy of temporomandibular disorders (2001, 2007) and The role of CBCT diagnostics in patients with osteoarthritis of the jaw joint (2018), from which a sample was collected for retrospective analysis.]

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Author contribution: M.P. - data collection and analysis, analysis of CBCT and MR images, figure and table preparation, writing of Abstract, Introduction, Materials and Methods, Results, Discussion, Conclusion and References, literature search; T.B. - clinical examination and data collection; B.B. - statistical and data analysis, table preparation, writing of Material and Methods; E.N.D. - help in literature search and writing; J.H. - help in literature search and writing; H.Ž. - consultations on data analysis; M.S.B. - analysis of CBCT and MR images; D.Z. - consultations on study design and writing.

s težim degenerativnim koštanim promjenama, uključujući subhondralne ciste, erozije, generaliziranu sklerozu i osteofite. Nedostatak značajne povezanosti između slobodnih kalkificiranih tijela i pomaka diska zahtijeva daljnja istraživanja. Osjetljivost MR-a na rane promjene mekog tkiva omogućuje vrijedne dijagnostičke informacije koje CBCT ne može zabilježiti, no CBCT ostaje ključan za sveobuhvatnu procjenu koštane patologije. Obzirom na složenost OA TMZ-a i varijabilnost u kliničkoj prezentaciji, za sveobuhvatnu procjenu zgloba preporučuje se multimodalni pristup snimanju koji kombinira CBCT i MR.

Buduće longitudinalne studije potrebne su da bi se utvrdile vremenske poveznice između radioloških nalaza i identificirali rani prediktivni biljezi napredovanja bolesti.

Sukob interesa: Autori nisu bili u sukobu interesa.

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Doprinos autora: M. P. – prikupljanje i analiza podataka, analiza CBCT i MR slika, priprema slika i tablica, pisanje sažetka, uvoda, materijala i metoda, rezultata, rasprave, zaključka i referencija, pretraživanje literature; T. B. – klinički pregled i prikupljanje podataka; B. B. – statistička i podatkovna analiza, priprema tablica, pisanje materijala i metoda; E. N. D. – pomoć u pretraživanju i pisanju literature; J. H. – pomoć u pretraživanju i pisanju literature; H. Ž. – konzultacije o analizi podataka; M. S. B. – analiza CBCT i MR slika; D. Z. – konzultacije o dizajnu i pisanju studije

Sažetak

Cilj rada: Osteoartritis (OA) temporomandibularnoga zgloba (TMZ) degenerativni je proces koji zahvaća i koštane strukture i meka tkiva. Dok konusna kompjutorizirana tomografija (CBCT) omogućuje precizan prikaz koštanih promjena, magnetska rezonancija (MR) zlatni je standard u procjeni mekih tkiva, posebice zglobnog diska. Povezanost između koštanih degenerativnih promjena i poremećaja položaja diska još uvijek nije u cijelosti razjašnjena. U ovom istraživanju ispitala se korelacija između CBCT-om identificiranih koštanih radioloških značajki OA TMZ-a i MR-om detektiranih obrazaca pomaka diska. **Materijali i metode:** Provedena je presječna studija na 198 TMZ-a kod 99 pacijenata s kliničkom dijagnozom OA-e. Kako bi se omogućila izravna komparativna analiza, za svakog je pacijenta učinjena dijagnostika i MR-om i CBCT-om. S pomoću MR-a položaj diska klasificiran je kao normalan, kao djelomična dislokacija s redukcijom, potpuna dislokacija s redukcijom (DDR) te potpuna dislokacija bez redukcije (DDWR). CBCT analizom ocjenjivane su degenerativne promjene poput subhondralnih cisti, erozija, generalizirane skleroze, osteofita i slobodnih zglobnih tijela. Stupanj OA-e određen je prema Ahmadovim i Schiffmanovim kriterijima, a statistička obrada podataka obavljena je Fisherovim egzaktim testom. **Rezultati:** Utvrđena je statistički značajna korelacija između stupnja progresije OA-e i tipa dislokacije diska ($p < 0,001$). Dislokacija bez redukcije (DDWR) najčešće je bila povezana sa stupnjem 2 OA-e (26,8 %). Prevalencija subhondralnih cisti ($p = 0,004$), erozija ($p < 0,001$), generalizirane skleroze ($p < 0,001$) i osteofita ($p < 0,001$) bila je značajno viša kod bolesnika s DDWR-om. Prisutnost slobodnih zglobnih tijela nije pokazala značajnu povezanost s položajem diska ($p = 0,191$). **Zaključak:** Postoji jasna povezanost između degenerativnih promjena kosti i obrazaca dislokacije diska kod OA TMZ-a. Ako se dijagnosticira DDWR, to stanje je napredniji stadij unutar-njeg poremećaja zgloba praćen intenzivnim koštanim remodeliranjem. Ti rezultati potvrđuju nužnost kombinirane primjene CBCT-a i MR-a za cjelovitu dijagnostičku procjenu OA TMZ-a.

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