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TMJ remodelling in response to clear aligner therapy: A Radiomic perspective

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ABSTRACT:

Temporomandibular joint (TMJ) remodelling during clear aligner therapy (CAT) has emerged as a critical area of interest due to its implications for orthodontic biomechanics, treatment planning, and patient safety. While CAT delivers lighter, intermittent forces that may exert a protective effect on TMJ function compared with fixed appliances, subtle osseous and soft-tissue adaptations often remain undetectable through conventional imaging. Radiomics a quantitative technique that extracts high-dimensional features from CBCT and MRI offers a transformative approach to identifying microstructural changes in condylar morphology, cortical integrity, trabecular patterns, and disc-related alterations. By integrating radiomics with digital orthodontic workflows, clinicians can achieve early risk stratification, personalized force staging, and more precise monitoring of TMJ adaptation throughout treatment. However, variability in imaging protocols and segmentation methods highlights the need for standardized pipelines and multicentre validation. Radiomics-driven biomarkers hold promise for enhancing decision-making and advancing precision orthodontics.

Keywords: TMJ Remodelling, Clear Aligner Therapy, Radiomics, CBCT, MRI

Introduction

Temporomandibular joint (TMJ) function plays a crucial role in maintaining normal craniofacial biomechanics, and disorders affecting the joint are common among orthodontic patients, with reported prevalence ranging from 12% to over 30%, particularly in those with malocclusions.[1] Although the relationship between orthodontic treatment and TMD remains debated, orthodontic tooth movement can alter occlusion and mandibular positioning, thereby influencing TMJ loading and potentially triggering adaptive remodelling; however, existing evidence is mixed, with some studies suggesting slightly increased odds of TMD (OR ~1.8) and others reporting no significant association.[2] The rapid rise of clear aligner therapy (CAT) has renewed interest in this discussion, as aligners deliver intermittent, controlled, and generally lighter forces compared to the continuous, bracket-based forces of fixed appliances, potentially minimizing muscular strain and modifying TMJ loading patterns.[3] Several clinical observations indicate that CAT may help reduce or avoid exacerbation of TMD symptoms possibly due to its occlusal-splint-like effect and more physiologic force delivery highlighting its biomechanical advantages.[4] At the same time, traditional imaging assessments of the TMJ rely on linear and volumetric morphometrics, which are insufficient for capturing subtle microstructural changes occurring during orthodontic treatment.[5] Radiomics offers a transformative alternative by extracting high-dimensional features related to texture, intensity, and shape from CBCT or MRI, enabling detection of early or nuanced remodelling changes in bone and soft tissues that are not visible through conventional analysis. This integrative perspective highlights the importance of understanding TMJ adaptation during orthodontic treatment, the potential protective role of clear aligners in minimizing joint strain, and the emerging value of radiomics in providing sensitive, quantitative biomarkers for personalized monitoring of TMJ responses throughout orthodontic care.[6]

Biomechanical Characteristics of Clear Aligner Therapy and Their Influence on TMJ Loading

Clear Aligner Therapy (CAT) operates through a fundamentally different biomechanical paradigm compared to fixed appliances, as forces are generated by the elastic rebound of polymer aligner shells closely adapted to tooth crowns and attachments, producing distributed pushing forces rather than the continuous, wire-derived forces applied near the center of resistance in traditional braces.[7] These aligner-based forces are characteristically intermittent due to wear patterns of approximately 20–22 hours per day and tend to be lower, more variable, and less directionally precise because of material stress relaxation, aligner thickness, and subtle fit discrepancies. As a result, CAT more readily induces tipping and intrusion movements, while bodily translation, torque, and root control often require strategic use of composite attachments and carefully sequenced staging to enhance biomechanical efficiency.[8] These distinct force dynamics translate into unique TMJ loading patterns: intermittent, gentle forces and reduced continuous occlusal interference may lower muscular strain and joint loading fluctuations, while the full-arch, splint-like nature of aligners may contribute to a more stable mandibular posture with potential protective effects on TMJ function.[9] However, the propensity for uncontrolled tipping or occlusal alterations in poorly planned CAT cases may conversely influence mandibular dynamics and modulate TMJ forces in unintended ways. Clinically, this suggests that CAT may reduce TMJ stress and TMD symptoms relative to fixed appliances, yet still demands meticulous treatment planning, attachment design, and occlusal monitoring. Radiomic evaluation of TMJ tissues and joint spaces offers an advanced means to capture these subtle biomechanical adaptations, providing sensitive imaging biomarkers to guide personalized orthodontic care.[10]

Imaging Modalities for TMJ Remodelling Assessment

Evaluating TMJ remodelling requires a multimodal imaging approach because each modality offers unique advantages and inherent limitations. Cone Beam Computed Tomography (CBCT) is highly effective for assessing osseous components of the TMJ, providing detailed three-dimensional visualization of condylar morphology, cortical integrity, and joint space dimensions with relatively low radiation exposure and rapid acquisition; however, it lacks soft tissue contrast and its resolution varies with voxel size, limiting assessment of the disc and inflammatory changes.[11] Magnetic Resonance Imaging (MRI), by contrast, is the gold standard for soft tissue evaluation, allowing precise visualization of disc position, morphology, joint effusion, and inflammatory changes, as well as dynamic assessment of disc movement, though it is costlier, slower, and less capable of capturing fine bony detail compared to CBCT. Ultrasound serves as a radiation-free, accessible adjunct for assessing superficial soft tissues, such as disc displacement and muscle pathology, but remains operator-dependent and unable to reliably visualize deeper bony structures.[12] Functional imaging modalities like SPECT and PET can detect inflammatory or metabolic activity and may help identify early degenerative changes, though their use in routine orthodontic TMJ evaluation is limited. Traditional two-dimensional radiographs such as panoramic or transcranial views provide minimal diagnostic value because of structural superimposition and inability to capture three-dimensional joint relationships.[13] In contrast, modern 3D and voxel-based morphometric analyses, paired with radiomic feature extraction, offer substantial improvements in detecting subtle remodelling by quantifying microstructural bone and soft-tissue changes beyond the capability of conventional measurements.[14]

Radiomics Framework for Advanced TMJ Remodelling Assessment

Radiomics offers a powerful, data-driven approach to TMJ evaluation by extracting high-dimensional quantitative features from segmented joint structures, enabling detection of subtle remodelling or early pathology that conventional morphometrics may overlook. The process begins with standardized image acquisition typically CBCT for osseous detail or MRI for soft-tissue evaluation followed by voxel harmonization and pre-processing steps such as isotropic resampling, denoising, and intensity normalization to reduce variability across scanners and imaging sessions.[15] Accurate segmentation of regions of interest, including the condyle, glenoid fossa, cortical shell, and marrow, is essential but challenging due to thin cortical plates, partial-volume artifacts, and limited disc visibility on CBCT, often requiring manual or semi-automated methods supported by expert review. Feature extraction then generates a comprehensive set of descriptors, including first-order intensity metrics, shape parameters, and advanced texture features derived from matrices such as GLCM, GLRLM, and GLSZM, along with wavelet-based features capturing spatial frequency details.[16] Because radiomic datasets are high dimensional, feature selection techniques such as ICC-based stability testing, correlation filtering, LASSO, or PCA are crucial to isolate robust, non-redundant predictors before building diagnostic or prognostic models using statistical or machine-learning algorithms, ideally paired with explainability tools to interpret feature relevance. Rigorous validation through cross-validation, external datasets, test–retest studies, and phantom assessments ensures reproducibility and clinical applicability. Adhering to IBSI guidelines, TRIPOD/REMARK reporting standards, and maintaining adequate sample sizes further strengthens methodological rigor.[17] TMJ-specific considerations include anatomical complexity, the need for multimodal imaging to overcome limitations of individual modalities, harmonization strategies such as ComBat for multi-center datasets, and ethical justification of repeated CBCT exposure. When applied effectively, this radiomics workflow enables sensitive, quantitative tracking of TMJ remodelling during orthodontic interventions such as clear aligner therapy, supporting personalized treatment planning and advancing understanding of joint biomechanics.[18]

Practical Considerations for Radiomics Evaluation

From a radiomics perspective, practical challenges arise in achieving accurate and reproducible TMJ segmentation due to anatomical complexity, thin cortical structures, partial-volume artifacts, and the limited ability of CBCT to visualize the articular disc, often necessitating MRI integration; recent deep-learning models such as CNNs and YOLOv5 are increasingly enabling automated, high-fidelity 3D segmentation to reduce observer variability.[19] Optimal imaging selection remains critical CBCT serves as the preferred modality for bone-based radiomics owing to its high spatial resolution, whereas MRI is superior for extracting radiomic features from soft tissues, including the disc and masticatory muscles, with multimodal radiomics offering a more holistic assessment when supported by careful cross-modality registration. To ensure feature reproducibility across scanners and protocols, harmonization methods such as ComBat correction, intensity standardization, and modelling of vendor-related covariates are essential, alongside rigorous test–retest and inter-rater reliability analyses.[20] Ethical considerations are equally important, as repeated CBCT scans elevate cumulative radiation exposure, particularly in younger populations; this necessitates the use of low-dose protocols and clinically justified imaging intervals, with MRI serving as a safer but less accessible alternative.[21]

Radiomic Biomarkers in TMJ-Centered Clear Aligner Therapy

Radiomic biomarkers hold substantial potential to transform precision orthodontics by enabling early TMJ risk stratification, personalized force staging, and optimized monitoring of joint remodeling during clear aligner therapy. By extracting high-dimensional quantitative features from CBCT and MRI, radiomics can detect subtle, preclinical alterations in condylar morphology, cortical density, trabecular architecture, and soft-tissue integrity that signal susceptibility to adverse TMJ outcomes, allowing orthodontists to individualize aligner force levels, sequencing, and staging to minimize joint loading.[22] A major advantage lies in seamless integration with digital orthodontic workflows, where radiomic data can be embedded into aligner treatment-planning platforms to simulate force vectors, predict joint response, and generate adaptive feedback loops enabling real-time treatment modifications. Multimodal radiomics combining CBCT-derived bony metrics with MRI-based soft-tissue signatures provides a comprehensive view of TMJ remodeling, facilitating more informed decision-making on force application timing and intensity.[23] To translate these innovations clinically, prospective multicenter longitudinal cohorts, robust external validation, and automated deep-learning-driven segmentation pipelines are essential to ensure reproducibility and scalability.[24] Furthermore, coupling radiomic biomarkers with finite element analysis and biomechanical modeling can elucidate mechanobiological pathways linking imaging-derived features to actual joint loading patterns, enriching the scientific understanding of TMJ response to orthodontic forces. Explainable AI frameworks will be critical for clinical trust, clarifying which features influence predictions and enabling transparent, interpretable decision-support tools.[25]

Conclusion

Radiomics offers a transformative approach to understanding and managing TMJ remodeling during clear aligner therapy (CAT) by detecting subtle, high-dimensional imaging biomarkers that conventional methods overlook. Integrating TMJ biomechanics, multimodal imaging (CBCT for bone, MRI for soft tissue), and standardized radiomic workflows enables precise risk stratification for TMD, customized force staging to minimize joint loading, and adaptive monitoring within digital orthodontic platforms. Future directions emphasize multimodal radiomics, robust automation, and biomechanical integration to enable precision orthodontics, reducing TMD prevalence and enhancing outcomes in CAT patients.

References:

1. Sharab L, Shafi A, Butul B, Okeson JP. Clear aligner therapy and symptoms of temporomandibular disorders: a case report. Gen Dent. 2024 Nov-Dec;72(6):47-52. PMID: 39451089.
2. Rustia, Samantha & Lam, Jeffrey & Tahir, Peggy & Kharafi, Lateefa & Oberoi, Snehlata & Ganguly, Rumpa. (2022). Three-dimensional morphologic changes in the temporomandibular joint in asymptomatic patients who undergo orthodontic treatment: A systematic review. Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology. 134. 10.1016/j.oooo.2022.05.003.
3. Pinho, T.; Marcelino, V.; Gonçalves, M.; Azevedo, R.M.S.; Rocha, D.; Paço, M. The Impact of Clear Aligner Treatment in Masticatory Function and Temporomandibular Disorders: A Clinical Cohort Pilot Study. *Healthcare* 2025, *13*, 1541. https://doi.org/10.3390/healthcare13131541
4. Al-Somairi, M.A.A., Zheng, B., Yang, X. *et al.* Three-dimensional quantitative temporomandibular joint changes in skeletal class I malocclusion treated with extraction and non-extraction protocols: a comparative study of fixed orthodontic appliances and clear aligners. *Prog Orthod.* 26, 4 (2025). https://doi.org/10.1186/s40510-024-00551-1
5. Wang Y, Daraqel B, Wang Y, Yang D, Dong Y, Hu Y, et al. Biomechanical effects of different mandibular movements and torque compensations during mandibular advancement with clear aligners: a finite element analysis. Front Bioeng Biotechnol. 2024 Nov 13;12:1496517. doi: 10.3389/fbioe.2024.1496517.
6. Almalki SA, Al Jameel AH, Gowdar IM, Langaliya A, Vaddamanu SK, Di Blasio M, Cervino G, Minervini G. Impact of clear aligner therapy on masticatory musculature and stomatognathic system: a systematic review conducted according to PRISMA guidelines and the Cochrane handbook for systematic reviews of interventions. BMC Oral Health. 2024 Mar 19;24(1):350. doi: 10.1186/s12903-024-04029-8. PMID: 38504207; PMCID: PMC10949793.
7. Impact of Orthodontic Treatment on Temporomandibular Joint Disorders (TMD): An Observational Study. (2024). *African Journal of Biomedical Research*, *27*(4S), 4387-4390.
8. Coronel-Zubiate FT, Marroquín-Soto C, Geraldo-Campos LA, Aguirre-Ipenza R, Urbano-Rosales LM, Luján-Valencia SA, Tozo-Burgos JG, Arbildo-Vega HI. Association between orthodontic treatment and the occurrence of temporomandibular disorders: A systematic review and meta-analysis. J Clin Exp Dent. 2022 Dec 1;14(12):e1032-e1043. doi: 10.4317/jced.59970. PMID: 36601241; PMCID: PMC9799993.
9. Alam MK, Abutayyem H, Alzabni KMD, Almuhyi NHS, Alsabilah KAS, Alkubaydan FST, Alswairki HJ, Hajeer MY, Awawdeh MA. The Impact of Temporomandibular Disorders on Orthodontic Management: A Systematic Review and Meta-Analysis. Cureus. 2023 Aug 28;15(8):e44243. doi: 10.7759/cureus.44243. PMID: 37645665; PMCID: PMC10461594.
10. Talmaceanu D, Lenghel LM, Bolog N, Hedesiu M, Buduru S, Rotar H, Baciut M, Baciut G. Imaging modalities for temporomandibular joint disorders: an update. Clujul Med. 2018 Jul;91(3):280-287. doi: 10.15386/cjmed-970. Epub 2018 Jul 31. PMID: 30093805; PMCID: PMC6082607.
11. Huang L, Xu Y, Xiao Z, Liu Y, Luo F. Temporomandibular disorder prevalence in malocclusion patients: a meta-analysis. Head Face Med. 2025 Feb 26;21(1):13. doi: 10.1186/s13005-025-00490-0. PMID: 40011997; PMCID: PMC11863559.
12. Yuzbasioglu Ertugrul B, Veli İ. Evaluating the effects of orthodontic treatment with clear aligners and conventional brackets on mandibular condyle bone quality using fractal dimension analysis of panoramic radiographs. J Stomatol Oral Maxillofac Surg. 2022 Oct;123(5):538-545.
13. Sim D, Farella M. Methodological issues in current clear aligner research. Semin Orthod. 2025 Feb 18;31(1):50-58. doi: 10.1053/j.sodo.2024.11.006.
14. Li J, Si J, Xue C, Xu H. Seeking orderness out of the orderless movements: an up-to-date review of the biomechanics in clear aligners. Prog Orthod. 2024 Nov 18;25(1):44. doi: 10.1186/s40510-024-00543-1. PMID: 39551881; PMCID: PMC11570571.
15. Zhang M, Sang J, Yang C, Liu H, Xiao Y, Li J, et al. Cone-Beam Computed Tomography and Magnetic Resonance Imaging in Temporomandibular Joint Disorder Diagnosis: A Comparative Study. J Multidiscip Healthc. 2025 Jun 30;18:3793-3802. doi: 10.2147/JMDH.S521279.
16. Gharavi SM, Qiao Y, Faghihimehr A, Vossen J. Imaging of the Temporomandibular Joint. Diagnostics (Basel). 2022 Apr 16;12(4):1006. doi: 10.3390/diagnostics12041006. PMID: 35454054; PMCID: PMC9031630.

17. Dipalma G, Inchingolo AD, Guglielmo M, Morolla R, Palumbo I, Riccaldo L, et al. Imaging techniques for evaluating temporomandibular joint involvement in juvenile idiopathic arthritis: a systematic review. Oral Surg Oral Med Oral Pathol Oral Radiol. 2025 Dec;140(6):769-782.
18. Floca R, Bohn J, Haux C, Wiestler B, Zöllner FG, Reinke A, Weiß J, Nolden M, Albert S, Persigehl T, Norajitra T, Baeßler B, Dewey M, Braren R, Büchert M, Fallenberg EM, Galldiks N, Gerken A, Götz M, Hahn HK, Haubold J, Haueise T, Große Hokamp N, Ingrisch M, Iuga AI, Janoschke M, Jung M, Kiefer LS, Lohmann P, Machann J, Moltz JH, Nattenmüller J, Nonnenmacher T, Oerther B, Othman AE, Peisen F, Schick F, Umutlu L, Wichtmann BD, Zhao W, Caspers S, Schlemmer HP, Schlett CL, Maier-Hein K, Bamberg F. Radiomics workflow definition & challenges - German priority program 2177 consensus statement on clinically applied radiomics. Insights Imaging. 2024 Jun 3;15(1):124. doi: 10.1186/s13244-024-01704-w. PMID: 38825600; PMCID: PMC11144687.
19. Avery E, Sanelli PC, Aboian M, Payabvash S. Radiomics: A Primer on Processing Workflow and Analysis. Semin Ultrasound CT MR. 2022 Apr;43(2):142-146. doi: 10.1053/j.sult.2022.02.003. Epub 2022 Feb 12. PMID: 35339254; PMCID: PMC8961004.
20. Manek M, Maita I, Bezerra Silva DF, Pita de Melo D, Major PW, Jaremko JL, Almeida FT. Temporomandibular joint assessment in MRI images using artificial intelligence tools: where are we now? A systematic review. Dentomaxillofac Radiol. 2025 Jan 1;54(1):1-11. doi: 10.1093/dmfr/twae055. PMID: 39563454; PMCID: PMC11800278.
21. Santos GNM, da Silva HEC, Ossege FEL, Figueiredo PTS, Melo NS, Stefani CM, Leite AF. Radiomics in bone pathology of the jaws. Dentomaxillofac Radiol. 2023 Jan 1;52(1):20220225. doi: 10.1259/dmfr.20220225. Epub 2022 Nov 23. PMID: 36416666; PMCID: PMC9793454.
22. Lynn, S., Jani, P., Almpani, K., Yao, H., Duverger, O., & Lee, J. S. (2023). TMJ Symptoms Resolve With Orthognathic Surgery and Are Associated With Condylar Remodeling. *Journal of Oral and Maxillofacial Surgery*. https://doi.org/10.1016/j.joms.2023.08.074
23. Liu, C., Liu, Y., Yi, C., Xie, T., Tian, J., Deng, P., Liu, C., Yan, S., Dong, H., & Xu, Y. (2024). Application of a 3D Fusion Model to Evaluate the Efficacy of Clear Aligner Therapy in Malocclusion Patients: A Prospective Observational Study (Preprint). *Journal of Medical Internet Research*, *27*, e67378. https://doi.org/10.2196/67378
24. Al-Worafi, N. A., Al-Nasri, A., Al-Warafi, L. A., Al-Somairi, M. A. A., Alyafrusee, E. S., Alhashimi, N., Zheng, B., & Liu, Y. (2024). Effect of maxillary molars distalization using clear aligners and fixed orthodontic appliances on the positional and dimensional temporomandibular joint parameters: a three-dimensional comparative study. *BMC Oral Health*, *24*(1). https://doi.org/10.1186/s12903-024-05148-y
25. Martineli Filho, W. (2024). Advances in bone remodeling and clear aligners in orthodontics. *International Seven Multidisciplinary Journal*, *3*(1). https://doi.org/10.56238/isevmjv3n1-027