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EDITORS

PROF. DR. MERVE ERKMEN ALMAZ
ASSOS. PROF. DR. IDRIS KAVUT

SERÜVEN YAYINEVİ

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e-mail: seruvenyayinevi@gmail.com

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EDİTÖRLER

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Chapter 1

ANATOMICAL SPREAD AND RADIOLOGICAL EVALUATION OF ODONTOGENIC INFECTIONS IN THE MAXILLOFACIAL REGION

Batuhan Erdoğan[1]

Sümeyye Çelik Özsoy[2]

1Arş. Gör, Karamanoğlu Mehmetbey Üniversitesi, Ahmet Keleşoğlu Diş Hekimliği Fakültesi, Ağız, Diş ve Çene Radyolojisi AD, batuhanerdogan@kmu.edu.tr,
ORCID: 0009-0005-6094-055X
2 Dr. Öğr. Üyesi, Karamanoğlu Mehmetbey Üniversitesi, Ahmet Keleşoğlu Diş Hekimliği Fakültesi, Ağız, Diş ve Çene Radyolojisi AD, sumeyyecelik@kmu.edu.tr,
ORCID: 0000-0002 3294-2524

1. INTRODUCTION

Infections in the maxillofacial region may originate from dental sources (odontogenic) or non-dental sources (non-odontogenic). These infections exhibit a broad clinical spectrum. These infections can range from localised cellulitis or abscesses to life-threatening clinical conditions that can extend to deep neck spaces (1). Despite advances in antibiotic treatment and surgical approaches, morbidity remains a significant problem, particularly in cases involving spread along the facial planes. The occurrence of severe complications such as sepsis and mediastinitis, highlights the clinical importance of early diagnosis and appropriate management of these infections (2).

Non-odontogenic infections frequently develop from upper respiratory tract infections centred on the tonsillopharyngeal region, trauma, foreign bodies, infected cystic lesions, salivary gland pathologies, or other head and neck sources (3). The aetiology of deep neck infections varies depending on the centre where the study was conducted and the patient population; while tonsillopharyngeal sources are predominant in some series, odontogenic infections are among the most frequently identified aetiological factors in other studies (4). This variability makes the accurate identification of the source of infection and timely implementation of effective source control even more important in clinical practice (5).

Odontogenic infections mostly originate from dental foci such as pulp and periapical infections, periodontal diseases or pericoronitis. Although the infection may initially remain confined within the alveolar bone, following cortical bone perforation, it tends to spread along low-resistance facial planes into neighbouring anatomical spaces. This pattern of spread is closely related to the location of the tooth where the infection originated, the level at which cortical perforation occurred, and the surrounding muscle-fascia relationships (6). Clinically, the emergence of findings such as trismus, dysphagia, or dyspnoea often indicates involvement of deep anatomical spaces and suggests that the infection has progressed to a more advanced stage (7).

The threshold at which clinical risk significantly increases in odontogenic infections is the progression of the infection from the primary facial spaces to the deep neck spaces (3). Multiple space involvement has been associated with higher inflammatory markers, prolonged hospital stay, and the need for intensive care. Therefore, accurate assessment of the anatomical spread patterns of the infection not only improves diagnostic accuracy but also directly contributes to predicting prognosis and determining the appropriate treatment strategy (7,8).

At this point, the role of oral and maxillofacial radiology becomes clear. In situations where clinical examination is limited in deep anatomical areas, imaging methods guide the clinical decision-making process by revealing the actual spread of the infection (9). Contrast-enhanced computed tomography (CT) is one of the most frequently used imaging methods in practice because it allows for the rapid evaluation of both bone and soft tissue and demonstrates critical findings such as abscess location and extent, gas presence, and airway narrowing (10).

Magnetic resonance imaging (MRI) is a powerful complementary method that allows for a more detailed assessment of facial planes, muscle-fascia components, and deep neck involvement due to its superior soft tissue contrast. Evidence regarding the diagnostic accuracy of MRI and its contribution to clinical decision-making processes, particularly in acute neck infections, is increasing (11). It has been reported that MRI demonstrates high accuracy in detecting abscesses in odontogenic maxillofacial infections and can contribute to predicting the responsible tooth in some cases (12).

Cone beam computed tomography (CBCT) is a valuable method for three-dimensional and high-resolution hard tissue assessment. However, due to its limited soft tissue contrast, it is not preferred as the primary imaging method for evaluating facial cavity spread, abscess collections, and deep neck complications. CBCT plays a more supportive role in identifying odontogenic sources (13). Although ultrasound (USG) can contribute to staging and localising infection in superficial anatomical spaces in selected cases, the superiority of MRI in deep space infections is clearly emphasised in the literature (14).

2. ANATOMICAL CAVITIES AND ODONTOGENIC SPREAD

A significant portion of the areas referred to as "anatomical spaces" in the maxillofacial region are not structures that appear as hollow cavities. They are potential spaces filled with loose connective tissue and adipose tissue, bounded by facial planes. When infection develops, exudate separates these planes. Therefore, when examining odontogenic infection, it is necessary to consider not only the specific tooth but also which facial compartment the infection is directed towards and which compartments it may progress to (15,16).

The odontogenic focus often originates in the periapical or periodontal tissues and may initially remain confined within the alveolar bone. However, once cortical perforation develops, the infection tends to follow the path of least resistance. Here, the decisive factor is not only the position of the root tip but also whether the perforation is above or below the level of muscle attachment (17). Even infections originating from the same group of teeth can break into different spaces depending on the level of perforation. Clinically, visible swelling on the surface does not always reflect the degree of deep spread (18).

2.1. Odontogenic Infections Originating from Maxillary Teeth

Odontogenic infections originating from maxillary teeth tend to follow specific routes. In particular, the buccal cortex of the maxilla is more frequently perforated, facilitating the spread of infection to superficial soft tissue planes. In addition to superficial spread, the infection can extend to larger compartments and the upper facial region via the canine, infraorbital line, and sinus connections (19).

In infections originating from the maxillary anterior teeth covering the canine region, the canine fossa and the associated infraorbital and levator muscle planes are important sites of spread. Inflammation developing in this region is characterised by the disappearance of the nasolabial fold, marked swelling of the upper lip and cheek, and in some cases, spread towards the infraorbital area. The ability of maxillary anterior foci to extend along the mimic muscles explains how a clinical picture that begins with toothache can quickly turn into midface swelling. Series examining the spread of infections originating from maxillary teeth have shown that anterior tooth infections can often progress along the levator labii superioris and levator anguli oris muscles, paving the way for significant soft tissue involvement in the canine and infraorbital regions (19).

When it comes to posterior maxillary teeth, the spread patterns become significant along two main axes. The first is the extension of the infection towards the masticatory components and deep posterior compartments. Particularly in posterior maxillary foci, trismus and deep facial pain become more pronounced clinically when the pterygoid muscles and associated deep planes are affected due to anatomical proximity (20). Regarding the relationship with the maxillary sinus, the close anatomical relationship between the roots of the maxillary canine, premolar, and molar teeth and the sinus floor facilitates the spread of periapical infection to the sinus, forming the fundamental pathophysiological basis of odontogenic maxillary sinusitis (21).

Odontogenic maxillary sinusitis is often misdiagnosed as "rhinosinusitis" in clinical practice, and overlooking its odontogenic origin is a major cause of treatment failure. In this scenario, focusing solely on sinonasal treatment without eliminating the dental source may result in persistent or recurrent sinusitis. Therefore, keeping in mind the possibility of an odontogenic aetiology in cases of unilateral sinusitis associated with maxillary posterior teeth directly influences clinical management and may require an interdisciplinary approach. Reviews focusing on odontogenic maxillary sinusitis emphasise that appropriate management often requires dental focus control, combined with endoscopic sinus surgery if necessary (20,21).

A less common but clinically significant extension of maxillary infections involves the infratemporal fossa and associated deep compartments. This region, due to its proximity to critical neurovascular structures and masticatory muscles, can present diagnostic and therapeutic challenges when infection develops. A systematic review examining infratemporal fossa abscesses indicated that in a significant proportion of cases, the aetiology was related to odontogenic infection or dental procedures, the presenting symptoms were often pain, swelling and trismus, and delayed diagnosis could increase the risk of neurological and systemic complications. Therefore, the possibility of infratemporal extension should be considered when evaluating cases with maxillary posterior focus, marked trismus, and unexplained superficial findings (22).

2.2. Odontogenic Infections Originating from Mandibular Teeth

In odontogenic infections originating from mandibular teeth, one of the most critical anatomical thresholds is the mylohyoid muscle and its insertion level in the mandible. When the infection breaks above the mylohyoid line, the likelihood of sublingual involvement increases, and when it breaks below, the likelihood of submandibular compartment involvement increases. This determines not only the location of the swelling but also the risk to the airway and the possibility of secondary deep neck spread (17). In sublingual space involvement, fullness in the floor of the mouth, restricted tongue movement, and dysphagia are prominent in the clinic. In the submandibular space, swelling, tenderness, and sometimes restricted mouth opening are seen in the lateral neck line below the jaw (23). Submandibular involvement is more alarming from a clinical perspective. The submandibular space is connected to adjacent deep neck compartments, and bilateral spread can rapidly become a dangerous condition (24).

The most dramatic clinical manifestation of this condition is Ludwig's angina. It is a rapidly progressing condition, often of odontogenic origin, causing widespread cellulitis in the floor of the mouth and suprahyoid region, classically involving bilateral submandibular and sublingual involvement, frequently accompanied by submental involvement, and requiring urgent admission due to the risk of airway obstruction. In this scenario, posterior superior displacement of the tongue, elevation of the floor of the mouth, and widespread rigidity can rapidly progress to respiratory distress. This is the fundamental reason why Ludwig's angina and submandibular space infections are considered potentially fatal (24,25). Extensive clinical evaluations of submandibular space infections highlight factors that increase the risk of complications, such as systemic diseases like diabetes and variables such as spread to specific compartments, with airway obstruction and mediastinal spread being among the most critical complications. Therefore, in cases originating from the mandible with rapid spread, considering the sublingual, submandibular, and submental lines together is important not only for anatomical accuracy but also for clinical safety (1,24).

The buccal cavity can be considered a compartment within the soft tissues of the cheek, associated with the superficial facial planes. The most typical clinical finding is localised swelling and tenderness in the cheek (17). Infections that break into the buccal cavity generally present with a superficial appearance. However, as the buccal region is part of the transition line adjacent to the masticatory compartments posteriorly and the mandibular cavities inferiorly, it should not be assumed that the infection always remains confined to the superficial border. The practical determinant of infection reaching the buccal cavity is the location of cortical perforation relative to the buccinator and surrounding mimic muscles. If the perforation remains on the mucosal side of the muscle attachment, more limited presentations are observed, whereas perforations that extend beyond the muscle attachment show more pronounced buccal spread. Therefore, in a case presenting with cheek swelling, the possibility of progression to adjacent compartments should be kept in mind rather than focusing solely on the visible borders of the swelling (18).

Inflammation developing in the masticatory compartment significantly restricts the patient's ability to open their mouth, and trismus is often the predominant symptom. This compartment is considered together with subregions such as the masseteric, pterygoid, and temporal components, and the mandibular posterior teeth are classic sources for this pathway. In addition to causing trismus, the masticatory compartment can also act as a bridge extending to the deep neck spaces. Studies examining the spread of mandibular infections describe how the infection often tends to spread in two main directions. On the one hand, it spreads upwards to the masticatory components, while on the other hand, it can progress downwards to the sublingual–submandibular line. This model explains why the combination of trismus and neck symptoms is considered to be at higher risk in clinical practice (26).

Odontogenic infections may remain confined to the primary facial spaces, but in some cases, secondary extension to the parapharyngeal and retropharyngeal compartments may occur. The parapharyngeal region is a clinically critical transition area due to its proximity to the lateral pharynx and its relationship with major vascular and neural structures. Extension to this region may be seen with dysphagia, odynophagia, neck movement restriction, and a more severe systemic picture (26). It has been reported that involvement of the masticatory compartment may be a frequent concomitant step in the spread of odontogenic infection to the parapharyngeal region, i.e., masticatory involvement may be considered a warning sign for deepening (27).

The retropharyngeal region and deeper facial planes are associated with classic anatomical corridors through which infection can spread downward into the mediastinum (28). Modern reviews focusing on the 'danger zone', the potential space between the alar fascia and the prevertebral fascia, emphasise that this area may act as a corridor for infection spread and that infections progressing along this route may be associated with serious complications such as mediastinitis, necrotising fasciitis, and empyema (29). Clinical studies have demonstrated that the risk is significantly increased in cases with mediastinal spread, and that the involvement of multiple spaces and the retropharyngeal tract may be a strong warning sign for mediastinal extension (2,30).

3. IMAGING METHODS

Imaging in odontogenic infections is used to accurately identify the odontogenic source, map the anatomical spaces to which the infection has spread, differentiate between cellulitis and abscess, and predict critical complication risks such as airway involvement, proximity to vascular structures, and deep neck spread at an early stage (1). Although clinical examination is valuable in assessing superficial swelling, it may not always fully reveal the true extent of spread in infections progressing between facial planes. At this point, imaging directly shapes the treatment strategy (12). It is necessary to select the imaging method appropriate for the clinical question in order to locate the source of infection, detect soft tissue spread, or assess the spread to deep neck spaces (14).

Periapical and panoramic radiographs provide clues suggesting an odontogenic focus in most patients quickly and at low cost. For this reason, they are still used in clinical practice for initial imaging. However, these methods do not reliably show soft tissue spread and facial space involvement. Therefore, if the clinical picture favours a widespread, deep infection, advanced cross-sectional imaging methods are required (31).

3.1. Ultrasonography

Ultrasonography makes the distinction between abscess and cellulitis in superficial facial spaces more reliable than clinical examination and can indicate the target site for aspiration when necessary. This reduces unnecessary incisions and prevents delays (32).

The addition of colour Doppler supports the distinction between the vascularity of the inflammatory area and the collection area, thereby strengthening the question "is it cellulitis or an abscess?" A study of thirty-four cases reported that USG was effective in determining the stage and location of infection with high sensitivity and specificity compared to clinical and radiographic evaluation (33). Clinical studies on superficial facial space infections emphasised that USG can provide a meaningful contribution to detecting the presence of abscesses compared to clinical evaluation (32).

3.2. Computed Tomography

In clinical situations requiring rapid decision-making, CT is generally the first choice. The reasons for its preference include its rapid accessibility, the ability to evaluate bone and soft tissue simultaneously, its ability to spread across facial planes, and its ability to quickly reveal critical findings such as mediastinal extension (6).

Findings suggestive of abscess on computed tomography are mostly central hypodense collection, peripheral contrast enhancement, and circumferential inflammation (8). In cellulitis, diffuse soft tissue oedema and blurring of fat planes are more commonly observed. This distinction is crucial in clinical management as it directly influences the decision for drainage (10).

Limitations of computed tomography include radiation exposure, the need for iodinated contrast, and the presence of metal artefacts in some areas. Therefore, in certain clinical scenarios, switching to MRI or a complementary approach with ultrasound may be considered (11,13).

3.3. Magnetic Resonance

Although magnetic resonance imaging takes longer than CT, it is preferred for evaluating muscle–fascia planes, vascular–nerve relationships, deep spaces, and complications due to its high soft tissue contrast (11). Therefore, MRI is a valuable adjunct, particularly when the clinical picture is complex or when CT provides an inadequate answer (12).

The practical benefit of MRI is that it can draw a more refined anatomical map of the spread, rather than simply indicating "presence or absence". This contributes to the planning of the surgical approach, the early detection of complications, and a more accurate assessment of risk in multidisciplinary management (11,12).

Diffusion-weighted imaging provides a pathophysiology-based window into the question of whether an abscess formation process is present in odontogenic infections. Diffusion restriction is expected in abscesses with viscous and cellular content. In a comparative study of soft tissue infections, it was reported that the combination of non-contrast MRI and diffusion-weighted imaging showed similar diagnostic performance to contrast-enhanced MRI in detecting abscesses. This finding is clinically significant in patients who cannot receive contrast (34).

Data indicate that diffusion-weighted imaging may be useful in distinguishing between necrotic tumours and infectious necrosis–abscesses in the head and neck region. This can reduce misdiagnosis, particularly in atypical clinical scenarios (35).

3.4. Cone Beam Computed Tomography

The strength of cone beam computed tomography lies in its ability to provide detailed images of bone and dentoalveolar structures with high spatial resolution. For this reason, it is used in selected cases involving periapical or periodontal pathology suggestive of an odontogenic source of infection, suspected cortical perforation, and maxillary posterior tooth-sinus relationships. The fundamental problem with CBCT is its inadequate soft tissue contrast. Consequently, it is not suitable for reliably demonstrating facial space involvement, abscess–cellulitis differentiation, and deep neck spread. If such clinical suspicion exists, contrast-enhanced CT or MRI should be preferred over CBCT (14).

3.5. Nuclear Medicine Methods

Nuclear medicine methods are not routine first-line treatment in acute odontogenic maxillofacial space infections. However, they may be used to obtain information based on metabolic activity in selected cases where the infection has become chronic, osteomyelitis is suspected, or the response to treatment is uncertain (36).

Although nuclear medicine methods are not yet standardised, technical reports have been published discussing the potential of non-invasive methods such as medical infrared thermography in odontogenic facial cellulitis for demonstrating the boundaries of superficial inflammation and supporting clinical decision-making (37).

The most tangible benefit of these imaging outputs in the clinic is to confirm the presence of an abscess and clarify the drainage decision, guide the surgical approach by showing which anatomical spaces are involved, and detect danger areas such as deep neck, vascular proximity, and possible mediastinal extension at an early stage (33,34).

4. CLINICAL USE OF RADIOLOGICAL IMAGING TECHNIQUES

The most important contribution of imaging findings in the management of odontogenic infections is not only the confirmation of the diagnosis, but also the accurate classification of clinical risk and the guidance of the treatment strategy. Imaging directly influences the clinical decision-making process by revealing the presence of an abscess, determining which anatomical spaces are involved, and identifying areas at risk in terms of the airway and vascular structures. In this context, radiological evaluation should be considered an integral part of infection management (38).

4.1. Abscess–Cellulitis Differentiation

The detection of abscesses in clinical management strengthens the decision for surgical drainage, particularly in deep spaces. The most typical appearance favouring abscess on CT is the peripheral enhancement surrounding a central low-density collection and the obliteration of the surrounding inflammatory fat plane. In cellulitis, more diffuse oedema and heterogeneous enhancement predominate (10). However, despite the high performance of CT in diagnosing abscesses, it has been observed that it can produce false results, particularly in early-stage phlegmonous processes and some complex neck infections. Therefore, meta-analyses have demonstrated that CT images should not be used as the sole decision-making mechanism but should be interpreted in conjunction with clinical and laboratory data (8).

Although some centres employ biphasic approaches or assessment criteria to enhance abscess differentiation, the primary value of the report for the clinician lies not so much in knowing the presence or absence of an abscess, but rather in the location, size, neighbouring structures, and presence of multiple foci of suspected abscess (10).

4.2. Space Mapping and Airway Assessment

The area where the radiology report is most useful to surgery is that it clearly and comprehensively indicates which anatomical spaces are affected by the infection. The surgeon's approach, antibiotic strategy and the patient's level of care are determined according to the affected spaces. The association of multiple space involvement with higher inflammatory markers, longer hospitalisation duration, and intensive care requirements demonstrates that the space mapping in the report carries prognostic value (7).

Studies examining the typical spread patterns of odontogenic infections have shown that in mandibular cases, the masticatory components and the sublingual and submandibular lines frequently form a junction, and that the transition from this junction to the parapharyngeal area significantly increases the clinical risk. Therefore, in CT reports, the masticatory, submandibular, and sublingual spaces should be evaluated together, particularly in mandibular cases. The parapharyngeal and retropharyngeal compartments should be carefully scanned (21,22).

Studies comparing odontogenic and non-odontogenic deep neck infections based on CT findings have reported that in odontogenic cases, the submandibular, masticatory and parapharyngeal lines may be more frequently involved, and airway compromise may be more pronounced (39). Airway assessment is not limited to a rough measurement of the lumen diameter. Oedema around the larynx, involvement of the epiglottis, aryepiglottic folds, arytenoid level, and soft tissues around the pharynx significantly affect the difficulty of intubation and postoperative airway management (40). Clinical assessments from an anaesthesia perspective emphasise that preoperative evaluation of airway anatomy using CT is critical in determining the method (41).

In a study focusing on predicting difficult postoperative airway management in severe odontogenic cases, it is noted that the presence of parapharyngeal and retropharyngeal abscesses on preoperative CT scans, along with findings of laryngeal oedema, may be associated with a greater need for difficult airway management. In particular, tracheotomy may be a more appropriate option in cases where a retropharyngeal abscess is present. Such data indicate that pharyngeal space involvement and laryngeal oedema findings in the CT report are among the key pieces of information influencing clinical decision-making (42).

4.3. Proximity to Vascular Structures and Mediastinal Extension

In infections involving the parapharyngeal and carotid sheath, the risk of complications associated with large vessels and cranial nerves increases. Therefore, the report should include an assessment of the proximity of the collection to the carotid sheath and an evaluation to rule out potential vascular complications (2). Although conditions such as Lemierre syndrome are less common in odontogenic cases, they serve as a reminder that vascular complications in deep neck infections should not be underestimated (26).

The progression of infection to the retropharyngeal space and extension to the mediastinum is associated with complications with high mortality (1). Clinical data addressing predisposing factors for mediastinal extension in deep neck infections have shown that multiple space involvement and the involvement of specific deep planes may increase the risk. Therefore, the CT report should not be limited to the neck alone; if clinically suspected, extension up to the thoracic inlet should be evaluated (30).

5. DIFFERENTIAL DIAGNOSIS

In cases presenting with maxillofacial swelling, pain, and tenderness, the clinical picture often suggests odontogenic infection. However, some non-odontogenic pathologies may present with similar findings. Therefore, differential diagnosis should be broad, particularly in patients where a clear dental focus cannot be identified, who do not respond as expected to antibiotics, incision and drainage, or whose swelling is not localised in a manner consistent with dental foci (43).

One of the groups that should first come to mind in differential diagnosis is inflammatory pathologies originating from the salivary glands. Acute sialadenitis developing in the submandibular region and submandibular lymph node inflammation can clinically overlap to a significant degree. Although submandibular lymphadenitis in adult patients may be odontogenic in origin, distinguishing between sialadenitis and lymphadenitis is important for planning the correct approach. In addition to clinical examination and laboratory findings, keeping salivary gland origin in mind in cases where no dental focus can be identified reduces diagnostic delay (43).

The second important group consists of infected cystic lesions. Dermoid and epidermoid cysts, which can be located in the floor of the mouth, submental and submandibular regions, can mimic odontogenic submandibular and submental abscesses when infected and may be confused with odontogenic infections. When odontogenic causes cannot be demonstrated in these lesions, the possibility of a mass or cystic lesion should be evaluated using appropriate advanced imaging techniques, and approaches such as fine needle aspiration should be considered when necessary (44).

Non-odontogenic lymphadenopathies may present with swelling in the submandibular region and may be confused with odontogenic abscesses. Pathologies originating from lymph nodes should be considered, particularly in cases where the focus tooth cannot be identified, the course is atypical, or the clinical course is longer than expected (43,45).

6. CONCLUSION

Maxillofacial odontogenic infections can originate from a dental focus and progress along facial planes into potential anatomical spaces. These infections present a broad clinical spectrum, ranging from limited cellulitis to deep neck spread, airway compromise, and mediastinal extension, which are associated with high morbidity and mortality.

Therefore, effective clinical management is only possible not only through antibiotic selection, but also through a correct understanding of the anatomical spread pattern of the infection, early risk classification, source control, and timely implementation of an appropriate drainage strategy.

The clinical application of anatomical cavity information is to predict the possible routes of spread, while imaging objectifies treatment decisions by revealing the actual plane in which this route occurred in that patient. The fact that multiple cavity involvement can be correlated with clinical severity indicators and healthcare utilisation demonstrates that radiological mapping has not only diagnostic but also prognostic value.

Clinically, the most critical juncture is when the submandibular, sublingual and parapharyngeal components become involved, leading to scenarios such as Ludwig's angina and deep neck infection. It should be remembered that these scenarios require urgent intervention in terms of airway management.

Among imaging methods, contrast-enhanced CT stands out as the primary method for rapid assessment of deep neck spread, suspected purulent focus formation, and complication screening in practice, while MRI serves as a powerful adjunct in terms of soft tissue contrast and complication assessment in selected cases. The contribution of diffusion-weighted imaging to the distinction between abscess and cellulitis increases diagnostic confidence in patients who cannot receive contrast or in borderline cases. Ultrasound can contribute to triage and intervention planning in selected cases involving superficial spaces, while the role of CBCT remains more limited to supporting the identification of dentoalveolar sources and hard tissue details.

In conclusion, successful management of maxillofacial odontogenic infections depends on the combined application of the principles of clinical assessment based on anatomical spread logic, appropriate imaging selection and standardised reporting, timely drainage and source control, and early management of airway and systemic complication risks.

REFERENCES

1. Bali, R., Sharma, P., Gaba, S., Kaur, A., & Ghanghas, P. (2015). A review of complications of odontogenic infections. National Journal of Maxillofacial Surgery, 6(2), 136–43.

2. Velhonoja, J., Lääveri, M., Soukka, T., Irjala, H., & Kinnunen, I. (2019). Deep neck space infections: An upward trend and changing characteristics. European Archives of Oto-Rhino-Laryngology, 277(3), 863–72.

3. Maharaj, S., Ahmed, S. M., & Pillay, P. (2019). Deep neck space infections: A case series and review of the literature. Clinical Medicine Insights: Ear, Nose and Throat, 12, 1179550619871274.

4. Gujrathi, A. B., Ambulgekar, V., & Kathait, P. (2016). Deep neck space infection: A retrospective study of 270 cases at a tertiary care centre. World Journal of Otorhinolaryngology - Head and Neck Surgery, 2(4), 208–13.

5. Pucci, R., Cassoni, A., Di Carlo, D., et al. (2020). Odontogenic-related head and neck infections: From abscess to mediastinitis—A 5-year survey. Journal of Cranio-Maxillofacial Surgery, 48(10), 968–74.

6. Wabik, A., Hendrich, B., Nienartowicz, J., et al. (2014). Odontogenic inflammatory processes of head and neck in computed tomography examinations. Polish Journal of Radiology, 79, 431–38.

7. de Jesus da Silva, R., Barbosa, R. A. L., Okamura, F. K., & Luz, J. G. C. (2022). CT analysis of fascial space involvement correlates with laboratory markers and outcomes in odontogenic infections. Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology, 134(3), 345–52.

8. Hagelberg, A., Pape, E., et al. (2022). Diagnostic accuracy of contrast-enhanced CT for neck abscesses: Systematic review and meta-analysis. European Radiology, 32(10), 6915–26.

9. Liang, J., Jiang, L., Li, M., Liu, L., & Li, H. (2022). Should preoperative CT be routine for cervicofacial space infections? Journal of Craniofacial Surgery, 33(6), e545–e549.

10. Eissa, L., & Mehanna, A. (2020). Biphasic CT imaging of deep neck infections: Differentiating collections. Egyptian Journal of Radiology and Nuclear Medicine, 51, 172.

11. Hirvonen, J., Heikkinen, J., Nyman, M., et al. (2023). MRI of acute neck infections: Evidence summary and pictorial review. Insights into Imaging, 14(1), 45.

12. Heikkinen, J., Jokihaka, V., Nurminen, J., et al. (2022). MRI of odontogenic maxillofacial infections: Diagnostic accuracy and reliability. European Radiology, 32(7), 4757–66.

13. Ghali, S., Katti, G., et al. (2021). Fascial space odontogenic infections: Ultrasonography as an alternative to MRI. Journal of Maxillofacial and Oral Surgery, 20(3), 456–62.

14. Weiss, R., & Read-Fuller, A. (2019). Cone beam computed tomography in oral and maxillofacial radiology: An evidence-based review. Dentomaxillofacial Radiology, 48(1), 20180301.

15. Guidera, A. K., Dawes, P. J. D., Fong, A., & Stringer, M. D. (2014). Head and neck fascia and compartments: No space for spaces. Head & Neck, 36(5), 665–70.

16. Guidera, A. K., Dawes, P. J. D., & Stringer, M. D. (2012). Cervical fascia: A terminological pain in the neck. ANZ Journal of Surgery, 82(10), 735–39.

17. Yonetsu, K., Izumi, M., & Nakamura, T. (1998). Deep facial infections of odontogenic origin: Pathways of space involvement. American Journal of Neuroradiology, 19(1), 123–28.

18. Verma, S., Mohan, R., Singh, A., Singh, U., & Agarwal, N. (2014). Pathways of spread in deep space infections of odontogenic origin. Journal of Maxillofacial and Oral Surgery, 13(4), 451–55.

19. Schuknecht, B., Stergiou, G., & Graetz, K. (2008). Masticator space abscess derived from odontogenic infection: Pathways of extension. European Radiology, 18(4), 804–09.

20. Ogura, I., Minami, Y., Sugawara, Y., et al. (2020). Odontogenic infection pathway to the parapharyngeal space. Oral Radiology, 36(3), 258–63.

21. Ohshima, A., Ariji, Y., Goto, M., et al. (2004). Anatomical considerations for spread from pericoronitis of impacted mandibular third molar. Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology, 98(5), 589–94.

22. Boscolo-Rizzo, P., & da Mosto, M. C. (2009). Submandibular space infection: A potentially lethal infection. International Journal of Infectious Diseases, 13(3), 327–33.

23. Candamourty, R., Venkatachalam, S., Babu, M. R. R., & Kumar, G. S. (2012). Ludwig's angina—An emergency: Case report with literature review. Journal of Natural Science, Biology and Medicine, 3(2), 206–08.

24. Kang, S., Lee, S., Oh, H., et al. (2012). Predisposing factors for mediastinal extension in deep neck infections. European Archives of Oto-Rhino-Laryngology, 269(5), 1395–1400.

25. Phan, T. H., Lay, J., & Scali, F. (2022). The alar fascia and danger space: A modern review. Surgical and Radiologic Anatomy, 44(9), 1287–95.

26. Feigl, G., Hammer, G., Litz, R., & Kachlík, D. (2020). The intercarotid (alar) fascia and related terminology: Anatomical clarification. Annals of Anatomy, 228, 151431.

27. Aarthi Nisha, V., P, J., Santana, N., et al. (2013). The role of colour Doppler ultrasonography in the diagnosis of fascial space infections—A cross-sectional study. Journal of Clinical and Diagnostic Research, 7(5), 962–67.

28. Shah, A., Ahmed, I., Hassan, S., Samoon, A., & Ali, B. (2015). Evaluation of

ultrasonography as a diagnostic tool in the management of head and neck facial space infections: A clinical study. National Journal of Maxillofacial Surgery, 6(1), 55–61.

29. Arslan, Z., Demir, H., Yıldız, D. B., & Yaşar, F. (2020). Diagnostic accuracy of panoramic radiography and ultrasonography in detecting periapical lesions using periapical radiography as a gold standard. Dentomaxillofacial Radiology, 49(5), 20190290.

30. Chun, C., Jung, J. Y., Baik, J., et al. (2018). Detection of soft-tissue abscess: Comparison of diffusion-weighted imaging to contrast-enhanced MRI. Journal of Magnetic Resonance Imaging, 47(1), 60–68.

31. Koc, O., Paksoy, Y., Erayman, I., Kıvrak, A., & Arbağ, H. (2007). Role of diffusion-weighted MRI in the discrimination diagnosis of cystic and/or necrotic head and neck lesions. European Journal of Radiology, 62(2), 205–13.

32. Ogura, I., Sasaki, Y., Kameta, A., Sue, M., & Oda, T. (2017). Diffusion-weighted imaging in the oral and maxillofacial region: Usefulness of ADC maps and MIP for characterisation of normal structures and lesions. Polish Journal of Radiology, 82, 571–77.

33. Reinert, C., Pfannenberg, C., Dittmann, H., et al. (2022). [18F] Fluoride PET/CT and [18F] FDG PET for assessment of osteomyelitis of the jaw compared to CT and MRI: A prospective PET/CT and PET/MRI pilot study. Journal of Clinical Medicine, 11(14), 3998.

34. Derruau, S., Bogard, F., Exartier-Menard, G., Mauprivez, C., & Polidori, G. (2021). Medical infrared thermography in odontogenic facial cellulitis as a clinical decision support tool: A technical note. Diagnostics, 11(11), 2045.

35. Iwata, E., Inokuchi, G., Kawakami, M., Matsui, T., Kusumoto, J., Tachibana, A., & Akashi, M. (2024). Predictive factors in difficult postoperative airway management of severe odontogenic deep neck infection. Odontology, 113(3), 1253–62.

36. Cho, S. Y., Woo, J. H., Kim, Y. J., et al. (2016). Airway management in patients with deep neck infections: A retrospective analysis. Medicine, 95(27), e4125.

37. Lin, Y., Gao, W., Yue, H., et al. (2021). A novel risk score for the prediction of airway management in patients with deep neck space abscess: A multicentre retrospective cohort study. Journal of Intensive Care, 9(1), 41.

38. McClay, J. E., Murray, A. D., & Booth, T. (2003). Intravenous antibiotic therapy for deep neck abscesses defined by computed tomography. Archives of Otolaryngology–Head & Neck Surgery, 129(11), 1207–12.

39. Kim, M. K., Kim, H. D., & Kim, J. S. (2018). CT features of odontogenic deep neck infections. Clinical Radiology, 73(3), 304.e1–304.e7.

40. Yankov, Y. (2024). Acute sialoadenitis of the submandibular salivary glands and acute inflammation of the submandibular lymph nodes: A review article. Scripta Scientifica Medicinae Dentalis, 10.

41. Rahpeyma, A., Khajehahmadi, S., & Ghasemi, A. (2015). Epidermoid/dermoid cysts mimicking odontogenic infections: Review of literature. Reviews in Clinical Medicine, 2(4), 190–94.

42. Goswami, M., Johnson, R. M., & Singh, A. (2025). Orofacial tuberculosis mimicry of odontogenic abscess: A diagnostic dilemma! Journal of Family Medicine and Primary Care, 14(5), 2058–61.

43. Kim, S. J. (2019). Definition and management of odontogenic maxillary sinusitis. Maxillofacial Plastic and Reconstructive Surgery, 41(1), 13.

44. Psillas, G., Papaioannou, D., Petsali, S., Dimas, G., & Constantinidis, J. (2021). Odontogenic maxillary sinusitis: A comprehensive review. Journal of Dental Sciences, 16(2), 474–81.

45. Young, K., Tang, D. M., & Wu, A. W. (2025). Infratemporal fossa abscesses: A systematic review of cases. Ear, Nose & Throat Journal, 104(6), 375–82.

Chapter 2

VONLEY RESTORATIONS

Duygu Ece KESKİN[1]
Beyza ARLI[2]
Beşar İZZETAĞA[3]

1 Assistant Professor, Department of Prosthodontics, Faculty of Dentistry, Karabük University, Karabük, Turkey Orcid: 0000-0002-8906-1760
2 Prosthodontics, İstanbul, Turkey Orcid: 0009-0007-0559-9365
3 Assistant Professor, Department of Prosthodontics, Faculty of Dentistry, Karabük University, Karabük, Turkey Orcid: 0000-0007-7075-2265

INTRODUCTION

Advances in prosthetic dentistry have led to a reshaping of treatment approaches in accordance with biological principles. With the adoption of the concept of minimally invasive dentistry, preserving healthy tooth structure to the maximum extent has become a primary objective (1). This approach aims not only to achieve esthetic and functional rehabilitation but also to ensure long-term biomechanical durability and preservation of pulpal health. Therefore, partial restorations such as inlay, onlay, and overlay have emerged as important alternatives in the treatment of posterior teeth with extensive loss of tooth structure (2,3).

In the treatment of extensive structural loss in posterior teeth, indirect restorative approaches are preferred in order to increase biomechanical resistance while preserving as much tooth structure as possible. Inlay restorations constitute an important treatment option in cavities where cusp coverage is not required but the cavity size exceeds the limitations of direct composite restorations. These restorations allow controlled re-establishment of marginal adaptation, contact stability, and occlusal morphology (4,5). In addition, developments in material science, particularly ceramic-based systems, have improved both the esthetic and mechanical performance of these restorations (6).

Although conventional full crown restorations provide high retention and durability, they require the removal of a considerable amount of sound tooth structure. In contrast, inlay restorations restore only the structural loss within the cavity boundaries, whereas onlay restorations cover one or more cusps, and overlay restorations provide biomechanical support in extensive tissue loss involving the entire occlusal surface (7,8). These restoration types aim to reduce the risk of fracture by preserving remaining tooth structure, particularly in posterior teeth that have undergone endodontic treatment or contain large restorations (9).

A more recent treatment option, the term “vonlay,” also referred to as “veneerlay,” represents a partial crown design developed particularly for the posterior region. This design combines an onlay restoration with an extended buccal veneer surface and is indicated in areas where sufficient enamel is available for cementation (10). Although it provides esthetic and structural benefits similar to a full crown, it requires significantly less invasive tooth preparation.

The veneer and onlay components are combined to improve the appearance of the remaining tooth structure while providing function and long-term durability (11,12).

Figure 1. *Table-top, inlay, onlay, overlay and veneerlay restorations (13)*

Systematic reviews and meta-analyses reported in the literature indicate that ceramic and composite inlay, onlay, and overlay restorations demonstrate high survival rates during follow-ups of 5–10 years. The most common causes of failure include secondary caries, restoration fracture, and adhesive failure. However, when appropriate case selection, proper preparation design, and suitable material selection are ensured, the clinical performance of these restorations is highly satisfactory (14,15).

Inlay, onlay, and overlay restorations are indirect restorative options that support the minimally invasive approach while fulfilling esthetic and functional requirements and offering biomechanical advantages. When combined with modern adhesive systems and digital manufacturing technologies, these restorations are gaining an increasingly important role in prosthetic dentistry (16).

Clinical Procedures and Comparative Evaluation of Table-Top, Inlay, Onlay, Overlay, and Vonlay Restorations

In the treatment of extensive structural loss in the posterior region, indirect adhesive restorations aim to establish a balance between biomechanical durability and minimally invasive treatment (16). Cavity width, cusp support, and occlusal load distribution are the main criteria for determining the appropriate restoration type. Inlay, onlay, overlay, and veneerlay (vonlay) restorations differ in terms of the degree of tissue preservation and cusp coverage (8).

1. Table-Top Restorations

Table-top restorations are minimally invasive indirect restorations used particularly in the treatment of occlusal surface loss in posterior teeth. These restorations are commonly preferred for the rehabilitation of tissue loss resulting from severe occlusal wear, erosion, or attrition. Compared with conventional full crown restorations, they provide a more conservative approach aimed at preserving healthy tooth structure. With the development of adhesive dentistry and the use of high-strength ceramic materials, table-top restorations have increasingly gained popularity in clinical practice (7).

Table-top restorations are indicated in:

- Severe occlusal wear and erosion cases
- Patients requiring restorative reconstruction of vertical dimension
- Extensive occlusal surface loss in posterior teeth
- Conservative restorative treatments requiring minimal preparation

The main objective of these restorations is to restore only the occlusal surface of the tooth, thereby achieving functional and esthetic rehabilitation (17).

Preparation Characteristics

- Occlusal cusp reduction
- Minimally invasive preparation on the occlusal surface
- Marginal transitions designed to harmonize with the esthetic zone (8,16)

2. Inlay Restorations

Inlay restorations are indirect restorations confined within the cavity boundaries and do not require cusp coverage. They are generally indicated for large Class I and Class II cavities where the remaining cusp structure has sufficient thickness (14).

Preparation Principles

- Slightly convergent cavity walls
- Rounded internal line angles
- Marginal boundaries terminating within enamel
- Minimum material thickness of 1.5–2 mm for ceramic restorations

Elimination of sharp internal angles reduces the risk of ceramic fracture (18).

Clinical Procedure

After conventional impression or digital scanning, the restoration is fabricated in the laboratory. For ceramic restorations, adhesive cementation is performed using resin cement following hydrofluoric acid etching and silane application (6).

3. Onlay Restorations

Onlay restorations involve coverage of one or more cusps. They are preferred when weakened cusp structures require reinforcement and are particularly useful in extensive proximal lesions to reduce the risk of tooth fracture (4).

Preparation Characteristics

- Reduction of the cusp to be covered (generally 1.5–2 mm)
- Greater thickness required on functional cusps
- Rounded transition areas

This design allows occlusal forces to be distributed more evenly between the restoration and the tooth structure (5).

Clinical Procedure

The impression and cementation protocol is similar to that used for inlay restorations. However, accurate reconstruction of occlusal morphology is more critical.

4. Overlay Restorations

Overlay restorations are extensive indirect restorations covering all cusps. They provide a conservative alternative in cases of large structural loss where a full crown is not required. This restoration type provides complete occlusal coverage without the need for circumferential tooth preparation (19,20).

Preparation Characteristics

- Adequate reduction on all cusps
- Reshaping of the occlusal surface
- Marginal boundaries positioned supragingivally whenever possible

Overlay restorations may increase fracture resistance by supporting the remaining tooth structure through adhesive bonding (6).

5. Vonlay (Veneerlay) Restorations

Vonlay (veneerlay) restorations are hybrid designs combining occlusal coverage with buccal surface veneering in posterior teeth. They are especially preferred in cases where esthetic expectations are high and where discoloration or enamel loss exists on the buccal surface.

This design combines the occlusal coverage of a traditional onlay restoration with the esthetic advantages of laminate veneers (21,22).

Preparation Characteristics

- Occlusal reduction: approximately 1–1.5 mm
- Partial cusp coverage for weakened cusps

- Buccal veneer preparation of 0.5–0.7 mm
- Rounded internal line angles
- Preparation margins kept within enamel as much as possible

Preservation of enamel surfaces is essential for successful adhesion. Therefore, preparation should be confined within enamel whenever possible (5).

Vonlay restorations are commonly fabricated from materials providing high esthetic quality and durability, such as:

- Lithium disilicate ceramics
- Feldspathic ceramics
- CAD/CAM ceramic blocks

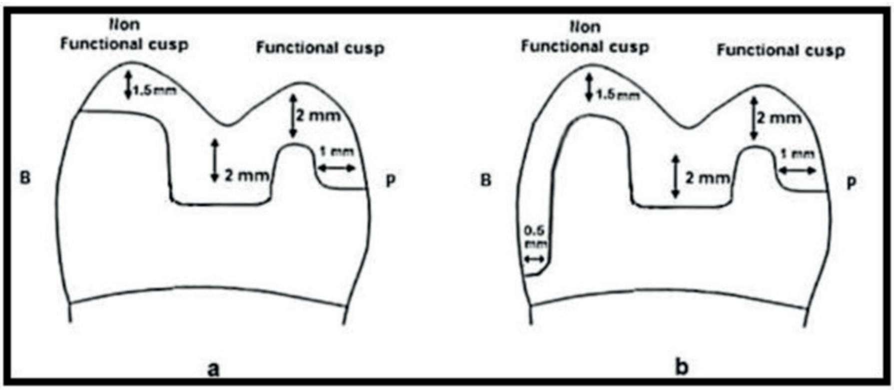

Figure 2. *a) onlay preparation dimensions, b) vonlay preparation dimensions (23)*

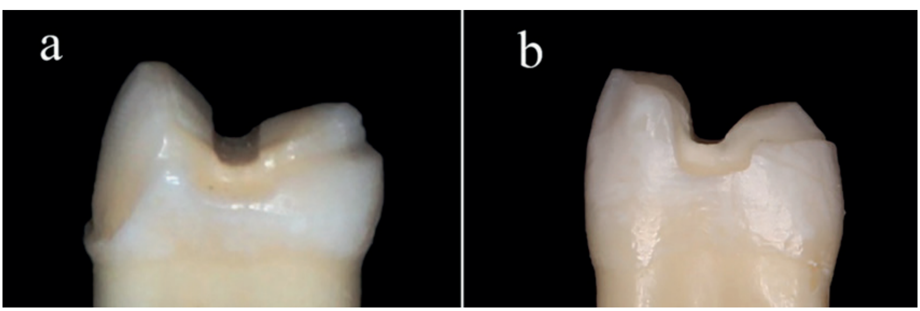

Figure 3. *(a) a vonlay tooth preparation, (b) overlay tooth preparation (24)*

Advantages and Disadvantages of Vonlay (Veneerlay) Restorations

Veneerlay (vonlay) restorations are hybrid indirect restorations that combine occlusal coverage with a buccal laminate veneer-like extension. This design aims to provide both functional durability and esthetic rehabilitation within a single restoration (4,5).

Advantages

1. Buccal coverage improves esthetics in posterior teeth with discoloration or enamel defects.

2. Occlusal coverage increases functional durability.

3. Less tooth structure is removed compared with full crowns.

4. In posterior regions with high esthetic demands, both occlusal and vestibular morphology can be corrected.

5. They provide a conservative alternative to full crowns in cases of extensive tissue loss (4).

Disadvantages

1. Because it combines veneer and onlay principles, preparation and cementation require high technical sensitivity.

2. Inadequate isolation may compromise bonding success.

3. Long-term success largely depends on proper adhesive protocol.

4. The thin buccal extension may increase the risk of ceramic fracture, particularly in patients with parafunctional habits.

5. Laboratory fabrication or CAD/CAM production increases cost compared with direct restorations.

6. Improper design may lead to periodontal irritation (25-27).

Indications

- Extensive structural loss in posterior teeth
- Presence of weakened cusps with risk of fracture
- Esthetic problems on the buccal surface (discoloration, enamel defects)
- Cases requiring both functional and esthetic restoration
- Occlusal rehabilitation in worn dentition

Cementation Protocol

For all indirect adhesive restorations:

1. Internal surface treatment of the restoration (etching and silane application)
2. Adhesive application on the tooth surface
3. Bonding with resin cement
4. Removal of excess cement and polymerization
5. Occlusal adjustment and polishing

Resin-based cements are preferred because of their low solubility and high bonding strength (6).

Comparative Evaluation

Restoration Type	Cusp Coverage	Indication	Tissue Preservation
Table-Top	Usually none (occlusal surface only)	Occlusal wear, erosion, vertical dimension rehabilitation	Very high
Inlay	None	Moderately wide cavities	High
Onlay	Partial	Presence of weakened cusps	Moderate
Overlay	Full	Extensive structural loss	Moderate
Vonlay (Veneerlay)	Partial + Buccal veneer	Esthetic and structural requirements	High

Table 1. *Comparative evaluation of restorations*

General Evaluation

Veneerlay restorations represent a rational treatment option in cases where esthetic demands and structural reinforcement are both required. However, success depends on proper case selection, enamel-dominant preparation, and meticulous application of adhesive protocols. Careful planning is particularly necessary in patients with strong parafunctional forces.

Conclusion

Inlay, onlay, overlay, and veneerlay restorations are indirect treatment options that aim to achieve a clinical balance between preservation of tooth structure and mechanical durability. The choice of restoration type should be based on the remaining tooth structure, occlusal load, and esthetic requirements.

REFERENCES

1. Edelhoff D, Sorensen JA. Tooth structure removal associated with various preparation designs for posterior teeth. Int J Periodontics Restorative Dent. 2002;22(3):241-249.
2. Fan J, Xu Y, Si L, Li X, Fu B, Hannig M. Long-term clinical performance of composite resin or ceramic inlays, onlays, and overlays: A systematic review and meta-analysis. Oper Dent. 2021;46(1):25–44.
3. Angeletaki F, Gkogkos A, Papazoglou E, Kloukos D. Direct versus indirect inlay/onlay composite restorations in posterior teeth: A systematic review and meta-analysis. J Dent. 2016;53:12-21.
4. Roberson TM, Heymann HO, Swift EJ. Sturdevant's art and science of operative dentistry. 6th ed. St. Louis: Elsevier; 2019.
5. Summitt JB, Robbins JW, Hilton TJ, Schwartz RS. Fundamentals of operative dentistry. 4th ed. Chicago: Quintessence Publishing; 2013.
6. Anusavice KJ, Shen C, Rawls HR. Phillips' science of dental materials. 12th ed. St. Louis: Elsevier; 2013.
7. Magne P, Belser UC. Bonded porcelain restorations in the anterior dentition: a biomimetic approach. Chicago: Quintessence Publishing; 2002.
8. Veneziani M. Posterior indirect adhesive restorations: updated indications and the morphology-driven preparation technique. Int J Esthet Dent. 2017;12(2):204-230.
9. Naik VB, Jain AK, Rao RD, Naik BD. Comparative evaluation of clinical performance of ceramic and resin inlays, onlays, and overlays: A systematic review and meta-analysis. J Conserv Dent. 2022;25(4):347–355.
10. McLaren EA, Figueira J, Goldstein RE. Vonlays: A conservative esthetic alternative to full-coverage crowns. Compend Contin Educ Dent. 2015;36(4):282–287.
11. Elsayed M, Sherif R, El-Khodary N. Fracture resistance of Vita Suprinity versus IPS e.max CAD vonlays restoring premolars: An in vitro study. Int J Appl Dent Sci. 2020;6(3):734–741.
12. Guess PC, Schultheis S, Wolkewitz M, Zhang Y, Strub JR. Influence of preparation design and ceramic thicknesses on fracture resistance and failure modes of premolar partial-coverage restorations. J Prosthet Dent. 2013;110(4):264–273.
13. Dentaire365. Numérique et restaurations indirectes unitaires partielles postérieures: l'évidence actuelle [Internet]. Available from: https://www.dentaire365.fr/clinique/numerique-et-restaurations-indirectes-unitaires-partielles-posterieures-levidence-actuelle/
14. Morimoto S, Rebello de Sampaio FBW, Braga MM, Sesma N, Ozcan M. Survival rate of resin and ceramic inlays, onlays, and overlays: A systematic review and

meta-analysis. J Dent Res. 2016;95(9):985-994.

15. Peumans M, Van Meerbeek B, Lambrechts P, Vanherle G. Porcelain veneers: A review of the literature. J Dent. 2000;28(3):163-177.
16. Rocca GT, Krejci I. Bonded indirect restorations for posterior teeth: From cavity preparation to provisionalization. Quintessence Int. 2007;38(5):371-379.
17. Güth JF, Edelhoff D. Minimally invasive rehabilitation of worn dentition. Int J Esthet Dent. 2015;10(3):368–389.
18. Kelly JR, Benetti P. Ceramic materials in dentistry: Historical evolution and current practice. Aust Dent J. 2011;56(Suppl 1):84–96.
19. Fennis WM, Kuijs RH, Kreulen CM, Roeters FJ, Creugers NH. A survey of cusp fractures in a population of general dental practices. Int J Prosthodont. 2002;15(6):559–563.
20. Dietschi D, Spreafico R. Current clinical concepts for adhesive cementation of tooth-colored posterior restorations. Pract Periodontics Aesthet Dent. 1998;10(1):47–54.
21. Ferraris F. Posterior indirect adhesive restorations (PIAR): preparation designs and adhesthetics clinical protocol. Int J Esthet Dent. 2017;12(4):482-502.
22. Mohamad AH, Omaima S, Eman M, Anwar M. Clinical outcomes of premolars restored with ceramic vonlays versus onlays. Pharmacophore. 2021;12(6):38-44.
23. Hazzaa MA, El-Mahallawi OS, Anwar E, Badran A. Clinical outcomes of premolars restored with ceramic vonlay restorations versus onlay using modified USPHS criteria: A randomized clinical trial. J Conserv Dent. 2023;14(3):1010–1021.
24. Abdelaal AM, Kehela HA, Holiel AA. Fracture resistance and fractographic analysis of pressable glass ceramics with different partial coverage designs for maxillary premolars. BMC Oral Health. 2024;24(1):1078.
25. Zarow M, Devoto W, Saracinelli M. Reconstruction of endodontically treated posterior teeth with minimal invasive adhesive restorations. J Prosthet Dent. 2009;101(4):243–251.
26. Blatz MB, Sadan A, Kern M. Resin-ceramic bonding: a review of the literature. J Prosthet Dent. 2003;89(3):268–274.
27. Fasbinder DJ. Chairside CAD/CAM: an overview of restorative material options. Compend Contin Educ Dent. 2012;33(1):50–58.

Chapter 3

DIGITAL TWINS IN ENDODONTICS: BRIDGING SIMULATION, RESEARCH AND CLINICAL DECISION-MAKING

Mevlüt Sinan OCAK[1]

1 Assistant Professor, Department of Endodontics, Faculty of Dentistry, Fırat University
ORCID ID: 0000-0002-3121-2116

Introduction: Why Endodontics Needs a Paradigm Shift

Over the past two decades, endodontics has undergone a remarkable digital transformation. Advanced imaging modalities such as cone beam computed tomography (CBCT), computer-aided design/computer-aided manufacturing (CAD/CAM) workflows, guided endodontics, and artificial intelligence (AI)–assisted diagnostic tools have significantly enhanced the clinician's ability to visualise complex root canal anatomy, detect periapical pathology, and improve procedural accuracy. Despite these advances, contemporary endodontic workflows largely remain non-adaptive and time-static, offering single time-point representations of anatomy and disease rather than dynamic, patient-specific predictions (Patel et al., 2019; Connert et al., 2022; Krastl et al., 2016).

Current digital technologies in endodontics frequently operate as partially isolated modules. CBCT provides high-resolution three-dimensional anatomical information, yet it is typically interpreted as a static dataset and does not evolve as treatment progresses. Similarly, AI-based systems have shown promise in radiographic interpretation and outcome prediction; however, most applications remain limited to diagnostic support and lack integration into continuous feedback loops incorporating longitudinal patient data (Aminoshariae et al., 2021; Setzer et al., 2024; Nagendrababu et al., 2023). Consequently, treatment planning and prognostic assessment continue to rely heavily on clinician experience rather than fully integrated, data-driven predictive systems.

These limitations are particularly evident in complex clinical scenarios, including teeth with pulp canal obliteration, severe calcification, or atypical canal morphologies. In such contexts, standardised treatment strategies may increase the risk of iatrogenic complications and compromise structural integrity. Guided endodontics has demonstrated clear benefits in managing calcified canals and improving access precision; nevertheless, it remains primarily a task-specific solution rather than a comprehensive platform for adaptive and predictive care (Vasudevan et al., 2022; Jain et al., 2023; Connert et al., 2018).

Digital twin (DT) technology has emerged as a conceptual framework capable of addressing these challenges by enabling patient-specific simulation and predictive decision-making. Originating in aerospace and industrial engineering, a digital twin is defined as a high-fidelity virtual replica of a physical system that is continuously updated using new data throughout its lifecycle. In healthcare, digital twins have been increasingly discussed as enablers of precision medicine by integrating multimodal data streams to simulate physiological responses and optimise interventions (Björnsson et al., 2020; Corral-Acero et al., 2020).

When applied to endodontics, digital twins could theoretically integrate CBCT imaging, intraoral scanning data, electronic dental records, procedural parameters, biomechanical simulations, and follow-up findings into an adaptive virtual model of the tooth and surrounding tissues. Such a system would allow clinicians to compare access cavity designs, shaping strategies, and disinfection protocols in silico before irreversible clinical steps are undertaken, while continuously refining prognostic estimates as new data become available. Recent literature has highlighted digital twins as a potential pathway from reactive to predictive root canal treatment, while also emphasising the current translational and validation gaps (Turky & Dummer, 2026).

At present, fully operational digital twin systems are not available in routine endodontic practice. However, the convergence of CBCT-based planning, guided endodontic workflows, AI-driven analytics, and patient-specific biomechanical modelling suggests that the development of digital twins represents an achievable translational goal rather than a distant aspiration (Patel et al., 2019; Krastl et al., 2016; Nagendrababu et al., 2023).

The aim of this book chapter is to explore the conceptual foundations, potential clinical and research applications, and translational pathways of digital twin technology in endodontics. By synthesising evidence from digital dentistry, biomedical engineering, and computational modelling, this chapter proposes a structured roadmap towards predictive and personalised root canal care.

2. Digital Twin Concept: Beyond Artificial Intelligence and Three-Dimensional Models

The concept of a digital twin (DT) is frequently conflated with artificial intelligence–based systems or three-dimensional (3D) digital models. Although these technologies share certain overlapping components, a digital twin represents a fundamentally different paradigm. Clarifying this distinction is essential before considering the potential role of DTs in endodontics (Tao et al., 2019; Saghiri et al., 2023).

Conventional 3D digital models in dentistry, such as CBCT-based reconstructions or surface scan–derived models, provide static representations of anatomical structures. These models are invaluable for visualisation, education, and procedural planning; however, once generated, they do not adapt to biological variation, procedural changes, or post-treatment outcomes. Even when integrated into computer-aided design or navigation workflows, traditional 3D models capture anatomy but not the dynamic biological or mechanical behaviour of dental tissues (Patel et al., 2019; Patel et al., 2015).

Artificial intelligence, by contrast, excels in pattern recognition, classification, and prediction based on large datasets. In endodontics, AI applications have predominantly focused on radiographic interpretation, detection of periapical lesions, identification of anatomical features, and prediction of treatment outcomes. While these systems can enhance diagnostic consistency and efficiency, most current AI models function as isolated decision-support tools and are not continuously updated using patient-specific feedback or longitudinal clinical data (Aminoshariae et al., 2021; Setzer et al., 2024; Nagendrababu et al., 2023).

A digital twin transcends both static modelling and stand-alone AI by integrating geometry, data streams, and predictive simulation into a continuously evolving virtual entity. A DT can be defined as a living digital counterpart of a physical system that remains synchronised with its real-world analogue throughout its lifecycle. This synchronisation is achieved through the continuous ingestion of data from imaging, clinical records, sensors, and follow-up assessments, allowing the virtual model to learn, adapt, and refine its predictions over time (Björnsson et al., 2020; Corral-Acero et al., 2020; Tao et al., 2019).

From a functional perspective, three core characteristics distinguish a digital twin from other digital technologies. First, DTs operate through bidirectional data exchange, whereby information from the physical system updates the virtual model and insights from the virtual model inform clinical decision-making. Second, DTs are inherently predictive, enabling the simulation of multiple treatment scenarios and their potential outcomes before irreversible clinical actions are undertaken. Third, digital twins are patient-specific by design, reflecting individual anatomical, biological, and biomechanical characteristics rather than population-based averages (Corral-Acero et al., 2020; Saghiri et al., 2023).

In healthcare, these attributes have enabled DTs to model complex physiological systems such as cardiac mechanics, tumour growth, and orthopaedic load distribution. The clinical value of DTs in these disciplines lies not only in enhanced visualisation but also in their capacity to forecast responses to interventions, optimise treatment strategies, and reduce uncertainty in complex decision-making processes (Björnsson et al., 2020; Corral-Acero et al., 2020). Translating this framework into endodontics opens new possibilities for modelling the pulp–dentine complex as a dynamic biological system rather than a static anatomical space.

Within an endodontic context, a digital twin could theoretically integrate CBCT-derived canal morphology, intraoral scanning data, patient-specific biological parameters, and computational biomechanical models into a unified adaptive platform. Unlike current digital workflows, such a system would not merely assist in procedural planning but would actively simulate how a specific tooth might respond to access cavity preparation, canal shaping, disinfection protocols, and restorative loading over time. As new clinical or radiographic data become available, the digital twin would update accordingly, refining prognostic estimates and guiding follow-up strategies (Turky & Dummer, 2026; Saghiri et al., 2023).

Importantly, the digital twin concept should be understood not as a single technology but as an overarching architectural framework that orchestrates multiple digital components into a coherent, adaptive system. Artificial intelligence, finite element analysis, computational fluid dynamics, and advanced imaging are not alternatives to digital twins; rather, they function as enabling technologies within a DT ecosystem. Recognising this integrative nature is crucial for appreciating why digital twins represent a qualitative leap, rather than an incremental upgrade, in digital endodontic care and research (Corral-Acero et al., 2020; Tao et al., 2019).

3. Existing Digital Foundations in Endodontics

Although fully integrated digital twin systems are not yet available in routine endodontic practice, many of the technological components required for their development are already well established. Contemporary endodontics is characterised by a rapidly expanding digital ecosystem that enables the acquisition, processing, and interpretation of patient-specific data. When considered collectively rather than as isolated tools, these technologies constitute a robust foundation for the future development of digital twin frameworks in endodontics (Patel et al., 2019; Connert et al., 2022).

3.1 Cone Beam Computed Tomography and Intraoral Scanning

Cone beam computed tomography (CBCT) has become a cornerstone of modern endodontic diagnosis and treatment planning by providing high-resolution three-dimensional visualisation of root canal morphology, periapical tissues, and surrounding anatomical structures. CBCT facilitates the detection of additional canals, complex curvatures, resorptive defects, and periapical pathology that may not be evident on conventional radiographs (Patel et al., 2019; Patel et al., 2015; European Society of Endodontology, 2014). However, CBCT data are typically interpreted as static datasets representing a single time point and do not inherently capture procedural or biological changes occurring during or after treatment.

Intraoral scanning complements CBCT by capturing accurate digital representations of coronal tooth structure, occlusal relationships, and restorative margins. The integration of CBCT and intraoral scan data enables comprehensive three-dimensional reconstruction of both internal and external tooth anatomy, forming the geometric backbone of contemporary digital workflows such as guided endodontics and CAD/CAM-based restorative planning (Mangano et al., 2017; Ender & Mehl, 2013). Within a digital twin framework, these imaging modalities would serve as the initial anatomical reference model that could be iteratively updated as new clinical or radiographic data become available.

3.2 Guided Endodontics: Static and Dynamic Navigation Systems

Guided endodontics represents one of the most clinically mature applications of digital technology in complex endodontic scenarios. Static guided endodontics relies on CBCT-derived datasets and surface scans to fabricate customised guides that direct bur trajectories during access cavity preparation, particularly in teeth with pulp canal obliteration or severe calcification (Krastl et al., 2016; Vasudevan et al., 2022). Dynamic navigation systems extend this concept by providing real-time tracking of the handpiece relative to patient anatomy, allowing intraoperative adjustments based on live feedback (Vasudevan et al., 2022; Jain et al., 2023; Connert et al., 2018).

Clinical and laboratory studies consistently demonstrate that guided endodontic techniques improve access accuracy, reduce unnecessary dentine removal, and minimise iatrogenic complications. Nevertheless, these systems remain primarily task-specific solutions focused on access cavity preparation. They do not incorporate biological variables, microbial dynamics, or long-term biomechanical considerations, thereby limiting their capacity to support adaptive or predictive treatment planning (Connert et al., 2022; Connert et al., 2018).

3.3 Artificial Intelligence–Based Diagnostic Systems

Artificial intelligence has gained increasing prominence in endodontics, particularly in the automated interpretation of radiographic images. AI-driven algorithms have been developed to detect periapical lesions, identify root canal morphology, assess treatment outcomes, and support diagnostic decision-making with growing accuracy and consistency (Aminoshariae et al., 2021; Setzer et al., 2024; Nagendrababu et al., 2023). These systems have demonstrated potential to reduce observer variability and improve diagnostic standardisation across clinicians with varying levels of experience.

Despite these advantages, most current AI applications function as stand-alone analytical tools. They typically rely on pre-trained datasets and lack mechanisms for continuous learning from individual patient outcomes or longitudinal follow-up data. Within a digital twin ecosystem, AI would operate as an embedded analytical engine that continuously refines predictive simulations as new patient-specific data are acquired, rather than as an isolated diagnostic module (Nagendrababu et al., 2023; Saghiri et al., 2023).

3.4 Finite Element Analysis and Biomechanical Modelling

Finite element analysis (FEA) has been extensively applied in endodontic research to investigate stress distribution within root canal–treated teeth under various restorative and occlusal loading conditions. This approach enables non-destructive evaluation of how access cavity design, canal preparation, obturation techniques, and restorative materials influence biomechanical behaviour and fracture risk (Ausiello et al., 2017; Abdelhafeez, 2024; Versluis & Tantbirojn, 2013).

Historically, FEA models have relied on simplified geometries and average material properties, limiting their direct clinical applicability. Advances in imaging, segmentation, and computational power now allow the generation of patient-specific biomechanical models based on CBCT data. When integrated into a digital twin framework, such models could be dynamically updated to reflect progressive structural changes, enabling personalised predictions of long-term tooth survival rather than static, population-based estimates (Abdelhafeez, 2024; Versluis & Tantbirojn, 2013).

3.5 Digital Instrumentation and Irrigation Technologies

Technological advances in root canal instrumentation and irrigation further contribute to the digital foundation required for digital twin development. Contemporary irrigation systems designed to enhance intracanal fluid dynamics have demonstrated improved debridement and disinfection efficacy compared with conventional syringe irrigation (Haapasalo et al., 2014). In parallel, modern engine-driven instrumentation systems increasingly incorporate torque control, rotational speed modulation, and real-time feedback mechanisms to enhance procedural safety and efficiency (Peters et al., 2015).

Although these technologies are not yet integrated into comprehensive digital models, they generate valuable procedural data related to instrument stress, canal shaping dynamics, and irrigant behaviour. Such data streams could inform digital twin simulations by enabling real-time or retrospective modelling of procedural risks, including instrument fatigue and fracture potential (Ruffa et al., 2023).

3.6 Integrating Existing Technologies into a Digital Twin Ecosystem

Individually, CBCT imaging, guided endodontics, artificial intelligence, finite element analysis, and digital instrumentation represent incremental advances in endodontic care. Collectively, however, they form an interconnected digital infrastructure capable of supporting adaptive, patient-specific simulation. The transition from isolated digital applications to integrated digital twin systems does not require a complete technological overhaul; rather, it necessitates conceptual integration, data interoperability, and workflow harmonisation (Corral-Acero et al., 2020; Tao et al., 2019; Saghiri et al., 2023).

By leveraging these existing digital foundations, endodontics is uniquely positioned to evolve towards a predictive and personalised model of care. The following section explores how these foundational technologies could be orchestrated within digital twin frameworks to enable novel conceptual applications in clinical endodontics.

4. Conceptual Applications of Digital Twins in Endodontics

4.1 Patient-Specific Root Canal Anatomy Simulation

Anatomical complexity remains one of the principal challenges in endodontic treatment. Variations in root canal morphology, including complex curvatures, isthmuses, lateral canals, and apical deltas, are well-recognised contributors to procedural difficulty and treatment failure (Vertucci, 1984; Ahmed et al., 2017; Ordinola-Zapata et al., 2013). Conventional imaging modalities, even when three-dimensional, may not fully capture the clinical implications of such variability.

From a theoretical perspective, digital twins could integrate CBCT-derived datasets with advanced segmentation and reconstruction algorithms to generate patient-specific, high-fidelity anatomical models of the pulp–dentine complex. These models would enable detailed virtual exploration of canal systems beyond static image interpretation. Clinically, this capability would allow practitioners to assess canal morphology preoperatively and to virtually test alternative access cavity designs before initiating treatment.

Such simulations may be particularly valuable in teeth with pulp canal obliteration or severe calcification, where the risk of perforation or excessive dentine removal is high. By enabling in silico canal location and access strategies, digital twins could complement guided endodontic approaches and further enhance procedural safety and precision (Vasudevan et al., 2022; Connert et al., 2018).

4.2 Optimisation of Access Cavity Preparation and Canal Shaping

Access cavity design and canal shaping strategies have a direct influence on both disinfection efficacy and long-term structural integrity of endodontically treated teeth. From a theoretical standpoint, digital twins could integrate biomechanical modelling techniques, such as finite element analysis, to simulate how different access designs and shaping protocols affect stress distribution within the remaining tooth structure (Ausiello et al., 2017; Versluis & Tantbirojn, 2013; Abdelhafeez, 2024).

Clinically, this approach could allow practitioners to compare minimally invasive and traditional access cavities on a case-by-case basis rather than relying on generalised concepts. Similarly, instrumentation strategies—such as file sequence, taper selection, and working length—could be evaluated virtually to balance canal cleanliness with dentine preservation. This predictive capability supports a shift towards individualised shaping strategies tailored to each tooth's anatomical and biomechanical characteristics.

4.3 Modelling Microbial Biofilm Behaviour and Disinfection Efficacy

Persistent intraradicular infection remains the primary cause of endodontic treatment failure. Experimental and computational studies have demonstrated that anatomical complexity and irrigant flow dynamics significantly influence biofilm disruption and disinfection efficacy (Shen et al., 2010; Boutsioukis et al., 2010; Mohmmed et al., 2016). Digital twins could theoretically integrate patient-specific anatomy with computational fluid dynamics and microbiological models to simulate irrigant behaviour within complex canal systems.

From a clinical perspective, such modelling could support personalised disinfection strategies by enabling virtual comparison of irrigation solutions, activation techniques, and treatment durations. Rather than applying uniform protocols, clinicians could adapt antimicrobial approaches to the specific anatomical and microbial challenges of each case, potentially improving treatment predictability (Haapasalo et al., 2014; Haapasalo & Shen, 2012).

4.4 Instrument Stress, Fatigue, and Fracture Risk Prediction

Instrument separation remains a significant procedural complication in endodontics and is closely associated with canal curvature, cyclic fatigue, and torsional stress. Theoretically, digital twins could integrate canal geometry, instrument design parameters, and kinematic data to model stress accumulation and fatigue behaviour during canal preparation (Peters, 2004; Sattapan et al., 2000).

Clinically, this predictive capability could translate into preoperative or real-time risk assessment, enabling clinicians to modify instrumentation strategies before instrument failure occurs. By identifying high-risk regions within the canal system, digital twins may contribute to safer instrumentation and a proactive approach to fracture prevention (Ruffa et al., 2023).

4.5 Prediction of Long-Term Restorability and Prognosis

Long-term success in endodontics depends not only on effective infection control but also on the biomechanical resilience of the treated tooth. Digital twins could integrate anatomical data, restorative design parameters, and occlusal loading conditions to simulate long-term stress distribution and fracture risk. Such simulations build upon established biomechanical evidence linking access cavity design, restorative approach, and tooth survival (Ausiello et al., 2017; Versluis & Tantbirojn, 2013; Tang et al., 2010).

Clinically, this capability may assist practitioners in selecting appropriate post-endodontic restorative strategies and in identifying cases with compromised long-term prognosis despite technically adequate canal treatment. Continuous updating of the digital twin with follow-up clinical and radiographic data could further refine prognostic assessments and support early intervention.

4.6 Clinical Relevance and Conceptual Integration

Although these applications remain largely conceptual, they illustrate how digital twins could bridge theoretical modelling and everyday clinical decision-making. By enabling virtual testing of treatment strategies, digital twins may reduce uncertainty, enhance procedural safety, and improve outcome predictability. Importantly, these systems should be regarded as decision-support tools that augment clinical expertise rather than replace clinician judgement.

5. Digital Twins as a Research Accelerator in Endodontics

Beyond their anticipated clinical applications, digital twins hold particular promise as research accelerators capable of transforming how hypotheses are generated, tested, and translated in endodontics. Traditional experimental and clinical research in this field is often constrained by biological variability, ethical considerations, limited sample availability, and high costs. Digital twin–based research frameworks offer a complementary approach by enabling systematic *in silico* investigation before laboratory or clinical validation (Björnsson et al., 2020; Corral-Acero et al., 2020; Vertucci, 1984).

5.1 In Silico Modelling as a Translational Bridge

In silico modelling has increasingly been recognised as a valuable intermediary between laboratory research and clinical practice. Digital twins extend this paradigm by integrating multiple computational models—anatomical, biomechanical, biological, and procedural—into a unified, adaptive framework. In endodontic research, such models could simulate interactions between root canal anatomy, instrumentation strategies, irrigant dynamics, microbial behaviour, and restorative loading within a single virtual environment (Shen et al., 2010; Boutsioukis et al., 2010).

From a translational perspective, this approach allows researchers to explore a wide range of variables and treatment scenarios without the constraints inherent to physical experimentation. By identifying the most influential parameters *in silico*, digital twins may help refine experimental design, reduce unnecessary laboratory testing, and accelerate the translation of findings into clinically relevant protocols.

5.2 Monte Carlo Simulations and Optical Modelling of Dental Tissues

Monte Carlo simulation techniques are widely regarded as the gold standard for modelling light transport in biological tissues. In dentistry, these methods have been used to investigate optical properties of enamel, dentine, and pulp, supporting the development of non-invasive diagnostic technologies (Moradi & Chen, 2023; Jacques, 2013).

Within a digital twin framework, Monte Carlo simulations could be combined with patient-specific anatomical and physiological data to generate personalised optical models of teeth. Such integration would allow researchers to virtually evaluate optical diagnostic tools under controlled conditions, improving understanding of light–tissue interactions while minimising experimental variability. This capability is particularly relevant for advancing diagnostic approaches related to pulp vitality and periapical tissue assessment.

5.3 Digital Optical Twins for Pulp Vitality Assessment

The concept of digital optical twins represents a specialised application of digital twin methodology focused on the optical behaviour of dental tissues. Conventional pulp vitality tests often provide indirect or inconsistent information and may be influenced by patient-related or methodological factors. Digital optical twins aim to overcome these limitations by simulating how optical signals interact with pulp tissue based on parameters such as blood flow, oxygenation, and dentinal scattering properties (Hevisov et al., 2025).

As research tools, digital optical twins enable systematic exploration of how physiological and pathological changes influence optical measurements. These models can be iteratively refined and validated against experimental data, strengthening the evidence base before clinical translation. Such an approach exemplifies how digital twins can support innovation while reducing reliance on invasive or ethically sensitive experimentation.

5.4 Modelling Microbial Dynamics and Regenerative Processes

Digital twins also offer significant potential for advancing research into microbial ecology and regenerative endodontics. Computational models embedded within a digital twin could simulate biofilm formation, maturation, and disruption in response to different disinfection strategies, taking into account patient-specific anatomy and fluid dynamics (Shen et al., 2010; Boutsioukis et al., 2010; Mohmmed et al., 2016).

Similarly, regenerative endodontic procedures could benefit from digital twin–based modelling of stem cell behaviour, scaffold characteristics, and tissue healing dynamics. By integrating biological, mechanical, and chemical parameters, such simulations may help identify key determinants of regenerative success and guide the optimisation of treatment protocols prior to clinical implementation (Murray et al., 2007).

5.5 Enhancing Reproducibility and Reducing Experimental Burden

A persistent challenge in endodontic research is the limited reproducibility associated with biological specimens and experimental conditions. Digital twin methodologies can enhance reproducibility by providing standardised virtual environments in which hypotheses can be tested repeatedly under controlled conditions. Although digital simulations cannot replace empirical research, they can serve as a computational preclinical stage that informs study design and prioritises the most promising experimental pathways (Vertucci, 1984; Boutsioukis et al., 2010).

By reducing the number of required laboratory experiments and animal studies, digital twins align endodontic research with broader ethical, sustainability, and resource-efficiency goals. The iterative feedback loop between simulation and experimentation further strengthens the translational value of digital twin–based research frameworks.

5.6 Implications for the Future of Endodontic Research

Collectively, these research-oriented applications highlight digital twins as catalysts for innovation rather than mere technological novelties. By enabling systematic exploration of complex, multiscale phenomena, digital twins can shorten the distance between theoretical concepts and clinically applicable solutions.

As computational power, data availability, and interdisciplinary collaboration continue to expand, digital twin–based research frameworks are likely to become increasingly accessible to the endodontic research community. Their adoption has the potential to redefine how evidence is generated and translated, fostering a more predictive, efficient, and patient-centred approach to endodontic science.

6. Translational Roadmap: From Research to Chairside Application

The successful implementation of digital twin technology in endodontics depends on a structured translational strategy that bridges theoretical research and routine clinical practice. Rather than representing a single disruptive leap, the adoption of digital twins should be viewed as a progressive, multi-phase process that builds incrementally upon existing digital infrastructures, clinical workflows, and regulatory frameworks (Björnsson et al., 2020; Corral-Acero et al., 2020; Tao et al., 2019).

6.1 Phase I: Retrospective Data Integration and Static Digital Twins

The initial translational phase involves the creation of retrospective or semi-static digital twins derived from existing clinical datasets. CBCT archives, intraoral scans, treatment records, and outcome data can be retrospectively integrated to generate virtual representations of root canal systems and treatment trajectories. At this stage, digital twins primarily serve as research and hypothesis-generation tools rather than real-time clinical decision aids (Vertucci, 1984; Boutsioukis et al., 2010).

From a clinical research perspective, these models enable identification of anatomical, procedural, and restorative factors associated with treatment success or failure. Importantly, Phase I implementation does not require real-time sensors or advanced chairside hardware, making it feasible within current academic and specialist clinical settings (Saghiri et al., 2023; Vertucci, 1984).

6.2 Phase II: Predictive Simulation and Clinical Decision-Support Systems

The second translational phase introduces predictive simulation capabilities into preoperative treatment planning. By integrating artificial intelligence, finite element analysis, and computational fluid dynamics, digital twins can begin to simulate potential outcomes of different access cavity designs, shaping strategies, and disinfection protocols before clinical intervention (Abdelhafeez, 2024; Ausiello et al., 2017; Versluis & Tantbirojn, 2013; Shen et al., 2010).

At this stage, digital twins function as clinician-guided decision-support systems rather than autonomous entities. Predictive outputs assist clinicians in comparing alternative strategies, while final decisions remain grounded in clinical judgement and patient-specific considerations. Similar decision-support paradigms have demonstrated clinical value in other areas of digital dentistry and precision medicine, supporting the feasibility of this approach in endodontics (Corral-Acero et al., 2020; Mangano et al., 2017).

6.3 Phase III: Adaptive and Continuously Updated Digital Twins

The final phase of translation envisions fully adaptive digital twins capable of continuous synchronisation with the physical tooth and surrounding tissues. Such systems would integrate longitudinal imaging updates, procedural metrics, sensor-derived data, and follow-up clinical findings to maintain alignment between the virtual and real-world systems (Björnsson et al., 2020; Tao et al., 2019).

In this mature stage, digital twins could support real-time risk assessment, prognostic monitoring, and personalised treatment optimisation across the full lifecycle of endodontic care. Although this level of integration remains aspirational within endodontics, analogous implementations in cardiology and orthopaedics suggest that such systems are technically achievable with sufficient interdisciplinary collaboration (Corral-Acero et al., 2020; Mangano et al., 2017).

6.4 Regulatory, Validation, and Standardisation Considerations

Translational success also depends on robust validation and regulatory oversight. Digital twin models must demonstrate reliability, transparency, and clinical relevance through rigorous validation against experimental and clinical outcomes. Standardised reporting frameworks and consensus guidelines will be essential to ensure reproducibility and facilitate comparison across studies (Vertucci, 1984; Boutsioukis et al., 2010; Viceconti et al., 2016).

From a regulatory perspective, digital twins intended for clinical decision support may fall under medical device regulations, requiring clear definition of intended use, risk classification, and clinician responsibility. Early engagement with regulatory bodies can help align technological development with clinical and legal requirements (U.S. Food and Drug Administration, 2017).

6.5 Education, Interdisciplinary Collaboration, and Clinical Adoption

The translation of digital twins into routine endodontic practice will require parallel advances in professional education and interdisciplinary collaboration. Clinicians must acquire foundational digital literacy skills to critically interpret simulations, understand model limitations, and appropriately integrate predictive outputs into clinical decision-making (Saghiri et al., 2023; Topol, 2019a).

Interdisciplinary collaboration between endodontists, biomedical engineers, computer scientists, and data analysts will be central to developing clinically relevant digital twin systems. Embedding such collaboration within academic training programmes and research networks may accelerate innovation while ensuring that technological solutions remain aligned with real clinical needs.

6.6 From Translational Roadmap to Clinical Reality

Collectively, these phases outline a pragmatic roadmap for translating digital twin concepts into clinically meaningful tools. By progressing from retrospective modelling to predictive decision support and ultimately to adaptive digital twins, endodontics can gradually transition towards a more predictive and personalised model of care.

Rather than replacing established clinical expertise, digital twins should be regarded as enabling technologies that enhance decision-making, reduce uncertainty, and support evidence-informed practice. The following section addresses the ethical, educational, and practical challenges that must be navigated to ensure responsible and equitable implementation of digital twin systems in endodontics.

7. Ethical, Educational, and Clinical Challenges

The integration of digital twin technology into endodontic practice presents not only technical and translational challenges but also a series of ethical, educational, and clinical considerations that must be addressed to ensure responsible and equitable implementation. As digital twins increasingly influence diagnostic reasoning and treatment planning, clear frameworks are required to safeguard patient rights, maintain professional accountability, and support clinician competence (Floridi & Cowls, 2019; Mittelstadt et al., 2016; Topol, 2019b).

7.1 Data Privacy, Security, and Ethical Governance

Digital twin systems rely on the aggregation and continuous updating of large volumes of patient-specific data, including imaging records, clinical notes, procedural parameters, and longitudinal outcomes. Ensuring data privacy and security is therefore a fundamental ethical requirement. Compliance with data protection regulations, such as the General Data Protection Regulation (GDPR) and comparable international frameworks, is essential when handling sensitive health information (European Union, 2016; Rumbold & Pierscionek, 2017).

Beyond regulatory compliance, ethical governance must address issues of informed consent, data ownership, and secondary data use. Patients should be clearly informed about how their data contribute to digital twin models, how long data are retained, and whether data may be reused for research or algorithm refinement. Transparent governance structures are necessary to maintain public trust and support the long-term sustainability of digital twin initiatives (Mittelstadt et al., 2016; Rumbold & Pierscionek, 2017).

7.2 Accountability, Transparency, and Clinical Responsibility

As digital twins evolve from passive simulation tools to active decision-support systems, questions of accountability become increasingly salient. Predictive outputs generated by digital twins may influence clinical decisions, yet responsibility for treatment outcomes must remain clearly defined. Digital twins should be designed to augment clinician judgement rather than replace it, preserving professional autonomy and ethical responsibility (Floridi & Cowls, 2019; London, 2019).

Transparency of underlying models and algorithms is also critical. Clinicians must be able to understand, at least at a conceptual level, how predictions are generated and what assumptions underpin them. The use of explainable artificial intelligence within digital twin frameworks may help mitigate the risks associated with "black-box" decision-making and reduce inappropriate reliance on automated recommendations (London, 2019; Holzinger et al., 2019).

7.3 Educational Implications and Digital Literacy

The successful adoption of digital twin technology will require a corresponding evolution in dental education and continuing professional development. Clinicians must acquire digital literacy skills that enable them to interpret simulations, critically evaluate predictive outputs, and recognise model limitations. Without adequate training, there is a risk of misinterpretation or overreliance on digital predictions, potentially compromising patient care (Topol, 2019a; Schwendicke et al., 2020).

Integrating digital health, artificial intelligence, and simulation-based learning into undergraduate and postgraduate endodontic curricula may help prepare future clinicians for digital twin–enabled practice. Interdisciplinary educational initiatives involving collaboration between dentists, engineers, and data scientists may further enhance understanding and foster innovation while maintaining clinical relevance (Schwendicke et al., 2020; Ellaway & Masters, 2008).

7.4 Clinical Workflow Integration and Usability

From a practical standpoint, digital twin systems must be seamlessly integrated into existing clinical workflows to gain acceptance among practitioners. Systems that increase chairside time, require complex data entry, or disrupt established routines are unlikely to achieve widespread adoption. User-centred design, interoperability with electronic dental records, and intuitive visualisation tools are therefore critical determinants of clinical usability (Mittelstadt et al., 2016; Bates & Singh, 2018).

Additionally, variability in clinical settings, ranging from academic centres to private practices, necessitates scalable and adaptable implementation strategies. Digital twin platforms must accommodate differing levels of technological infrastructure and resource availability without compromising core functionality.

7.5 Equity, Access, and the Risk of Digital Disparities

While digital twin technology holds promise for improving precision and predictability in endodontic care, it also carries the risk of exacerbating existing inequalities in access to advanced dental technologies. High implementation costs, infrastructure requirements, and training demands may limit availability to well-resourced centres, widening disparities between healthcare systems and patient populations (Topol, 2019b; Veinot et al., 2018).

Addressing these challenges will require proactive strategies aimed at equitable access, including cost-effective system design, shared digital infrastructure, and evidence-based assessment of clinical value. Ensuring that digital twin technologies contribute to improved outcomes across diverse clinical contexts is essential for their ethical justification and long-term integration into endodontic practice.

7.6 Navigating Challenges Towards Responsible Implementation

Collectively, the ethical, educational, and clinical challenges outlined above underscore the importance of a cautious and principled approach to digital twin adoption. By embedding ethical governance, transparency, and education into translational strategies, the endodontic community can mitigate risks while maximising potential benefits.

Rather than viewing these challenges as barriers, they should be recognised as integral components of responsible innovation. Addressing them proactively will help ensure that digital twin technology enhances patient care, supports clinician expertise, and aligns with the broader goals of ethical and sustainable healthcare.

8. Future Perspectives and Conclusion

The concept of digital twin technology represents more than a technological advancement; it signifies a fundamental shift in how endodontic care may be conceptualised, planned, and delivered in the future. By integrating patient-specific data, predictive modelling, and continuous feedback, digital twins offer a framework through which endodontics can evolve from a predominantly reactive discipline to one that is predictive, adaptive, and personalised (Björnsson et al., 2020; Corral-Acero et al., 2020; Floridi & Cowls, 2019).

8.1 Future Perspectives

In the foreseeable future, the gradual convergence of advanced imaging, artificial intelligence, biomechanical modelling, and computational biology is likely to facilitate the development of increasingly sophisticated digital twin systems. Rather than fully autonomous platforms, early clinical implementations are expected to function as clinician-centred decision-support tools that enhance diagnostic precision and treatment planning while preserving professional judgement (Björnsson et al., 2020; Corral-Acero et al., 2020; Floridi & Cowls, 2019).

As data interoperability standards mature and computational power becomes more accessible, digital twins may expand beyond single-tooth models to encompass multi-tooth units and broader oral–systemic interactions. Such evolution could allow the exploration of relationships between endodontic pathology, occlusal loading, restorative design, and systemic health factors within unified virtual environments. This perspective aligns with current discussions on precision medicine and human-centred artificial intelligence in healthcare (Floridi & Cowls, 2019; London, 2019).

From a research perspective, digital twins are poised to play a central role in accelerating hypothesis generation, optimising experimental design, and reducing reliance on extensive in vitro and in vivo studies. The integration of *in silico* trials and simulation-based validation within digital twin frameworks reflects broader shifts towards computationally supported evidence generation in medicine and dentistry (Viceconti et al., 2016).

8.2 Limitations and Realistic Expectations

Despite their promise, digital twins should not be regarded as immediate solutions to all clinical challenges in endodontics. Data quality, model validity, and interpretability remain critical limitations that must be addressed through rigorous validation and transparent reporting. Moreover, the inherent complexity of biological systems means that predictive outputs will always be associated with a degree of uncertainty, underscoring the continued importance of clinical expertise and critical judgement (London, 2019; Holzinger et al., 2019).

Recognising these limitations is essential to avoid unrealistic expectations and inappropriate reliance on predictive technologies. Ethical frameworks emphasising transparency, explainability, and proportional use of artificial intelligence are therefore directly applicable to the responsible implementation of digital twins in clinical endodontics (Floridi & Cowls, 2019; London, 2019).

8.3 Concluding Remarks

In conclusion, digital twin technology provides a unifying conceptual framework that aligns ongoing digital innovations with the clinical realities of endodontic practice. By enabling virtual simulation of treatment strategies, prediction of biological and mechanical responses, and continuous model refinement, digital twins hold the potential to enhance diagnostic accuracy, procedural safety, and long-term treatment outcomes (Björnsson et al., 2020; Corral-Acero et al., 2020).

The successful integration of digital twins into endodontics will require more than technological innovation alone. Ethical governance, robust validation, interdisciplinary collaboration, and targeted educational reform are equally essential to ensure responsible adoption. When approached with these principles in mind, digital twins can serve not as replacements for clinical expertise, but as powerful allies that support evidence-informed, patient-centred care (Viceconti et al., 2016; Floridi & Cowls, 2019).

Ultimately, the journey towards digital twin–enabled endodontics reflects a broader transformation within healthcare—one that seeks to anticipate rather than react, to personalise rather than standardise, and to integrate technology in service of improved patient outcomes. Embracing this paradigm thoughtfully and critically may define the next frontier of contemporary endodontic practice.

References

Abdelhafeez, M. M. (2024). Applications of finite element analysis in endodontics: A systematic review and meta-analysis. *Journal of Pharmacy and Bioallied Sciences, 16*(Suppl 1), S26–S36.

Ahmed, H. M. A., Versiani, M. A., De-Deus, G., & Dummer, P. M. H. (2017). A new system for classifying root and root canal morphology. *International Endodontic Journal, 50*(8), 761–770.

Aminoshariae, A., Kulild, J. C., & Nagendrababu, V. (2021). Artificial intelligence in endodontics: Current applications and future directions. *Journal of Endodontics, 47*(9), 1352–1357.

Ausiello, P., Ciaramella, S., De Benedictis, A., et al. (2017). Stress distribution in endodontically treated teeth restored with different post systems: A 3D finite element analysis. *Dental Materials, 33*(4), 450–458.

Bates, D. W., & Singh, H. (2018). Two decades since *To Err Is Human*: An assessment of progress and emerging priorities in patient safety. *Health Affairs, 37*(11), 1736–1743.

Björnsson, B., Borrebaeck, C. A. K., Elander, N., et al. (2020). Digital twins to personalize medicine. *Genome Medicine, 12*, 4.

Boutsioukis, C., Verhaagen, B., Versluis, M., et al. (2010). Evaluation of irrigant flow using computational fluid dynamics. *International Endodontic Journal, 43*(10), 909–916.

Connert, T., Weiger, R., & Krastl, G. (2022). Present status and future directions – guided endodontics. *International Endodontic Journal, 55*(Suppl 4), 995–1002.

Connert, T., Zehnder, M. S., Amato, M., et al. (2018). Microguided endodontics. *International Endodontic Journal, 51*(2), 247–255.

Corral-Acero, J., Margara, F., Marciniak, M., et al. (2020). The digital twin to enable the vision of precision cardiology. *European Heart Journal, 41*(48), 4556–4564.

Ellaway, R., & Masters, K. (2008). AMEE Guide 32: E-learning in medical education. *Medical Teacher, 30*(5), 455–473.

Ender, A., & Mehl, A. (2013). Accuracy of complete-arch dental impressions: A new method of measuring trueness and precision. *Journal of Prosthetic Dentistry, 109*(2), 121–128.

European Society of Endodontology. (2014). European Society of Endodontology position statement: The use of CBCT in endodontics. *International Endodontic Journal, 47*(6), 502–504.

European Union. (2016). *General Data Protection Regulation (GDPR)* (Regulation (EU) 2016/679).

Floridi, L., & Cowls, J. (2019). A unified framework of five principles for AI in society.

Harvard Data Science Review, 1(1).

Haapasalo, M., & Shen, Y. (2012). Evolution of root canal irrigation. *Endodontic Topics, 27*(1), 3–20.

Haapasalo, M., Shen, Y., Wang, Z., & Gao, Y. (2014). Irrigation in endodontics. *British Dental Journal, 216*(6), 299–303.

Hevisov, D., Ertl, T. P., & Kienle, A. (2025). Simulating pulp vitality measurements via digital optical twins. *Sensors, 25*, 3217.

Holzinger, A., Langs, G., Denk, H., Zatloukal, K., & Müller, H. (2019). Causability and explainable AI. *Artificial Intelligence in Medicine, 100*, 101–110.

Jacques, S. L. (2013). Optical properties of biological tissues: A review. *Physics in Medicine & Biology, 58*(11), R37–R61.

Jain, R. N., Rao, R. D., Jain, A., et al. (2023). Accuracy of static-guided endodontics for access cavity preparation: A systematic review and meta-analysis. *World Journal of Dentistry, 14*, 1004–1012.

Krastl, G., Zehnder, M. S., Connert, T., & Weiger, R. (2016). Guided endodontics: A novel treatment approach for teeth with pulp canal calcification and apical pathology. *Dental Traumatology, 32*(3), 240–246.

London, A. J. (2019). Artificial intelligence and black-box medical decisions: Accuracy versus explainability. *Hastings Center Report, 49*(1), 15–21.

Mangano, F., Gandolfi, A., Luongo, G., & Logozzo, S. (2017). Intraoral scanners in dentistry: A review. *BMC Oral Health, 17*, 149.

Mittelstadt, B. D., Allo, P., Taddeo, M., Wachter, S., & Floridi, L. (2016). The ethics of algorithms: Mapping the debate. *Big Data & Society, 3*(2), 1–21.

Mohmmed, S. A., Vianna, M. E., Penny, M. R., et al. (2016). Confocal microscopy evaluation of biofilm removal. *International Endodontic Journal, 49*(10), 948–957.

Moradi, M., & Chen, Y. (2023). Monte Carlo simulation of diffuse optical spectroscopy for 3D modeling of dental tissues. *Sensors, 23*, 5118.

Murray, P. E., Garcia-Godoy, F., & Hargreaves, K. M. (2007). Regenerative endodontics: A review of current status. *Journal of Endodontics, 33*(4), 377–390.

Nagendrababu, V., Duncan, H. F., et al. (2023). Artificial intelligence in endodontics: A scoping review. *International Endodontic Journal, 56*(4), 526–544.

Ordinola-Zapata, R., Bramante, C. M., Versiani, M. A., et al. (2013). Morphologic micro-CT analysis of mandibular molars. *Journal of Endodontics, 39*(9), 1137–1141.

Patel, S., Brown, J., Semper, M., Abella, F., & Mannocci, F. (2019). European Society of Endodontology position statement: Use of cone beam computed tomography in endodontics. *International Endodontic Journal, 52*(12), 1675–1678.

Patel, S., Durack, C., Abella, F., Roig, M., Shemesh, H., & Lambrechts, P. (2015).

Cone beam computed tomography in endodontics – a review. *International Endodontic Journal, 48*(1), 3–15.

Peters, O. A. (2004). Current challenges in root canal preparation. *International Endodontic Journal, 37*(8), 557–567.

Peters, O. A., Arias, A., & Paqué, F. (2015). A micro–computed tomography assessment of root canal preparation with a novel instrument, TRUShape. *Journal of Endodontics, 41*(9), 1545–1550.

Ruffa, F., Lugarà, M., Fulco, G., et al. (2023). Prognostic health management using infrared thermography: The case of a digital twin of a NiTi endodontic file. *Sensors, 23*, 4296.

Rumbold, J. M. M., & Pierscionek, B. (2017). The effect of the General Data Protection Regulation on medical research. *Journal of Medical Internet Research, 19*(2), e47.

Saghiri, M. A., Vakhnovetsky, J., & Saghiri, A. M. (2023). The future of digital twins in precision dentistry. *Journal of Oral Biology and Craniofacial Research, 13*(1), 19–24.

Sattapan, B., Nervo, G. J., Palamara, J. E. A., & Messer, H. H. (2000). Defects in rotary NiTi instruments. *Journal of Endodontics, 26*(3), 161–165.

Schwendicke, F., Samek, W., & Krois, J. (2020). Artificial intelligence in dentistry: Chances and challenges. *Journal of Dental Research, 99*(7), 769–774.

Setzer, F. C., Li, J., & Khan, A. A. (2024). The use of artificial intelligence in endodontics. *Journal of Dental Research, 103*(9), 853–862.

Shen, Y., Gao, Y., Qian, W., et al. (2010). Three-dimensional numeric simulation of root canal irrigant flow. *Journal of Endodontics, 36*(10), 1787–1793.

Tang, W., Wu, Y., & Smales, R. J. (2010). Fracture resistance of endodontically treated teeth restored with posts. *International Endodontic Journal, 43*(3), 216–223.

Tao, F., Zhang, H., Liu, A., & Nee, A. Y. C. (2019). Digital twin in industry: State-of-the-art. *IEEE Transactions on Industrial Informatics, 15*(4), 2405–2415.

Topol, E. (2019a). *The Topol Review: Preparing the healthcare workforce to deliver the digital future*. Health Education England.

Topol, E. (2019b). *Deep medicine: How artificial intelligence can make healthcare human again*. Basic Books.

Turky, M., & Dummer, P. M. H. (2026). Digital twins technology in endodontics: From reactive to predictive – a new frontier towards personalised root canal treatment. *British Dental Journal, 240*(1), 21–25.

Vasudevan, A., Santosh, S. S., Selvakumar, R. J., Sampath, D. T. S., & Natanasabapathy, V. (2022). Dynamic navigation in guided endodontics – a systematic review. *European Endodontic Journal, 7*, 81–91.

Veinot, T. C., Mitchell, H., & Ancker, J. S. (2018). Good intentions are not enough: How informatics interventions can worsen inequality. *Journal of the American*

Medical Informatics Association, 25(8), 1080–1088.

Versluis, A., & Tantbirojn, D. (2013). Theoretical considerations of stress analysis in endodontically treated teeth. *Dental Clinics of North America, 57*(3), 551–567.

Viceconti, M., Henney, A., & Morley-Fletcher, E. (2016). In silico clinical trials: How computer simulation will transform the biomedical industry. *International Journal of Clinical Trials, 3*(2), 37–46.

Chapter 4

PEDIATRIC MANDIBULAR FRACTURES: ETIOLOGY, DIAGNOSIS AND MANAGEMENT

Oğuzhan TAPCI[1]
Ferhat AYRANCI[2]

1,DDS, Specialist Dentist, Research Assistant, Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Ordu University, Ordu, Turkey ORCİD: 0009-0002-2839-6775
2 DDS, Specialist Dentist, Professor, Department of Oral and Maxillofacial Surgery, Faculty of Dentistry, Ordu University, Ordu, Turkey ORCİD: 0000-0001-7126-5696

Introduction

Facial trauma in the pediatric population differs significantly from that observed in adults in terms of incidence, diagnostic evaluation, and treatment planning. Therefore, when assessing pediatric maxillofacial injuries, clinicians must take into account the child's age-related physiological characteristics as well as psychosocial considerations.

Bone fractures occur less frequently in the pediatric population compared with adults (Sardana et al., 2014). Children are generally under parental supervision and spend most of their time in relatively safe environments, which reduces their exposure to high-energy trauma. Furthermore, incomplete pneumatization of the facial bones, the relatively greater presence of soft and adipose tissues, and the biomechanical characteristics of the developing skeletal structure provide a certain degree of elasticity to the bones. These anatomical and biomechanical features contribute to the lower incidence of facial skeletal fractures observed in children (Barbosa & Mariano, 2017). Nevertheless, although craniofacial fractures are relatively uncommon in the pediatric population, the mandible has consistently been reported as the most frequently fractured facial bone(Dal Santo, 2024; Sharma et al., 2025).

Maxillofacial trauma occurring during childhood may not only affect the existing anatomical structures but may also have long-term consequences on craniofacial growth and development, functional capacity, and facial aesthetics (Goel et al., 2024).

Both surgical and conservative treatment approaches have been reported to yield satisfactory outcomes in pediatric and adolescent patients. However, there rema[1]ins no clear consensus regarding the optimal treatment strategy for this age group (Scheibl et al., 2024). Consequently, cranio-maxillofacial surgeons involved in the management of pediatric mandibular fractures must possess a thorough understanding of the growth and developmental characteristics of the pediatric facial skeleton (Hajibandeh & Peacock, 2023).

This chapter reviews the etiology, clinical features, treatment strategies, and potential complications of pediatric mandibular fractures in light of the current literature. The discussion is primarily based on studies and systematic reviews published between 2015 and 2025.

Age-Specific Characteristics of the Pediatric Maxillofacial Skeleton

The incidence and fracture patterns of pediatric maxillofacial trauma are directly influenced by anatomical and biomechanical characteristics unique to childhood. Although the relatively large head-to-body ratio in children increases the impact of traumatic forces, fractures in facial bones occur less frequently compared to adults. This can be explained by the distinctive properties of the pediatric craniofacial skeleton.

Bone tissue in children is more elastic than in adults; this elasticity reduces the likelihood of fracture under traumatic forces while simultaneously predisposing the pediatric skeleton to incomplete fractures, commonly referred to as "greenstick fractures." The presence of thick facial fat pads, lower body weight, and smaller overall size also provides a natural cushioning effect, further decreasing fracture risk. Consequently, higher-intensity traumatic forces are generally required to produce facial bone fractures in children.

Moreover, in younger children, the facial skeleton is smaller relative to the neurocranium and positioned more posteriorly, which helps protect the maxillofacial region from external trauma. These anatomical features represent key factors explaining the lower incidence of facial fractures in early childhood (Huang et al., 2023).

These anatomical and biomechanical differences directly influence the clinical approach to pediatric mandibular fractures. Age-specific factors such as the presence of permanent tooth germs, the growth potential of the mandibular condyle, short ramus height, and thin cortical bone must be considered in treatment planning(Kumari et al., 2025). Therefore, pediatric mandibular fractures require a clinical management approach distinct from that used in adult cases.

Epidemiology&Etiology

Maxillofacial trauma in the pediatric population accounts for approximately 3.3% of all trauma cases, and the mandible has been reported as the most frequently affected facial bone in children aged 15 years and younger (36%) (Kumar et al., 2017). Among hospitalized patients, mandibular fractures are also the most common, with a reported incidence of **32.7%**, followed by nasal bone fractures (30.2%) and midface/zygomatic fractures (28.6%) (Lodhi et al., 2021).

When mandibular fractures are evaluated according to anatomical location, the condylar region is the most commonly affected site (40–70%), followed by the symphysis and parasymphysis (2–30%), whereas corpus, angle, and ramus fractures are reported less frequently (Cleveland et al., 2021; Lodhi et al., 2021). Pediatric mandibular fractures occur more frequently in male children and typically affect those older than two years of age (Li et al., 2023; Nezam et al., 2018). Condylar head fractures are more common in children younger than eight years, whereas condylar neck fractures become more prevalent with increasing age. Corpus and angle fractures are generally observed at later ages when the mandible has completed more of its structural development (Hajibandeh & Peacock, 2023).

The mechanisms of trauma vary according to age. In children aged 6–11 years, trauma is most commonly associated with motor vehicle accidents, falls from height, play-related accidents, and bicycle injuries, while firearm-related injuries are reported more rarely (Bilgen et al., 2019). During adolescence (12–18 years), the etiology shifts, and interpersonal violence and sports-related injuries become more prominent causes of trauma. Sports injuries are reported to account for approximately 20–30% of oral and maxillofacial trauma cases (Cleveland et al., 2021; Li et al., 2023). In some cases, mandibular fractures may be accompanied by fractures of other facial bones or soft tissue injuries, and in rare instances, polytrauma may also occur (McGoldrick et al., 2019).

Clinical Findings&Evaluation

Pediatric mandibular fractures present with a variety of clinical manifestations depending on the severity, direction, and location of the trauma. The most commonly observed findings include facial bruising, irritability, and excessive crying. Soft-tissue injuries may result in gingival bruising as well as oral and oronasal bleeding. Trauma-related feeding difficulties and signs of inadequate nutrition may also occur. In some cases, transient loss of consciousness or seizure-like activity has been reported. Mandibular deformities and multiple areas of bruising are additional findings that should raise clinical suspicion (Koti et al., 2023).

During functional evaluation, limited mouth opening, tenderness on palpation, step deformity, restriction of condylar movements, and malocclusion or anterior open bite are important diagnostic indicators(Swayampakula et al., 2023; Wu et al., 2022). These clinical signs are particularly important for the early recognition of mandibular fractures in young children, in whom obtaining a reliable history may be difficult, and they help guide accurate diagnosis and timely treatment planning.

In posterior–superiorly displaced condylar fractures, external auditory canal injuries and bloody otorrhea may be observed. In bilateral cases, these findings may be confused with skull base fractures; therefore, careful radiological evaluation is required (Chan & Au-Yeung, 2017).

Imaging Methods

Although panoramic radiographs are frequently preferred during clinical evaluation, the superimposition of adjacent anatomical structures and their susceptibility to distortion may make accurate assessment of fracture lines difficult. This limitation can lead to diagnostic errors and inappropriate treatment planning. Currently, advanced imaging modalities such as helical multidetector computed tomography (MDCT) and cone-beam computed tomography (CBCT) allow more detailed and reliable visualization of fractures, particularly those located in the subcondylar region(Vesnaver, 2020).

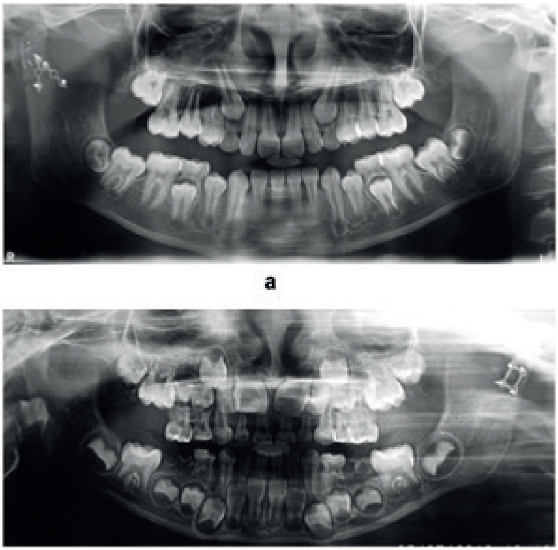

Figure 1. *Use of Panoramic Radiography in Pediatric Mandibular Fractures(Vesnaver, 2020)*

CBCT provides high-accuracy three-dimensional images with a lower radiation dose compared to multidetector CT, offering advantages in demonstrating the angular relationships of bony structures. However, MDCT is superior in evaluating the relationship of fracture fragments with surrounding anatomical structures and in detecting associated soft tissue injuries due to its higher soft tissue contrast (Scheibl et al., 2024).

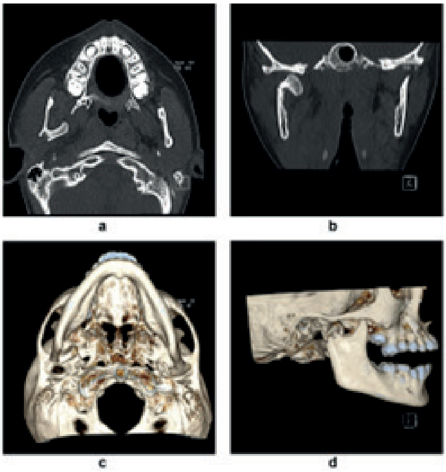

Figure 2. *Use of CBCT in Pediatric Mandibular Fractures.*

A. Axial section B. Coronal section C. Inferior view of the CBCT image D. Lateral view of the CBCT image(Scheibl et al., 2024)

Classification

Mandibular fracture classification systems proposed in the literature are largely descriptive in nature. These systems are generally based on the anatomical location of the fracture; additionally, they take into account factors such as whether the fracture is simple or open, the presence of associated soft tissue injuries, and the risk of fragment displacement related to muscle traction(Brown et al., 2022).

According to anatomical localization, mandibular fractures are classified as angle, ramus, alveolar region, subcondylar region, condyle, corpus, symphysis, and parasymphysis fractures(Bilgen et al., 2019). Brown et al. (2022) suggested that, in order to better reflect the clinical presentation and treatment complexity of mandibular fractures, they should be categorized into five main groups based on anatomical location and treatment difficulty:

- **Class I:** Isolated condylar fractures (condylar head or subcondylar region). These are usually seen as isolated injuries and can generally be managed with conservative or minimally invasive approaches.

- **Class II:** Angle fractures. These may occur either as isolated or combined fractures, and treatment (single or double plating, buccal or intraoral approach) varies depending on the characteristics of the case.

- **Class III:** Corpus, parasymphysis, and symphysis fractures. These fractures affect the anterior horizontal portion of the mandible and often require open reduction and internal fixation (ORIF) due to the risk of displacement and instability.

- **Class IV:** Multiple fractures without condylar involvement. These cases involve fractures in more than one region of the mandible but do not include the condylar area; treatment may require ORIF in multiple sites.

- **Class V:** Multiple fractures with a condylar component. When condylar fractures are part of multiple fractures, treatment planning requires careful evaluation of mandibular movement and occlusion during ORIF planning. Bilateral condylar fractures are defined as a separate subclass.

This classification system enables the systematic recording and reporting of mandibular fractures by incorporating both anatomical localization and treatment complexity. As a result, it supports clinical decision-making while providing consistent and comparable data in the literature(Brown et al., 2022).

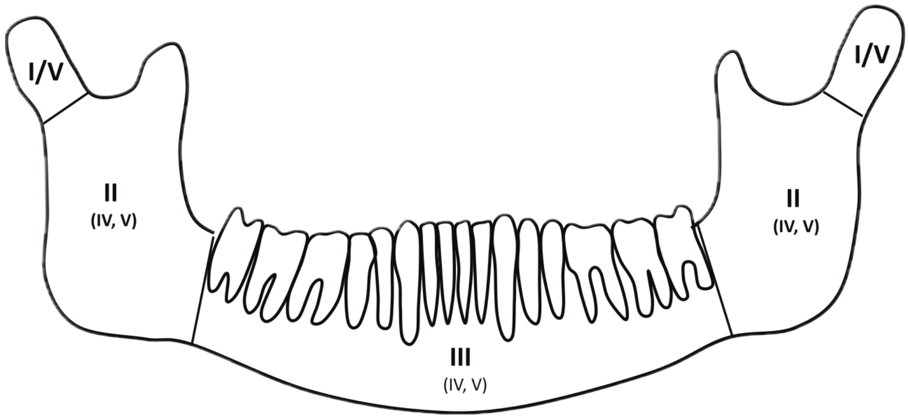

Figure 3. Mandibular fracture classification described by Brown et al.

Treatment Methods

When planning the treatment of maxillofacial fractures, factors such as the patient's age, the anatomical location and complexity of the fracture, the time elapsed since injury, and the presence of associated injuries should be considered(Bilgen et al., 2019). Although various treatment approaches for mandibular fractures have been reported in the literature, the heterogeneity in data presentation often makes individual patient management difficult to evaluate clearly. Current studies indicate that three main approaches are commonly used in the treatment of mandibular fractures: conservative management, closed reduction, and open reduction with internal fixation (ORIF) (Brown et al., 2022).

The management of mandibular fractures in children differs from that in adults due to ongoing craniofacial growth and the presence of developing permanent tooth germs. Treatment should aim to restore stability while preserving both esthetic and functional structures using the least invasive methods possible (Jha et al., 2023). In pediatric patients, conservative approaches are generally preferred in order to avoid potential adverse effects on growth and development (Nilesh et al., 2020). These approaches include a wide range of options, from observation with a soft diet and physiotherapy to wire applications, elastic-guided/intermaxillary fixation, and the use of various splints (Bansal et al., 2021).

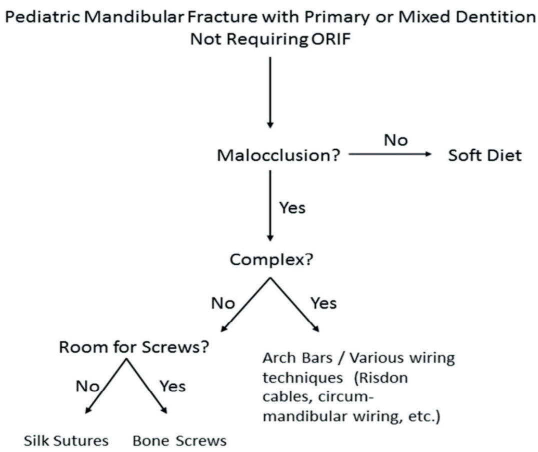

Figure 4. *Management of Pediatric Mandibular Fractures(Farber et al., 2016)*

In displaced fractures, the fundamental principle is anatomical reduction and stable immobilization. Although the indications for ORIF in pediatric cases are limited, fixation with mini- or microplates may be applied in markedly displaced or comminuted parasymphysis and angle fractures (Mulinari-Santos et al., 2017). In parasymphysis fractures, ORIF is considered a safe option after the eruption of the canine teeth (approximately 9 years of age and older); at this stage of dental development, the risk of damage to tooth roots during plate and screw placement is reduced (Posnick et al., 1993; Smartt et al., 2005).

Open fixation requiring subperiosteal dissection may affect the osteogenic potential of the periosteum and lead to scar tissue formation that could restrict growth. Therefore, conservative treatment is preferred in minimally displaced fractures (Bilgen et al., 2019). The need for a second surgical procedure to remove metal plates has led to the development of resorbable plating systems. Recent clinical studies have demonstrated that resorbable plates are safe and effective in the treatment of pediatric mandibular fractures(Chocron et al., 2019; Landes & Ballon, 2006; Smartt et al., 2005; Yang et al., 2015).

In pediatric condylar fractures, a conservative approach is generally preferred due to the high remodeling potential; however, surgical options may be considered in the presence of significant displacement or functional impairment (Vesnaver, 2020). External fixation can provide stabilization with minimal intervention to the growth center and may yield satisfactory morphofunctional outcomes (Cascone et al., 2017).

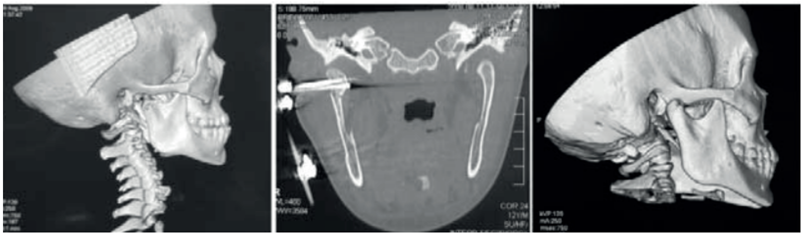

Figure 5. *CT image showing the use of an external fixator in a pediatric condylar fracture (Cascone et al., 2017).*

The elastic structure of the mandible and the embedded tooth germs in children naturally hold the fragments together; therefore, most fractures of the body and symphysis occur without displacement. Closed reduction and immobilization are applied in the presence of displacement(Nezam et al., 2018).

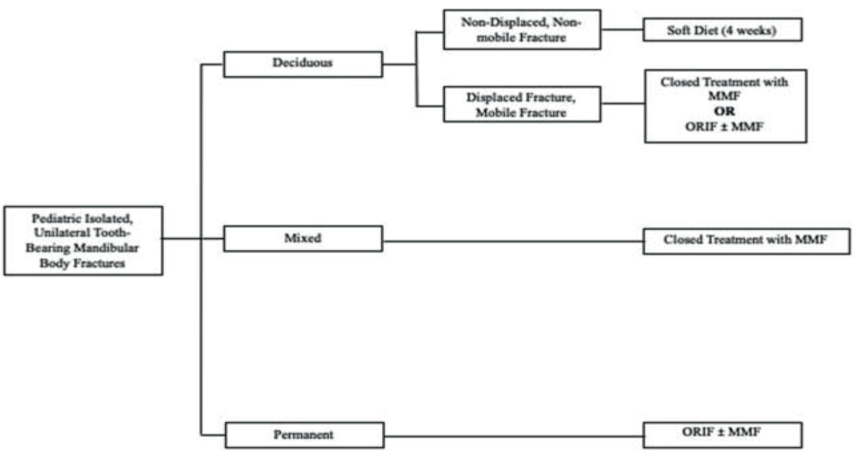

Figure 6. *Management of Pediatric Mandibular Body Fractures (Lopez et al., 2021).*

Evaluation parameters in postoperative and conservative follow-up of pediatric condylar fractures include facial symmetry, maximum mouth opening, lateral deviation, temporomandibular joint pain, condylar movement, pathological phenomena (clicking, crepitus), and occlusion (Vesnaver, 2020). Long-term effects of condylar fractures include pain, malocclusion, decreased posterior facial height, facial asymmetry, and TMJ ankylosis. Non-surgical maxillomandibular fixation (MMF) and physical therapy are preferred for greenstick fractures, while displaced or dislocated condylar fractures require a surgical approach (Aksoyler et al., 2021).

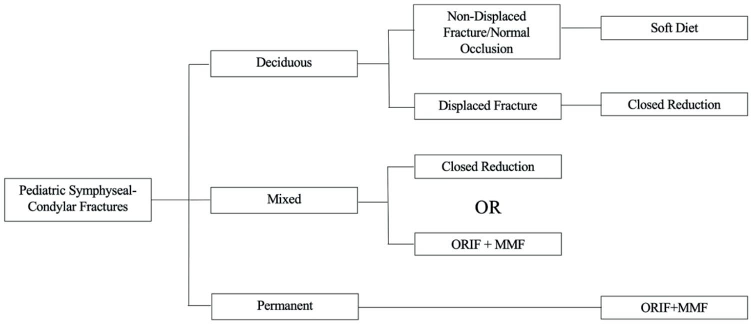

Figure 7. *Management of Pediatric Symphysis and Condyle Fractures (Yesantharao et al., 2021)*

Mandibular angle fractures generally occur as a result of high-energy trauma or direct impact/violence. The management of fractures in this region is particularly challenging due to their posterior location behind the dental arch and the complex biomechanics of the area. This anatomical region is subjected to distractive forces generated by the masticatory muscles and exhibits three-dimensional movement patterns. Consequently, these factors make stabilization of the fracture fragments more difficult (Yesantharao et al., 2020).

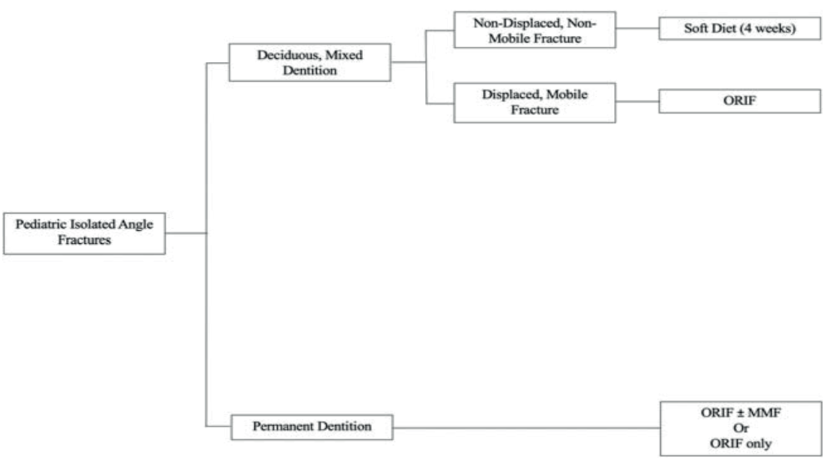

Figure 8. *Management of Pediatric Angular Fractures (Yesantharao et al., 2020).*

In infants with unerupted teeth, low-invasive techniques such as stabilization of parasymphysis fractures using a splint made from a simply shaped plastic airway tube and fixation of the fragment with circummandibular wiring for 2–3 weeks have been shown to achieve successful outcomes without increasing complication rates. This approach offers a treatment alternative that aligns with the goal of preserving growth potential and avoiding harm to dental development (Abdelhalim & El Fahar, 2021).

Figure 9. *Splinting of a parasymphyseal fracture in toothless infants using a plastic airway tube (Abdelhalim & El Fahar, 2021).*

Complications

Complications associated with pediatric mandibular fractures have not always been reported in detail in the literature, and most existing studies lack sufficient data correlating complications with fracture location, number of fractures, or treatment modality. Available evidence suggests that the risk of complications increases with fracture complexity. The main complications reported in pediatric patients include malocclusion, infection, the need for reoperation, and issues related to fixation materials. Patient age, dentition status, and growth potential should be considered when planning treatment(Brown et al., 2022).

When postoperative complications are evaluated according to dentition stage and treatment methods, higher complication rates are particularly observed in patients treated with open reduction and internal fixation (ORIF). In the ORIF group, the complication rate was reported as 55.6%, whereas no complications were reported in patients managed with a soft diet alone or with closed reduction and intermaxillary fixation (MMF). This finding supports the prioritization of conservative approaches whenever possible in pediatric patients (Yesantharao et al., 2020).

The most common complication in ORIF cases is transient alveolar nerve paresthesia (17.6%), reflecting the impact of surgical manipulation on neurovascular structures. However, the absence of a significant difference in complication rates across primary, mixed, and permanent dentition stages suggests that risk is not solely dependent on dentition; biomechanical characteristics and fracture severity are also important determinants (Yesantharao et al., 2020).

Regarding plate configurations, patients treated with miniplates applied only along the superior border showed lower complication rates. Although this difference was not statistically significant, less invasive and limited fixation approaches may offer biological advantages in the pediatric mandible (Yesantharao et al., 2020). Multivariate analyses indicate that fracture morphology is the most clinically relevant determinant, with comminuted and/or displaced fractures significantly increasing the risk of complications following ORIF.

Malocclusion, infection, inadequate reduction, and growth-development disturbances can occur after treatment of pediatric mandibular fractures. Condylar fractures, in particular, may affect long-term mandibular growth in patients with ongoing developmental potential. Malocclusion usually results from insufficient reduction or immobilization and can present as occlusal mismatch, deviation during mouth opening, temporomandibular joint (TMJ) dysfunction, ankylosis, and limited mandibular movement. Long-term sequelae may include mandibular asymmetry and chronic pain (Andrade et al., 2015).

Resorbable fixation materials have been reported as a safe and effective alternative in pediatric mandibular fractures. A review of 10 primary studies covering a total of 269 fractures reported an overall complication rate of 5.2% (n=12). The most common complication was postoperative infection (n=4), all of which were managed successfully with conservative antibiotic therapy. Other complications included wound dehiscence (0.86%), hardware exposure (1.3%), intraoral fistula (0.86%), and malocclusion (0.43%), with none of the hardware exposure cases requiring additional surgery (Chocron et al., 2019).

Condylar fractures, due to their critical role in mandibular growth, may lead to long-term functional and skeletal sequelae (McGoldrick et al., 2019). In pediatric condylar surgery, intraoperative and postoperative complications can include transient facial nerve palsy, parotid fistula, injury to the great auricular nerve, miniplate fracture, intraoperative bleeding, postoperative hematoma, infection, and malposition of fracture fragments. Postoperative scarring is also an important parameter to monitor (Vesnaver, 2020).

Therefore, close clinical and radiological follow-up in pediatric patients after treatment is critical for the early detection of potential growth disturbances and functional problems (Akkoç & Bülbüllüoğlu, 2022).

Examles of Case Reports in the Literature

Case Report 1

A 9-year-old male patient presented to the Department of Oral&Maxillofacial Surgery with complaints of pain in the anterior mandibular region and mild soft tissue discoloration. Anamnesis obtained from the family revealed a fall while playing the day before.

Clinical evaluation showed diastema between the right central and lateral mandibular incisors and a small laceration on the buccal gingiva (Figure 10A). Panoramic radiographic examination revealed a slightly displaced vertical fracture line in the parasymphysis region, with minimal step formation along the inferior cortical border of the mandible (Figure 10B). No additional fractures were observed in the condylar region or other mandibular structures. The patient's systemic history was unremarkable.

Due to the patient being in the mixed dentition stage, a conservative treatment approach was chosen. Alginate impressions of the maxilla and mandible were taken to fabricate study models. Model surgery was performed on the mandibular model using the maxillary model as a guide to achieve proper occlusal alignment. To enhance stability, a 2-mm-thick acrylic occlusal splint with partial extension onto the gingival tissues was prepared (Figure 10C). The buccal and lingual extensions of the splint were carefully adapted to avoid pressure on the soft tissues at gingival contact areas.

As the patient was cooperative, all procedures were performed under local anesthesia. The splint was secured using two 0.5-mm orthodontic wires twisted together to provide adequate flexibility and strength. Small perforations were made in the splint at the junction of the buccal and lingual surfaces of the primary second molars, and the wires were passed through these perforations and guided through the interdental spaces. Prior to perforation, the mobility of the relevant primary molars was assessed. The displaced mandibular segments were reduced with digital pressure, and stabilization of the splint was achieved by bending the wires on the buccal surface (Figures 10D–E). At the end of the procedure, the stability of the splint was confirmed clinically.

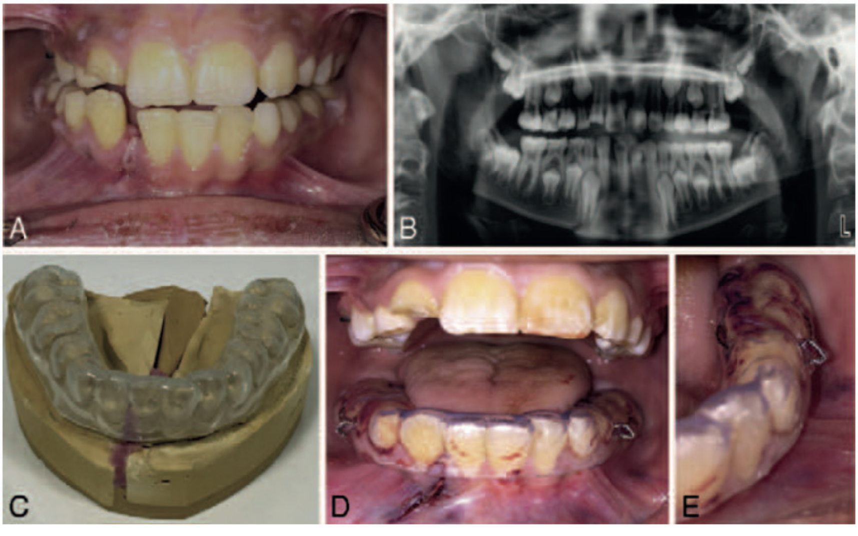

Figure 10. *Treatment of Pediatric Parasymphyseal Fracture with Acrylic Occlusal Splint*

In the third postoperative week, the splint was removed without the need for local anesthesia. No complications were observed during the healing period. Panoramic radiographs taken in the fourth week demonstrated adequate bone healing along the fracture line and proper reduction, with stable occlusion and normal masticatory function (Figures 11A–B)(Demirkol et al., 2016).

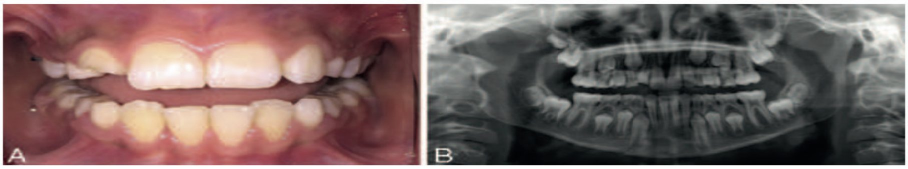

Figure 11. *Follow-up of a Pediatric Parasymphyseal Fracture Treated with an Acrylic Occlusal Splint*

Case Report 2

A 10-year-and-9-month-old male patient presented to the Department of Oral and Dental Health, Kunming Medical University, China, four days after a traffic accident. Initial evaluation was performed in the Department of Oral and Maxillofacial Surgery, and the patient was referred to the orthodontics clinic. He reported persistent facial pain, as well as limited masticatory and sleep functions following the trauma. Clinical examination revealed bilateral facial swelling, approximately 2 mm left deviation of the mandibular midline, a maximal mouth opening of 31 mm, and deviation of the mandible to the left during movement. A laceration at the chin and fractures of the maxillary central incisors were also noted.

Diagnostic assessment with computed tomography revealed a vertical fracture line at the left condylar head, a displaced fracture of the right condylar neck, and a fracture at the mandibular symphysis. Fracture healing was monitored long-term through five sequential CT scans (baseline, 4th, 20th, 37th, and 49th months).

Initial management included antibiotics, nonsteroidal anti-inflammatory analgesics, and a soft diet. The chin laceration was closed with primary sutures. Two treatment options were offered to the family: open reduction with rigid maxillomandibular fixation or conservative management using an arch bar and intermaxillary fixation. The family opted for the conservative approach to preserve occlusion through condylar remodeling and mandibular growth.

Orthodontic assessment revealed mild facial asymmetry, a convex facial profile, and early permanent dentition. While the maxillary dental midline was aligned, the mandibular midline was deviated 2 mm to the left. Class I molar relationship and mild Class II canine relationship were observed.

A conservative orthodontic treatment plan was implemented, with 0.022-inch slot brackets placed from the maxillary second premolars to the mandibular molars and supported by a lightly contoured 0.018-inch Australian archwire. Elastic connections were applied to the brackets, and intermaxillary elastics (1/8 inch, 3.5 oz) were used in a cross and symmetrical pattern, replaced daily for four weeks. The patient was instructed to limit mandibular opening exercises for hygiene purposes and to follow a liquid diet for the first two weeks (Xu et al., 2016).

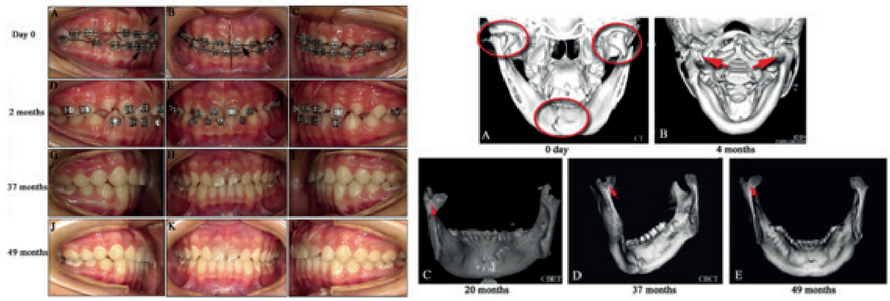

Figure 12. *Orthodontic-Based Conservative Treatment and Follow-Up of Pediatric Mandibular Fracture*

Case Report 3

A 4-year-old male patient presented to the Department of Pedodontics and Preventive Dentistry with pain in the right mandibular region during mastication. Medical history revealed a traffic accident caused by a motorcycle collision one week prior.

Intraoral examination showed asymmetry of the dental arch and a diastema in the region of primary teeth 82–83. Carious lesions were also observed in the primary dentition. Preoperative computed tomography (CT) revealed a fracture in the right parasymphyseal region extending along the inferior border of the mandible.

Based on clinical and radiographic findings, a diagnosis of right mandibular parasymphyseal fracture was established. A modified closed acrylic cap splint with one anterior and two posterior openings was fabricated. After reduction of the fracture fragments, the splint was cemented using glass ionomer cement (GC Fuji I). Oral hygiene instructions were provided, and analgesic therapy was initiated.

At the sixth-week follow-up, the splint was removed, and the patient was asymptomatic. Panoramic radiographic evaluation at the eighth month demonstrated radiologic evidence of fracture healing (Kumar et al., 2017).

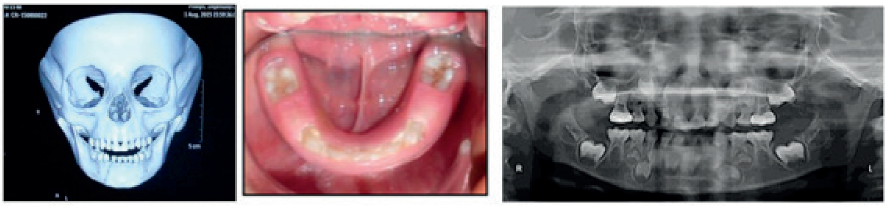

Figure 13. *Diagnosis of Pediatric Parasymphyseal Fracture, Treatment with Acrylic Cap Splint, Follow-up*

Case Report 4

A 6-year-old male patient presented to the Pedodontics Clinic following a fall while playing two days prior. There was no history of loss of consciousness, vomiting, or convulsions. The family reported gingival bleeding, difficulty in closing the mouth, and pain during mastication. Clinical examination revealed diffuse swelling in the lower right third of the face, resulting in facial asymmetry. The patient exhibited difficulty in opening and closing the mouth, with superficial lacerations observed on the chin and lower lip.

Intraoral examination showed a vertical fracture line between the right mandibular primary lateral incisor and canine, while the left mandibular dentoalveolar segment displayed medial displacement, step deformity, and occlusal discrepancy, resulting in an open bite appearance. Preoperative panoramic radiography (OPG) confirmed the fracture in the right parasymphyseal region and revealed an associated fracture in the left mandibular angle.

Treatment planning included taking alginate impressions of the maxilla and mandible to fabricate dental casts, upon which an acrylic splint was prepared. The mandibular fracture was immobilized under general anesthesia using a circum-mandibular wiring technique with the acrylic splint. Small skin incisions were made approximately 3–4 cm lateral to the midline on both sides of the mandible. A mandibular bone awl was used to pass the wire lingually along the mandibular body, exiting through the lingual mucosa. The wire was then guided from lingual to buccal sulcus along the mandibular body and adapted onto the acrylic splint (regions 83–84). The procedure was repeated on the contralateral side, and an additional circum-mandibular wire was placed on the left body to stabilize the fractured segment.

Postoperatively, panoramic radiographs were obtained with the wires in place, and the patient was followed up weekly. At the fourth postoperative week, the splint and wires were removed under ketamine sedation, and control OPG confirmed stable fracture segments. Clinical evaluation revealed no mobility along the fracture line, uneventful postoperative healing, and satisfactory occlusion (Nezam et al., 2018).

Figure 14. *Treatment of Pediatric Parasymphyseal Fracture with Circummandibular Wire*

Case Report 5

A 10-year-old female patient presented to the emergency department following a bicycle accident, reporting pain, bleeding and difficulty breathing. The patient had no known systemic diseases or allergy history. Extraoral examination revealed posterior displacement of the mandible, step deformity along the inferior mandibular border and noticeable facial asymmetry. Intraoral assessment demonstrated gingival sulcus bleeding, crepitus and tenderness on palpation.

Three-dimensional computed tomography revealed a bilateral parasymphyseal mandibular fracture with posterior displacement of the segments. Due to respiratory compromise, airway management was prioritized; secretions were aspirated and anterior traction of the tongue was applied to maintain patency.

Surgical treatment was performed under general anesthesia via an incision in the lower vestibular fornix. On the left side, anatomical reduction was achieved and fixation was provided using 1.5 mm and 2.0 mm titanium plates with monocortical screws. On the right side, stabilization was achieved with two 1.5 mm titanium plates and monocortical screws.

At the 21st postoperative day, facial edema had markedly decreased, the patient's symptoms had resolved, and no signs of infection or inflammation were observed. Waters' radiography confirmed appropriate anatomical positioning and stability of the bone segments (Mulinari-Santos et al., 2017).

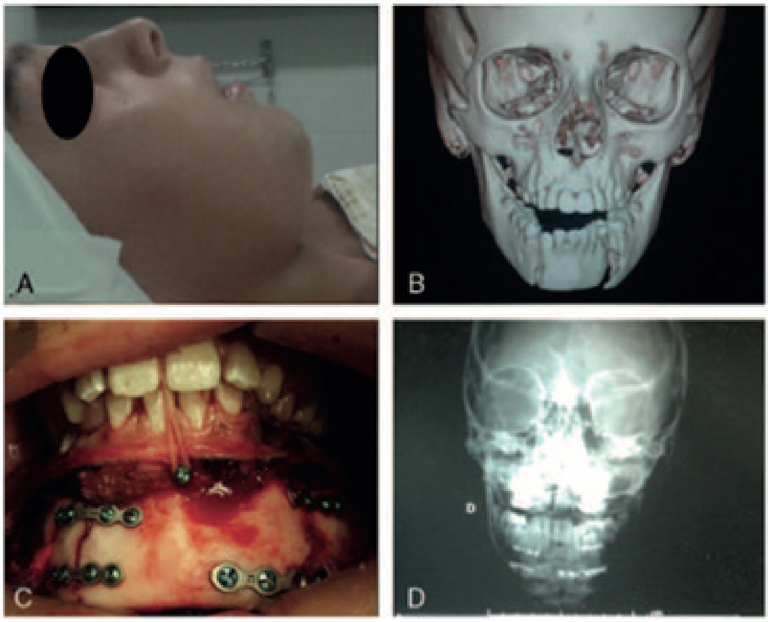

Figure 15. *Treatment of Bilateral Parasymphyseal Fracture with Open Reduction Internal Fixation*

Case Report 6

A 14-year-old male patient was referred to the pediatric maxillofacial surgery unit following mandibular trauma sustained during a mountain biking accident. Clinical examination revealed mild bilateral cheek ecchymosis and edema, an anterior open bite of approximately 1.5 cm, mandibular deviation to the right, and premature contacts in the molar region. No dental fractures or alveolar mobility were observed. Bilateral epistaxis was present, while neurological examination was normal.

Panoramic radiography and computed tomography revealed a left parasymphyseal fracture, a fracture of the left condylar head, and an intracranial intrusion of the right mandibular condyle. A multidisciplinary surgical approach was planned and performed by the maxillofacial and neurosurgery teams. The left parasymphyseal fracture was stabilized using miniplates and screws, and the displaced condyle was reduced from the temporal fossa via mandibular inferior traction. The neurosurgery team drained the hematoma through a pterional approach and reconstructed the comminuted glenoid fossa roof with a thin cranial bone graft.

Postoperatively, no neurological complications were observed. Intermaxillary fixation was maintained for three weeks, followed by elastic guidance. One-month follow-up CT demonstrated stable reconstruction, although early findings suggestive of temporomandibular joint ankylosis were noted.

This case illustrates that significant intracranial condylar intrusion may occur in pediatric patients despite mild clinical findings and underscores the importance of a multidisciplinary approach in such cases (Le Roux et al., 2019).

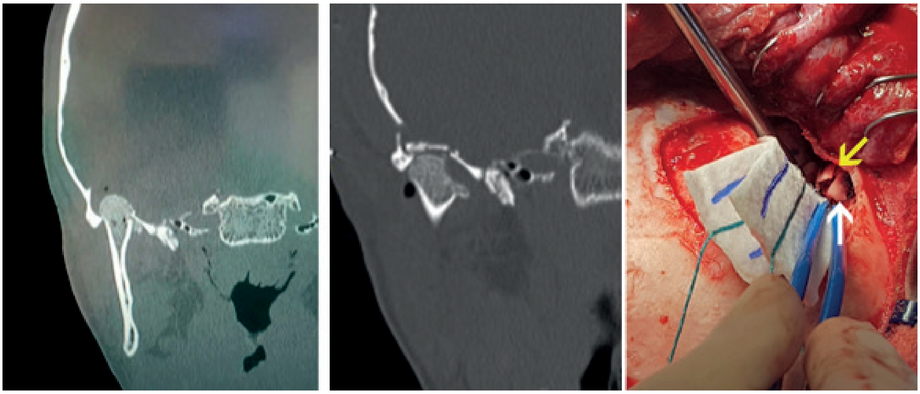

Figure 16. *Treatment of a Trifocal Mandibular Fracture*

Case Report 7

A 9-year-old female patient was brought to the emergency department following a motorcycle accident, presenting with unconsciousness and severe intraoral bleeding; orotracheal intubation had been performed. Neurological evaluation revealed a Glasgow Coma Scale score of 10, necessitating intensive care monitoring. Extraoral examination demonstrated right submandibular edema, while intraoral assessment revealed bone crepitus, mucosal bone exposure, and active bleeding. Computed tomography showed a markedly displaced fracture of the right parasymphyseal region and the developing germ of the right lower canine.

Initial management included achieving hemostasis, placing mucosal sutures, and temporary stabilization using Essig wire ligature. Definitive surgical treatment was performed two weeks after the trauma. Under general anesthesia, orthodontic buttons were bonded to selected teeth to facilitate intraoperative maxillomandibular fixation. Through a submandibular approach, the fracture site was accessed, the canine germ at the fracture line was removed, and the fracture was reduced. Stabilization was achieved using a 2.0 mm titanium plate with monocortical screws.

At the 60-day follow-up, the patient demonstrated satisfactory occlusion and fracture healing, with no impairment of facial nerve function observed (Rodrigues et al., 2021).

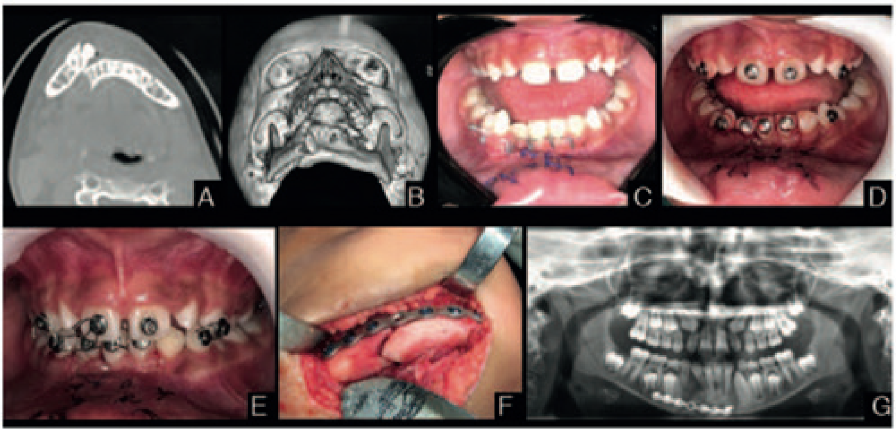

Figure 17. *Surgical Management of a Delayed Pediatric Mandibular Fracture*

Conclusion&Recommendations

Pediatric mandibular fractures exhibit distinct clinical characteristics compared to adult mandibular trauma due to the developmental features of the craniofacial skeleton. Factors such as the elastic nature of the pediatric bone, the presence of a thick periosteum, developing tooth germs, and the condyle as a critical growth center directly influence both fracture patterns and treatment strategies. Therefore, management of pediatric mandibular fractures should not rely solely on the anatomical location of the fracture; patient age, dentition stage, growth potential, degree of displacement, and associated craniofacial injuries must all be carefully considered.

Current literature indicates that the condyle is the most frequently affected region in pediatric mandibular fractures and conservative treatment approaches often yield satisfactory functional outcomes. Rapid bone healing in children, coupled with significant remodeling capacity in the condylar region, supports the preference for minimally invasive treatment strategies whenever feasible. Conservative approaches, including soft diet, functional monitoring, elastic guidance, splint therapy, and closed reduction, can provide adequate stabilization in minimally displaced fractures while avoiding surgical trauma to growth centers.

However, in cases with significant displacement, comminuted fractures, or where occlusal stability cannot be achieved conservatively, open reduction and internal fixation may be necessary. In such surgical interventions, preservation of periosteal blood supply, protection of permanent tooth germs, and avoidance of interference with mandibular growth centers are fundamental principles. Accordingly, minimal dissection techniques, low-profile fixation systems, and, when appropriate, resorbable osteosynthesis materials offer significant advantages in the pediatric population.

Successful management of pediatric mandibular fractures extends beyond early stabilization. Condylar fractures, in particular, can have long-term effects on mandibular growth direction, facial symmetry and temporomandibular joint function. Therefore, postoperative follow-up should include regular clinical and radiographic assessments of facial development, occlusion, mandibular range of motion, and temporomandibular joint function.

In conclusion, the primary objective in treating pediatric mandibular fractures is to stabilize fracture segments while preserving mandibular growth and developmental potential. Conservative and minimally invasive methods should be prioritized, whereas surgical treatment should be reserved for carefully selected indications. Current evidence highlights that a multidisciplinary approach, appropriate imaging and long-term follow-up are critical for achieving optimal functional and esthetic outcomes in pediatric mandibular fractures.

References

Abdelhalim, M. M., & El Fahar, M. H. (2021). Novel and Affordable Low-Cost Technique for Fixation of Parasymphyseal Fractures in Infants With Unerupted Dentition. *Journal of Oral and Maxillofacial Surgery*, *79*(8), 1732.e1-1732.e6. https://doi.org/10.1016/j.joms.2021.02.037

Aksoyler, D., Doğan, F., Bolletta, A., Sengenc, E., Sönmez, T., & Yavan, M. A. (2021). Management of Medially Displaced Sub-Condylar Mandibular Fractures in Pediatric Population Using Novel Atraumatic Approach. *Journal of Craniofacial Surgery*, *32*(3), 851–854. https://doi.org/10.1097/SCS.0000000000006993

Andrade, N. N., Choradia, S., & Sriram S., G. (2015). An institutional experience in the management of pediatric mandibular fractures: A study of 74 cases. *Journal of Cranio-Maxillofacial Surgery*, *43*(7), 995–999. https://doi.org/10.1016/j.jcms.2015.03.020

Bansal, A., Yadav, P., Bhutia, O., Roychoudhury, A., & Bhalla, A. S. (2021). Comparison of outcome of open reduction and internal fixation versus closed treatment in pediatric mandible fractures-a retrospective study. *Journal of Cranio-Maxillofacial Surgery*, *49*(3), 196–205. https://doi.org/10.1016/j.jcms.2020.12.013

Barbosa, A. A., & Mariano, R. C. (2017). Open Reduction in Pediatric Condylar Fracture. *Journal of Craniofacial Surgery*, *28*(3), e289–e292. https://doi.org/10.1097/SCS.0000000000003538

Bilgen, F., Ural, A., & Bekerecioğlu, M. (2019). Our Treatment Approach in Pediatric Maxillofacial Traumas. *Journal of Craniofacial Surgery*, *30*(8), 2368–2371. https://doi.org/10.1097/SCS.0000000000005896

Brown, J. S., Khan, A., Wareing, S., & Schache, A. G. (2022). A new classification of mandibular fractures. *International Journal of Oral and Maxillofacial Surgery*, *51*(1), 78–90. https://doi.org/10.1016/j.ijom.2021.02.012

Cascone, P., Marra Marcozzi, M., Ramieri, V., Bosco, G., Vellone, V., & Spallaccia, F. (2017). Mandibular Condylar Fractures in Children: Morphofunctional Results After Treatment With External Fixation. *Journal of Craniofacial Surgery*, *28*(7), 1742–1745. https://doi.org/10.1097/SCS.0000000000003914

Chan, Y. C., & Au-Yeung, K. L. (2017). A paediatric case of bilateral mandibular condyle fracture presenting with bloody otorrhoea following trauma. *BMJ Case Reports*, *2017*, bcr-2016-218995. https://doi.org/10.1136/bcr-2016-218995

Chocron, Y., Azzi, A. J., & Davison, P. (2019). Management of Pediatric Mandibular Fractures Using Resorbable Plates. *Journal of Craniofacial Surgery*, *30*(7), 2111–2114. https://doi.org/10.1097/SCS.0000000000006002

Cleveland, C. N., Kelly, A., DeGiovanni, J., Ong, A. A., & Carr, M. M. (2021). Maxillofacial trauma in children: Association between age and mandibular fracture site. *American Journal of Otolaryngology*, *42*(2), 102874. https://doi.org/10.1016/j.amjoto.2020.102874

Dal Santo, K. (2024). Bilateral mandible fractures in the paediatric patient in a case of peer-to-peer violence: a case report and literature review. *Australian Dental Journal*, *69*(4), 320–325. https://doi.org/10.1111/adj.13025

Demirkol, M., Demirkol, N., Abdo, O. H., & Aras, M. H. (2016). A Simplified Way for the Stabilization of Pediatric Mandibular Fracture With an Occlusal Splint. *Journal of Craniofacial Surgery*, *27*(4), e363–e364. https://doi.org/10.1097/SCS.0000000000002617

Farber, S. J., Nguyen, D. C., Harvey, A. A., & Patel, K. B. (2016). An Alternative Method of Intermaxillary Fixation for Simple Pediatric Mandible Fractures. *Journal of Oral and Maxillofacial Surgery*, *74*(3), 582.e1-582.e8. https://doi.org/10.1016/j.joms.2015.10.028

Goel, N., Jha, S., Singhal, R., Gupta, N., Namdev, R., & Dayma, C. (2024). Conservative Management of Dislocated Pediatric Unilateral Condylar Fracture Using Orthodontic Treatment and Guiding Elastics. *International Journal of Clinical Pediatric Dentistry*, *17*(2), 184–186. https://doi.org/10.5005/jp-journals-10005-2753

Hajibandeh, J., & Peacock, Z. S. (2023). Pediatric Mandible Fractures. *Oral and Maxillofacial Surgery Clinics of North America*, *35*(4), 555–562. https://doi.org/10.1016/j.coms.2023.05.001

Huang, W., Hu, S., Wang, C., & Xiao, J. (2023). Analysis of Pediatric Maxillofacial Fractures: A 10-year Retrospective Study. *Journal of Craniofacial Surgery*, *34*(2), 448–453. https://doi.org/10.1097/SCS.0000000000008846

Jha, S., Singhal, R., Goel, N., & Namdev, R. (2023). Modified Cap Splint: A Novel Approach to Treating Delayed Mandibular Fracture in Pediatric Patients. *International Journal of Clinical Pediatric Dentistry*, *16*(4), 645–648. https://doi.org/10.5005/jp-journals-10005-2643

Koti, A. S., Vega, S., Johnson, K. L., Schlatter, A., Ayson, N., Menashe, S. J., & Feldman, K. W. (2023). Accidental and Abusive Mandible Fractures in Infants and Toddlers. *Pediatric Emergency Care*, *39*(12), 923–928. https://doi.org/10.1097/PEC.0000000000002906

Kumar, N., Richa, & Gauba, K. (2017). Modified closed cap splint: Conservative method for minimally displaced pediatric mandibular fracture. *The Saudi Dental Journal*, *30*(1), 85–88. https://doi.org/10.1016/j.sdentj.2017.11.002

Kumari, N., Garima, J., Rahul, M., Tewari, N., Mathur, V. P., & Bansal, K. (2025). Conservative management of pediatric mandibular fractures with cap splints- A systematic review. *Oral and Maxillofacial Surgery*, *29*(1), 121. https://doi.org/10.1007/s10006-025-01405-8

Landes, C. A., & Ballon, A. (2006). Indications and Limitations in Resorbable P(L70/30DL)LA Osteosyntheses of Displaced Mandibular Fractures in 4.5-Year Follow-Up. *Plastic and Reconstructive Surgery*, *117*(2), 577–587. https://doi.org/10.1097/01.prs.0000200915.65693.29

Le Roux, M.-K., Gallucci, A., Le Flem, M., Pech-Gourg, G., Chossegros, C., & Graillon, N. (2019). Complicated trifocal mandibular fracture in a child. *Journal of Stomatology, Oral and Maxillofacial Surgery*, *120*(1), 82–83. https://doi.org/10.1016/j.jormas.2018.10.005

Li, L., Acharya, K., Ghimire, B., Li, Y., Xing, X., Hou, X., Hou, L., & Hu, X. (2023). Conservative management of mandibular fractures in pediatric patients during the growing phase with splint fiber and ligature arch wire. *BMC Oral Health*, *23*(1), 601. https://doi.org/10.1186/s12903-023-03309-z

Lodhi, T. G., Nimonkar, P. V, Patil, S. B., Bahetwar, S. K., Peter, B. K., & Sharma, A. B. (2021). Management of Fracture Mandible by Open Occlusal Acrylic Splint in Pediatric Patients: A Case Series. *International Journal of Clinical Pediatric Dentistry*, *14*(6), 812–815. https://doi.org/10.5005/jp-journals-10005-2099

Lopez, J., Reategui, A., Yesantharao, P. S., Yang, R., Redett, R. J., Manson, P. N., & Dorafshar, A. (2021). Open Reduction, Internal Fixation, or Maxillo-Mandibular Fixation for Isolated, Unilateral, Tooth-Bearing, Mandibular Body Fractures in Children. *Journal of Craniofacial Surgery*, *32*(1), 73–77. https://doi.org/10.1097/SCS.0000000000006990

McGoldrick, D. M., Parmar, P., Williams, R., Monaghan, A., & McMillan, K. (2019). Management of Pediatric Condyle Fractures. *Journal of Craniofacial Surgery*, *30*(7), 2045–2047. https://doi.org/10.1097/SCS.0000000000005787

Mulinari-Santos, G., Lima, V. N., Palacio-Muñoz, X. M. J., Oliva, A. H. de, Momesso, G. A. C., Polo, T. O. B., Souza, F. Á., Garcia-Júnior, I. R., & Faverani, L. P. (2017). Andy Gump Fracture of the Mandible in a Pediatric Patient. *Journal of Craniofacial Surgery*, *28*(7), e679–e680. https://doi.org/10.1097/SCS.0000000000003811

Nezam, S., Kumar, A., Shukla, J., & Khan, S. (2018). Management of mandibular fracture in pediatric patient. *National Journal of Maxillofacial Surgery*, *9*(1), 106. https://doi.org/10.4103/njms.NJMS_54_17

Nilesh, K., Mahamuni, A., Taur, S., & Vande, A. V. (2020). A simple novel technique for the management of a dentoalveolar fracture in a pediatric patient using a vacuum-formed splint. *Journal of Dental Research, Dental Clinics, Dental Prospects*, *14*(1), 68–72. https://doi.org/10.34172/joddd.2020.010

Posnick, J. C., Wells, M., & Pron, G. E. (1993). Pediatric facial farctures: Evolving patterns of treatment. *Journal of Oral and Maxillofacial Surgery*, *51*(8), 836–844. https://doi.org/10.1016/S0278-2391(10)80098-9

Rodrigues, M. T. V., Schueng, F. E. A., Mendes, B. C., Vale, D. S., Souza, F. G. de, & Nóia, C. F. (2021). A Simple Method of Transoperative Maxillomandibular Fixation in Pediatric Facial Fractures. *Journal of Craniofacial Surgery*, *32*(4), e375–e376. https://doi.org/10.1097/SCS.0000000000007279

Sardana, D., Gauba, K., Goyal, A., & Rattan, V. (2014). Comprehensive management of pediatric mandibular fracture caused by an unusual etiology. *African Journal of Trauma*, *3*(1), 39. https://doi.org/10.4103/1597-1112.139469

Scheibl, D., Walch, B., Verius, M., Götz, C., & Emshoff, R. (2024). Association Between the Treatment Modality of Pediatric Subcondylar Fractures and Functional

Outcomes at the Six-Month Follow-Up: A Retrospective Pilot Study. *Cureus*. https://doi.org/10.7759/cureus.76226

Sharma, V., Shukla, P., Acharya, S., & Bedi, R. S. (2025). Innovative Approach in the Management of Displaced Mandibular Fracture in a Four-Year-Old Child: A Case Report. *Cureus*. https://doi.org/10.7759/cureus.78038

Smartt, J. M., Low, D. W., & Bartlett, S. P. (2005). The Pediatric Mandible: II. Management of Traumatic Injury or Fracture. *Plastic and Reconstructive Surgery*, *116*(2), 28e–41e. https://doi.org/10.1097/01.prs.0000173445.10908.f8

Swayampakula, H., Colvenkar, S., Kalmath, B., Vanapalli, J., & Ali Zaheer, M. (2023). Management of Pediatric Mandibular Fracture With Acrylic Cap Splint. *Cureus*. https://doi.org/10.7759/cureus.33324

Vesnaver, A. (2020). Dislocated pediatric condyle fractures — should conservative treatment always be the rule? *Journal of Cranio-Maxillofacial Surgery*, *48*(10), 933–941. https://doi.org/10.1016/j.jcms.2020.08.001

Wu, X., Ma, S. H., & Hwang, K. (2022). Change of the Inclination Angle in a Pediatric Bilateral Condylar Fracture Treated With Intermaxillary Fixation and an Occlusal Stop. *Journal of Craniofacial Surgery*, *33*(4), 1193–1196. https://doi.org/10.1097/SCS.0000000000008101

Xu, Y., Gong, S.-G., Zhu, F., Li, M., & Biao, X. (2016). Conservative orthodontic fixed appliance management of pediatric mandibular bilateral condylar fracture. *American Journal of Orthodontics and Dentofacial Orthopedics*, *150*(1), 181–187. https://doi.org/10.1016/j.ajodo.2016.02.012

Yang, R., Lv, K., Zhou, H., Li, Z., & Li, Z. (2015). Resorbable Plates for the Fixation of Isolated Mandibular Angle Fracture. *Journal of Craniofacial Surgery*, *26*(2), 447–448. https://doi.org/10.1097/SCS.0000000000001349

Yesantharao, P. S., Lopez, J., Reategui, A., Jenny, H., Najjar, O., Yu, J. W., Yang, R., Manson, P. N., Dorafshar, A., & Redett, R. J. (2021). Combined Symphyseal and Condylar Fractures: Considerations for Treatment in Growing Pediatric Patients. *Plastic & Reconstructive Surgery*, *148*(1), 51e–62e. https://doi.org/10.1097/PRS.0000000000008055

Yesantharao, P. S., Lopez, J., Reategui, A., Najjar, O., Yu, J. W., Pourtaheri, N., Redett, R. J., Manson, P. N., & Dorafshar, A. (2020). Open Reduction, Internal Fixation of Isolated Mandible Angle Fractures in Growing Children. *Journal of Craniofacial Surgery*, *31*(7), 1946–1950. https://doi.org/10.1097/SCS.0000000000006892

Chapter 5

CURRENT APPROACHES AND BIOMATERIALS IN VITAL PULP THERAPY

Tuba TUNÇ[1]

Suzan CANGÜL[2]

1 Uzm. Dt., Orcid: 0000-0003-2513-9386, Dicle Üniversitesi Diş Hekimliği Fakültesi Restoratif Diş Tedavisi Anabilim Dalı

2 Doç. Dr., Orcid: 0000-0002-1546-7688, Dicle Üniversitesi Diş Hekimliği Fakültesi Restoratif Diş Tedavisi Anabilim Dalı

The aim of pulp treatments is to preserve the tooth structure and for the dental and surrounding supporting tissues to remain healthy (American Academy of Pediatric Dentistry, 2016). In reversible pulp injuries, vital pulp treatment is a protective approach that aims to preserve tissue vitality and maintain functional integrity (Hargreaves, Cohen, & Berman, 2011).

Vital pulp may be exposed for various reasons such as decay or trauma (malocclusion, attrition, abrasion, erosion, mechanical trauma). Exposure of pulp tissue before caries are cleaned is defined as *caries-related, mechanical* when exposure is during the shaping of the cavity after cleaning caries, and *traumatic* when the pulp is exposed together with crown fractures occurring as a result of external force. In these types of conditions, *direct pulp capping* or *pulpatomy treatment* are performed with the aim of preserving the exposed pulp tissue. Direct pulp capping is defined as the placement of biocompatible dental material over the exposed pulp tissue (Schroder 1985) with the aim of maintaining pulp vitality (Bergenholtz, 2005; Bergenholtz et al., 1985) and forming a protective barrier at the base of the cavity (Bergenholtz et al., 1985; Couve, 1986).

There are many factors that have an effect on the success of vital pulp treatment. First, there must be sufficient blood flow. If there is any periodontal disease, the procedure should not be performed as the treatment will be negatively affected. In other words, a healthy periodontium is essential for success. In addition, when there is insufficient coronal impermeability, microleakage occurs due to the passage of bacteria from edge gaps, and this significantly reduces success (Tunçdemir & Al Rashid, 2023). Therefore, strong bonding between the restorative material and pulp capping material is essential to ensure adequate coverage of the permanent restoration (Tziafas, Smith, & Lesot, 2000; Savadi Oskoee et al., 2014).

In the context of vital pulp treatment, there are four different options based on the amount of pulp tissue removed. These are indirect pulp treatment, direct pulp capping, partial pulpotomy, and full pulpotomy.

Indirect Pulp Treatment

When the decayed dentin is close to the pulp, selective caries removal (a method of cleaning caries without touching the soft dentin in the region of the lesion adjacent to the pulp) is performed then this region is covered with a biocompatible material. In this treatment method it is important that the tooth is vital, no pathology is determined on radiography, and there is no long-term or severe pain in the clinical evaluation (Cohenca et al., 2013). One of the indications is that the tooth does not need a large crown or restoration. If perforation develops because of decay in the tooth, if there is irreversible pulpitis, if crown restoration is required due to excessive material loss, or there is clinical or radiographic evidence of pulpal or periradicular pathosis, indirect pulp treatment is contra-indicated (Üngör and Onay, 2017).

The aim of indirect pulp treatment is to maintain the tooth structure symptom-free and with protected integrity by preserving vitality (Velioğlu & Ünlü, 2020). Protection of the pulp is very important in deep caries and reversible pulpitis. With the correct treatment approach, pulp repair is achieved and pulp exposure is prevented. Indirect pulp treatment is generally applied as a single or two-stage treatment. The pulp coverage procedure in two stages is made with calcium hydroxide ($Ca(OH)_2$) or zinc oxide–eugenol (ZOE) (Bogen & Chandler, 2008). A point to which attention must be paid here is that the correct decision must be made as to how much of the carey is to be removed. The reason for selecting calcium hydroxide is that it has alkaline pH and has a biocompatible structure providing remineralisation of the pulp dentin. However, as there are concerns related to solubility in the long-term and not fully bonding to dentin, the use of materials such as resin-modified glass ionomer has been recommended as an alternative. Single-session pulp treatment (direct application of the permanent restoration leaving a part of the carey) is a more practical method than the two-stage approach but there is a need for follow-up evaluation of the long-term success. Recent studies have shown that high survival rates (90%) have been reached after indirect pulp treatment without any adverse clinical symptoms or radiographic pathology observed in the permanent teeth. In a systematic review by Mickenautsch et al., the efficacy of calcium hydroxide and resin-modified glass ionomer in deep cavities was evaluated, and there was seen to be no significant difference between them (Mickenautsch et al., 2010).

Direct Pulp Treatment

Direct pulp coverage is a vital pulp treatment that aims to prevent the loss of vitality of pulp exposed in the oral environment. In this procedure, repair by covering the exposed area of pulp with a suitable biomaterial promotes the formation of dentin, thereby attempting to provide continuity of pulp vitality (Velioğlu & Ünlü, 2020).

Direct pulp coverage, which is a more conservative treatment option than endodontic treatment, is accepted as a protective method between indirect pulp coverage and pulpotomy/pulpectomy, and over time there have been great increases in the success rate with the use of newly developed products. This treatment method is applied first, especially when iatrogenic perforation occurs in permanent teeth with young and vital pulp. The basic condition for obtaining treatment success is correct analysis of the current status of the tooth. Previous studies have reported that the vast majority of failures seen in direct pulp coverage are due to incorrect determination of indications. To be able to establish an indication for direct pulp treatment it is necessary for there to be a normal appearance of apical tissues on radiographic examination. In addition, biocompatible material should not be applied to the pulp chamber without obtaining bleeding control (Komabayashi et al., 2016).

Direct pulp capping is indicated when the tooth is vital and the patient has no spontaneous inflammation, there is no pathology on radiography, periapical tissues are healthy, bleeding can be controlled and does not contain exudate. There must also have been no previous form of swelling in the tooth (Cohenca et al., 2013). It can be performed when the patient has no systemic or blood disease and the general health status is good (McDonald et al., 2010). When contra-indications are evaluated, direct pulp capping is not recommended when spontaeous pain is present, radiolucent areas are observed in the periradicular region on radiological examination, the pulp is calcified, there is no bleeding in the pulp, or bleeding continues for longer than 5 minutes and exudate is present (Üngör and Önay, 2017; Cohenca et al., 2013).

One of the criteria for direct pulp capping that was accepted in the past is that the perforation exposed is wider than 1mm. However, more recent studies have shown that the perforation diameter is not a determining factor in treatment success. Pulp has healing capacity even when the whole dentin layer is removed. However, an increase in lesion size in decay-related perforations leads to a decrease in treatment success. Therefore, thorough cleaning of the decay tissue, uniform coverage of the exposed area with biomaterial, and then correct completion of the permanent restoration are of critical importance in terms of treatment success (Kuran, 2022). If there is no healthy pulp tissue remaining in the region where the pulp is exposed, and if bleeding is not brought under control, pulp tissue is removed in the apical direction. This procedure is continued until the ideal characteristics are obtained for wound healing. When these conditions cannot be met, root canal treatment should be performed (Cohenca et al., 2013; Cao et al., 2016).

The continuing presence of micro-organisms in the pulp or micro-organisms entering the pulp chamber through microleakage play a role in the basis of failure of direct pulp capping. Therefore, providing sterile conditions during the procedure, the use of a rubber dam, and coverage with good restorative material for impermeability of the cavity are important factors in obtaining success (Al Hiyasat et al., 2006).

Partial pulpotomy

Partial pulpotomy (Cvek pulpotomy) is a treatment approach that aims to preserve pulp tissue, thereby protecting vitality. This procedure is performed with the surgical removal of only a limited part of the coronal pulp. Thus, by eliminating inflamed or damaged superficial pulp tissue, the underlying healthy coronal pulp tissue is exposed and preserved (Bogen & Chandler, 2008).

When the pulp in young permanent teeth is exposed as a result of caries or trauma, partial pulpotomy can be performed when pulpal bleeding can be brought under control in a short time such as a few minutes. Protecting the vitality of the tooth is the fundamental condition for this treatment to be able to be performed (Gökçek & Hazar Bodrumlu, 2016). Another reason for selecting partial pulpotomy is that when it is necessary to clean a greater amount of deecayed tissue, it is possible for infected dentin remnants to move to the pulp (European Society of Endodontology, 2019).

The direct pulp coverage and partial pulpotomy methods are based on similar biological principles. However, the main difference betweeen these two applications is the amount of healthy pulp tissue remaining after the treatment. In other words, although the aim of both treatments is to maintain pulp vitality, more healthy tissue is preserved in partial pulpotomy, and in this respect is differentiated from direct pulp coverage. The success rates of partial pulpotomy have been reported to be 93%-96% (Ghoddusi et al., 2014).

The treatment steps of partial pulpotomy can be listed as follows; first, an approximately 2-3 mm part of the pulp tissue is removed. This demonstrates the main difference between direct pulp capping and partial pulpotomy. The aim in partial pulpotomy is to eliminate infected or inflamed tissue by removing a 2-3 mm surface section of the pulp in the exposed area. In contrast, no pulp tissue is removed in direct pulp capping, and only biocompatible material is applied to be in contact with the existing pulp surface, and finally the treatment s completed with the restorative procedure (Bjørndal et al., 2019).

Total Pulpotomy (Total Amputation)

Pulpotomy is a treatment method based on the preservation of root pulp with the removal of coronal pulp. The main aim of this procedure is to maintain pulpal vitality in young permanent teeth and to allow uninterrupted development of the root (Keçeci et al., 2017).

In teeth where the pulp tissue is exposed because of decay or trauma, and vitality is preserved, this treatment method can be applied when bleeding can be controlled during the procedure, there is no pathological appearance on radiography, and the radicular pulp is healthy, and is preferred especially in deciduous teeth and young permanent teeth. This approach is regarded as a more suitable treatment option in situations where pathological alterations are present in the exposed pulp tissue, inflammation in the coronal pulp has progressed to an advanced stage, and perforation is either extensive or involves multiple sites (Gökçek & Hazar Bodrumlu, 2016).

Total pulpotomy technique: This approach is fundamentally similar to partial pulpotomy, but the most significant difference is that a greater amount of pulp is removed in total pulpotomy. In this method, all the coronal pulp is removed, not only the surface section, and the procedure can be advanced as far as approximately 2-3mm apical from the entry of the root canals. The decision for how much tissue will be removed depends on clinical observation and the physician's experience (Kuran, 2022).

Ideal Properties and Types of Materials Used in Vital Pulp Therapy

The material used in vital pulp treatments should have the following properties (Sarı & Tufenkci, 2024):

- It should stimulate the formation of repair dentin.
- It should protect pulp vitality.
- It should be bactericidal or bacteriostatic.
- It should have high bonding strength to dental tissue and other restorative materials.
- It should be resistant to chewing forces.
- It should be radio-opaque.
- It should release fluoride.
- It should be sterile.
- It should have high impermeability.

In the literature, calcium hydroxide, resin-modified glass ionomer cement, mineral trioxide aggregate (MTA), biodentine, and bioceramics are given as examples of different pulp coverage materials (Qureshi et al., 2014).

Calcium Hydroxide

Calcium hydroxide was accepted as the gold standard by Hermann in the 1920s (Hermann, 1920). Calcium hydroxide is used in the preservation of pulp, in irrigation during canal treatment, in the treatment of fractures and periapical diseases, in the repair of resorption defects, in apexification and converting the basic pH of the acid environment formed in devital whitening, and in apexogenesis treatment (Alaçam, 2012).

Calcium hydroxide is still often used in pulp capping treatments. The material shows different effects on vital and devital pulp tissue and the main reason for this difference is the density of carbon dioxide. In vital pulp, the amount of carbon dioxide must be stable to be able to achieve balance. Thus, the amount of carbon dioxide absorbed by calcium hydroxide in contact with vital tissue can be kept in balance. A superficial necrotic layer is formed on the vital pulp surface in contact with calcium hydroxide. This is the slow death of pulp tissue without any micro-organisms. This necrotic layer that is formed stimulates the differentiation of healthy pulp tissue, fibroblasts and undifferentiated mesenchymal cells from odontoblasts. This process is seen in the healing mechanisms observed in vital pulp treatments in particular. By separating Ca^{2+} and OH^{-} ions in dentin tissue, calcium hydroxide raises the pH of the environment and demonstrates an antimicrobial effect. The alkaline conditions formed in the environment increase inorganic phosphate expression from the blood by activating phosphatase enzyme and causes the breakdown of calcium phosphate. It also stimulates the formation of a dentin bridge in the region where pulp is exposed (Kawakami et al., 1987).

$Ca(OH)_2$ has advantages such as excellent antibacterial properties and stimulating repair bridge formation when applied to pulp tissue. However, it cannot control pulpal inflammation sufficiently because of disadvantages such as it is not effective on *Enterococcus faecalis* in the dentin, the dentin bridge formed contains pores, bonding strength is weak, and by dissolving over time it cannot provide long-term impermeability against microleakage (Duncan et al., 2019).

Currently, silicate materials and resin-modified glass ionomer cements have achieved more successful results than calcium hydroxide. Silicate cements have become the most frequently preferred materials in clinical applications because of the high biocompatibility, stimulation of a regenerative response, and creation of an impermeable dentin bridge (Qiao et al., 2025).

Mineral Trioxide Aggregate (MTA)

MTA is a hydraulic calcium silicate cement, which was developed based on Portland cement, and is predominantly formed from calcium, silicone, aluminium, bismuth, and iron. Initially it was used as a root tip filling material in treatments. This material has been reported to induce the formation of repair dentin and have the potential to protect pulp vitality (Qiao et al., 2025; Komabayashi et al., 2016).

MTA is a modern and biocompatible biomaterial with a broad area of use. The material has been proven to be successful in many clinical applications including root perforations, apexification, retrograde filling, and direct pulp coverage. Various studies conducted in the field of pulp coverage have reported MTA to have the potential to form a better quality and thicker dentin bridge than calcium hydroxide. Due to the high alkaline pH, it also prevents the proliferation of micro-organisms remaining in the dentin after the removal of caries (Zhu et al., 2015; Koh et al., 1995).

Despite the many advantages of MTA, there some limitations preventing its use. The most important disadvantages are that the long hardening time (up to 284 mins) makes it difficult to use, it causes discolouration of the remaining tooth structure and there are heavy metals in the powder. As the first formulation of MTA was grey in colour, although no colour change was observed in the teeth, the chemical composition was changed, and a new version was introduced in the market. Although the white MTA that was launched in the market to prevent discolouration of the teeth does not contain an iron component, it continued to cause discolouration and this remains as one of the most important disadvantages of this material (Kunert & Lukomska-Szymanska, 2020).

Nevertheless, the toxicity of MTA is low and it causes less pulpal inflammation than calcium hydroxide. In a previous study, the application of MTA was reported to have a direct effect on the regeneration of dental pulp and increased the expression of TGF-β1 from pulp cells. This factor supports both the direct movement of progenitor cells to the material-pulp interface and their conversion to odontoblasts producing repair dentin. As a result of these mechanisms, the quality and structure of the hard tissue barrier formed is positively affected (Mente et al., 2014; Laurent et al., 2012). In a study by Dammaschke et al., it was observed that following vital pulp treatment with fast-hardening MTA, the hard tissue formation was not the product of actual odontoblast differentiation, and porous dentin had formed (Dammaschke et al., 2019).

Biodentine

Biodentine (Ca_3SiO_5) is a tricalcium silicate-based restoration material, which is obtained from Portland cement in the same way as MTA, and was produced to eliminate the disadvantages of MTA. In both direct and indirect pulp coverage treatments, Biodentine provides marginal impermeability, and protects pulp by stimulating repair dentin synthesis and remineralisation. It is accepted as a promising material with excellent physical and biological properties, and a pulp regeneration property similar to that of MTA. In addition, the hardening time of Biodentine is shorter and there is a lower probability of causing tooth discolouration compared to MTA (Kunert & Lukomska-Szymanska, 2020; Cushley et al., 2021).

The powder of the material contains tricalcium silicate, calcium carbonate, and zirconium oxide (contrast material), and in the liquid there is water, calcium chloride (this shortens the hardening time) and modified polycarboxylate. The powder and liquid are mixed in an amalgamator for 30 seconds. It is then applied directly with a manual instrument without any procedure made to the cavity. The open sandwich technique is used by applying resin-modified glass ionomer cement over the material. When mixed with water, $Ca(OH)_2$ is produced in a similar way to MTA. The formation of hydroxyapatite is achieved when $Ca(OH)_2$ is in contact with tissue fluids (Oğlakçı et al., 2016).

TheraCal

TheraCal was launched on the market as a pulp coverage material containing calcium silicate and resin monomers. It has advantages such as hardening with light in a short time, low solubility, high mechanical properties, and ease-of-use. It enables hard tissue formation by stimulating odontoblasts in the pulp due to calcium exposure at a high rate. In addition, the material raises the pH of the environment by stimulating the expression of hydroxyl ions and causes irritation in the pulp tissue. This creates superficial necrosis in the exposed pulp tissue and stimulates mineralisation over the necrotic region. However, the alkaline pH, and survival and proliferation of bacteria are negative effects. It has been observed that an extremely alkaline environment is created 3 hours after the application of TheraCal with very little change in the pH value after 24 hours (Giraud et al., 2019).

The solubility of TheraCal LC is lower than that of Dycal, ProRoot MTA, Angelus MTA, and Biodentine. Water absorption and the repair dentin structure formed show similarity to ProRoot MTA and Biodentine. Therefore, TheraCal can function as a matrix for the formation of repair dentin. Moreover, due to the ability to form apatite, it contributes to providing a chemical link with dentin and creates excellent impermeability (Arandi & Rabi, 2018). In a study that investigated the impermeability of MTA, Biodentine, and TheraCal LC, there was reported to be no significant difference between the MTA and Biodentine materials, whereas TheraCal LC showed a lower level of microleakage than the other materials (Makkar et al., 2016).

In a previous in-vitro study, Biodentine and MTA were reported to induce the formation of repair dentin at a significantly higher rate and intensity than TheraCal LC. While Biodentine application protected cell vitality, a significant decrease in cell proliferation was observed with TheraCal (Li et al., 2017). Direct pulp coverage materials were applied to healthy pulp tissue in another study and a large amount of mineralised dentin was determined to have formed below Biodentine, whereas irregular pulp tissue with limited and scattered areas of mineralisation were observed with the application of TheraCal (Jeanneau et al., 2017).

Bioceramics

Bioceramics can be classified as bioactive or bioinert according to the responses formed in tissues with which they have interacted. Bioactive substances such as glass and calcium phosphate induce the formation of stronger structures by entering into interaction with tissues. Bioinert substances such as zirconium and aluminium oxide function without a biological or physiological effect on the tissues with which they interact (Vallet-Regí, 2010).

Bioceramic materials have found an area of use in dentistry practice as they show biocompatible and osteoconductive properties together with successful physical and biological properties, the ability for chemical bonding with dental tissues, the provision of impermeable coverage, not dissolving in tissue fluids, and being radio-opaque and easy to manipulate (Swarup & Rao, 2013).

The areas of use of materials with bioceramic content are:

- Perforation repair
- As root canal filling and retrograde filling material
- Regenerative pulp treatments
- As pulp coverage material
- In apexogenesis and apexification procedures.

Bioaggregate

Bioaggregate is a bioceramic first produced with nanoparticle dimensions. The main component is formed from tricalcium silicate but tantalum oxide has been added to the formulation to provide the material with radio-opacity. The most important properties of this material are that it does not contain aluminium, which is toxic for vital tissues, and that application and manipulation are easy. It also shortened to 5 minutes the lengthy hardening period observed in MTA (Batur et al., 2013; Chung et al., 2010).

Bioaggregate does not cause discolouration of the teeth and provides more successful responses to pulpal inflammation compared to MTA. The material shows efficacy by stimulating cytokine expression. To determine biocompatibility, the material is examined in respect of the ability to form apatite crystals on the surface as a result of contact with bodily fluids in an in-vivo environment. Due to these apatite crystals, the material forms a chemical link with dental tissues and filling materials. The hydrophilic property of the material and low surface tension increase the chemical bonding. Thus an impermeable filling is obtained. It has also been reported that the bonding strength of the material is not affected by the presence of a smear layer (Chung et al., 2010; Koch et al., 2012; Bidar et al., 2014).

Resin-Modified Glass Ionomer Cements (RMGIC)

RMGICs are defined as glass ionomer materials with the addition of resin monomers to traditional glass ionomer cements in clinical applications with a hardening mechanism based on both the acid-base reaction and a polymerisation with light process. This hybrid approach decreases microleakage while providing bonding of the material to the tooth with fluoride expression. The use of RMGICs is easier compared to traditional glass ionomer cements and the bonding strength to composite materials is high (Singh et al., 2024).

Despite successful results in indirect pulp capping, RMGICs have been reported to lead to inflammation and necrosis when in direct contact with pulp and to remain insufficient in dentin bridge formation. Therefore, the use of RMGICs is not recommended in applications where there is direct contact with the pulp (Ghoddusi et al., 2014).

Various studies have compared the physical properties of RMGICs with those of traditional glass ionomer cements. At the end of a 3-year follow-up period of Class II cavities restored with RMGICs and traditional glass ionomer cements (TGIC), Hubel et al. reported success rates of 94% in the RMGIC restorations and 81% in the TGIC restorations. Retention loss, secondary decay formation, and fracture were observed in the restorations accepted as failures (Aratani et al., 2005; Hübel & Mejàre, 2003).

Adhesive System

Composite resins are used in vital pulp treatments but have been reported to show a toxic effect when in direct contact with pulp. Long-term successful results have not been obtained with this method and there are conflicting results in the literature. It has been reported that at 60 days after the direct coverage of affected pulp with the adhesive bonding technique, a permanent inflammatory reaction was determined without any pulp repair. This could be associated with incomplete bonding of the composite to the perforated area because of the presence of pulp fluid, and the subsequent formation of microleakage. Many studies have also reported negative effects such as hypersensitivity reactions due to the potential toxicity of the adhesive technique (Schuurs et al., 2000; Paranjpe et al., 2005).

Conclusion

In conclusion, vital pulp therapies are important conservative treatment approaches that aim to preserve the vitality of the pulp tissue through proper indication, appropriate clinical techniques, and the selection of biocompatible materials. With the development of modern biomaterials, the success rates of these treatments have increased, leading to more predictable clinical outcomes. However, treatment success depends not only on the material used, but also on the condition of the pulp, effective infection control, the provision of a well-sealed restoration, and accurate clinical decision-making. In this context, adherence to evidence-based principles and the selection of appropriate treatment protocols play a decisive role in achieving long-term success.

REFERENCES

Alaçam, T. (2012). Dentin ve pulpa tedavileri. In T. Alaçam (Ed.), *Endodonti*. Ankara: Özyurt Matbaacılık.

Al-Hiyasat, A. S., Barrieshi-Nusair, K. M., & Al-Omari, M. A. (2006). The radiographic outcomes of direct pulp-capping proce- dures performed by dental students: a retrospective study. J Am Dent Assoc. 137(12), 1699-1705.

American Academy of Pediatric Dentistry. (2016). Guideline on pulp therapy for primary and immature permanent teeth. *Pediatric Dentistry*, 38(6), 280–288.

Arandi, N. Z., & Rabi, T. (2018). TheraCal LC: From biochemical and bioactive properties to clinical applications. *International Journal of Dentistry*, 2018, 3484653.

Aratani, M., Pereira, A. C., Correr-Sobrinho, L., Sinhoreti, M. A. C., & Consani, S. (2005). Compressive strength of resin-modified glass ionomer restorative material: Effect of powder/liquid ratio and storage time. *Journal of Applied Oral Science*, 13, 356–359.

Batur, Y. B., Acar, G., Yalçın, Y., Dindar, S., Sancaklı, H., & Erdemir, U. (2013). Cytotoxic evaluation of mineral trioxide aggregate and bioaggregate in subcutaneous connective tissue of rats. *Medicina Oral, Patología Oral y Cirugía Bucal*, 18(4), e745–e751.

Bergenholtz, G. (2005). Advances since the paper by Zander and Glass (1949) on the pursuit of healing methods for pulpal exposures: Historical perspectives. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology, 100*(2 Suppl.), S102–S109. https://doi.org/10.1016/j.tripleo.2005.03.032

Bergenholtz, G., Mjör, I. A., Cotton, W. R., Hanks, C. T., Kim, S., Torneck, C. D., & Trowbridge, H. O. (1985). *Pulp capping and pulpal wound healing*. Oslo, Norway: Scandinavian University Press.

Bidar, M., Sadeghalhoseini, N., Forghani, M., et al. (2014). Effect of the smear layer on apical seals produced by two calcium silicate-based endodontic sealers. *Journal of Oral Science*, 56(3), 215–219.

Bjørndal, L., Simon, S., Tomson, P. L., & Duncan, H. F. (2019). Management of deep caries and the exposed pulp. International Endodontic Journal, 52(7), 949–973.

Bogen, G., & Chandler, N. P. (2008). Vital pulp therapy. In J. I. Ingle, L. K. Bakland, & J. C. Baumgartner (Eds.), Ingle's endodontics (6th ed., pp. 1310–1330). Hamilton, Ontario: BC Decker.

Cao, Y., Bogen, G., Lim, J., & Lee, B. S. (2016). Bioceramic materials and the changing concepts in vital pulp therapy. *Journal of the California Dental Association*, 44, 278–285.

Chung, R. C., Kim, E., & Shin, S. J. (2010). Biocompatibility of bioaggregate cement on human pulp and periodontal ligament-derived cells. *Journal of Korean Academy of Conservative Dentistry*, 35(6), 473–478.

Cohenca, N., Paranjpe, A., & Berg, J. (2013). Vital pulp therapy. *Dental Clinics of North America*, 57, 59–73.

Couve, E. 1986. Ultrastructural Changes Durıng The Lıfe Cycle Of Human Odontoblasts. Vol. 31.

Cushley, S., Duncan, H. F., Lappin, M. J., Chua, P., Elamin, A. D., Clarke, M., & El-Karim, I. A. (2021). Efficacy of direct pulp capping for management of cariously exposed pulps in permanent teeth: A systematic review and meta-analysis. *International Endodontic Journal*, 54, 556–571.

Dammaschke, T., Nowicka, A., Lipski, M., & Ricucci, D. (2019). Histological evaluation of hard tissue formation after direct pulp capping with fast-setting mineral trioxide aggregate (RetroMTA) in humans. *Clinical Oral Investigations*, 23, 4289–4299.

Duncan, H. F., Galler, K. M., Tomson, P. L., Simon, S., El-Karim, I., Kundzina, R., … Markvart, M. (2019). European Society of Endodontology position statement: Management of deep caries and the exposed pulp. *International Endodontic Journal*, 52, 923–934.

European Society of Endodontology. (2019). European Society of Endodontology position statement: Management of deep caries and the exposed pulp. *International Endodontic Journal*, 52(7), 923–934.

Ghoddusi, J., Forghani, M., & Parisay, I. (2014). New approaches in vital pulp therapy in permanent teeth. *Iranian Endodontic Journal*, 9(1), 15.

Giraud, T., Jeanneau, C., Rombouts, C., et al. (2019). Pulp capping materials modulate the balance between inflammation and regeneration. *Dental Materials*, 35(1), 24–35.

Gökçek, M., & Hazar Bodrumlu, E. (2016). Vital pulpa tedavilerinde güncel yaklaşımlar (New approaches in vital pulp therapy). *Atatürk Üniversitesi Diş Hekimliği Fakültesi Dergisi*, Supplement 14, 118–129.

Hargreaves, K. M., Cohen, S., & Berman, L. H. (2011). *Cohen's pathways of the pulp* (10th ed.). St. Louis, MO: Mosby Elsevier.

Hermann, B. W. (1920). *Kalziumhydroxid als Mittel zum Behandeln und Füllen von Zahnwurzelkanälen* (Doctoral dissertation). University of Würzburg, Würzburg.

Hübel, S., & Mejàre, I. (2003). Conventional versus resin-modified glass-ionomer cement for class II restorations in primary molars: A 3-year clinical study. *International Journal of Paediatric Dentistry*, 13, 2–8.

Jeanneau, C., Laurent, P., Rombouts, C., Giraud, T., & About, I. (2017). Light-cured tricalcium silicate toxicity to the dental pulp. *Journal of Endodontics*, 43, 2074–2080.

Kawakami, T., N. C., Hasegawa, H., & Eda, S. (1987). Fate of 45Ca-labelled calcium hydroxide in a root canal filling paste embedded in rat subcutaneous tissue. *Journal of Endodontics*, 13, 220–223.

Keçeci, A. D., Basa, Ş. E., & Küçük, Ö. (2017). Vital pulpa tedavilerinde klinik uygulama teknikleri. *Turkiye Klinikleri Journal of Endodontics-Special Topics*, 3(3), 165–180.

Koch, K., Brave, D., & Nasseh, A. A. (2012). A review of bioceramic technology in endodontics. *Compendium of Continuing Education in Dentistry*, 4, 6–12.

Koh, E. T., Pitt Ford, T. R., Torabinejad, M., & McDonald, F. (1995). Mineral trioxide aggregate stimulates cytokine production in human osteoblasts. *Journal of Bone and Mineral Research*, 10(Suppl), S406.

Komabayashi, T., Zhu, Q., Eberhart, R., & Imai, Y. (2016). Current status of direct pulp-capping materials for permanent teeth. *Dental Materials Journal*, 35, 1–12.

Kunert, M., & Lukomska-Szymanska, M. (2020). Bio-inductive materials in direct and indirect pulp capping: A review article. *Materials*, 13(5), 1204.

Kuran, H. M. (2022). *Vital pulpa tedavileri* (Undergraduate thesis). İstanbul Üniversitesi, Endodonti Anabilim Dalı, İstanbul, Türkiye.

Laurent, P., Camps, J., & About, I. (2012). Biodentine™ induces TGF-β1 release from human pulp cells and early dental pulp mineralization. *International Endodontic Journal*, 45, 439–448.

Li, X., DeMunck, J., Van Landuyt, K., Pedano, M., Chen, Z., & Van Meerbeek, B. (2017). How effectively do hydraulic calcium-silicate cements remineralize demineralized dentin? *Dental Materials*, 33, 434–445.

Makkar, S., Kaur, H., Anurag, A., & Vashisht, R. (2016). A confocal laser scanning microscopic study evaluating the sealing ability of mineral trioxide aggregate, biodentine and a new pulp capping agent-TheraCal. *Dental Journal of Advance Studies*, 3(1), 19–25.

McDonald, R. E., Avery, D. R., & Dean, J. A. (2010). Treatment of deep caries, vital pulp exposure and pulpless teeth. In R. E. McDonald, D. R. Avery, & J. A. Dean (Eds.), Dentistry for the child and adolescent (8th ed., pp. 343–365). Missouri: Mosby.

Mente, J., Hufnagel, S., Leo, M., Michel, A., Gehrig, H., Panagidis, D., … Pfefferle, T. (2014). Treatment outcome of mineral trioxide aggregate or calcium hydroxide direct pulp capping: Long-term results. *Journal of Endodontics*, 40, 1746–1751.

Mickenautsch, S., Yengopal, V., & Banerjee, A. (2010). Pulp response to resin-modified glass ionomer and calcium hydroxide cements in deep cavities: A quantitative systematic review. *Dental Materials*, 26(8), 761–770. https://doi.org/10.1016/j.dental.2010.03.021

Oğlakçı, B., Arhun, N., & Tuncer, D. (2016). Restoratif diş tedavisinde pulpa kaplamaları. *Atatürk Üniversitesi Diş Hekimliği Fakültesi Dergisi*, 26(4).

Paranjpe, A., Bordador, L., Wang, M. Y., Hume, W., & Jewett, A. (2005). Resin monomer 2-hydroxyethyl methacrylate (HEMA) induces apoptotic cell death in human and mouse cells. *Journal of Dental Research*, 84(2), 172–177.

Qiao, L., Zheng, X., Xie, C., Wang, Y., Ye, L., Zhao, J., & Liu, J. (2025). Bioactive materials in vital pulp therapy: Promoting dental pulp repair through inflammation modulation. *Biomolecules*, 15.

Qureshi, A., E. S., Nandakumar, Pratapkumar, & Sambashivarao. (2014). Recent advances in pulp capping materials: An overview. *Journal of Clinical and Diagnostic Research*, 8(1), 316–321.

Sarı, M., & Tufenkci, P. (2024). Matür daimi dişlerde vital pulpa tedavilerine güncel bir bakış: Derleme makalesi. *Acta Odontologica Turcica*, 41(2), 75–81.

Savadi Oskoee, S., Bahari, M., Kimyai, S., Motahhari, P., Eghbal, M. J., & Asgary, S. (2014). Shear bond strength of calcium enriched mixture cement and mineral trioxide aggregate to composite resin with two different adhesive systems. *Journal of Dentistry (Tehran)*, 11(6), 665–671.

Schroder, U. 1985. *Effects of Calcium Hydroxide-Containing Pulp-Capping Agents on Pulp Cell Migration, Proliferation, and Differentiation*.

Schuurs, A., Gruythuysen, R., & Wesselink, P. (2000). Pulp capping with adhesive resin-based composite vs calcium hydroxide: A review. *Dental Traumatology*, 16(6), 240–250.

Singh, S., Kulkarni, G., Kumar, R. S. M., Jain, R., Lokhande, A. M., Sitlaney, T. K., Ansari, M. H. F., & Agarwal, N. S. (2024). Comparative evaluation of the biological response of conventional and resin-modified glass ionomer cement on human cells: A systematic review. *Restorative Dentistry and Endodontics*, 49(4), e41.

Swarup, S., & Rao, A. (2013). *Bioceramics in pediatric endodontics*. Trivandrum: Lambert Academic Publishing.

Tunçdemir, M. T., & Al Rashid, A. H. E. (2023). Vital pulpa tedavileri: Direkt ve indirekt pulpa kuafajı. In *Diş hekimliği bilimlerinde güncel tartışmalar 3* (pp. 119-141). Ankara: BIDGE Yayınları.

Tziafas, D., Smith, A. J., & Lesot, H. (2000). Designing new treatment strategies in vital pulp therapy. *Journal of Dentistry*, 28(2), 77–92.

Üngör, M., & Önay, E. O. (2017). Vital pulpa tedavisi endikasyonları. *Turkiye Klinikleri Journal of Endodontics-Special Topics*, 3(3), 160–164.

Vallet-Regí, M. (2010). Evolution of bioceramics within the field of biomaterials. *Comptes Rendus Chimie*, 13, 174–185.

Velioğlu, M. S., & Ünlü, N. (2020). Direkt pulpa kapaklamasında kullanılan materyaller. In B. Balpetek (Ed.), *Research in health sciences* (pp. 73–90). Ankara: Duvar Yayınları.

Zhu, C., Ju, B., & Ni, R. (2015). Clinical outcome of direct pulp capping with MTA or calcium hydroxide: A systematic review and meta-analysis. *International Journal of Clinical and Experimental Medicine*, 8(10), 17055–17060.

Chapter 6

CHILD ABUSE AND NEGLECT: DIAGNOSTIC PARAMETERS, PREVENTION POLICIES, AND ORAL FINDINGS AND LEGAL RESPONSIBILITIES IN DENTISTRY

Yasemin Derya FİDANCIOĞLU[1]
Havva VAROL[2]

1 Öğr. Gör. Dr., Necmettin Erbakan Üniversitesi Diş Hekimliği Fakültesi Çocuk Diş Hekimliği Anabilim Dalı
ORC-ID: 0000-0002-0260-6458
2 Dt., Özel Klinik
ORC-ID: 0009-0004-9511-7689

Child abuse refers to situations in which a child is exposed to behaviors by parents, other family members, caregivers, or any unfamiliar adult that conflict with the generally accepted values and norms of society, negatively affect the child's physical, emotional, or psychological well-being, and harm their developmental process.

This type of abuse restricts a child's right to grow, learn, and develop emotionally, and constitutes a serious threat that may hinder the child's future life and their ability to take part in society as a healthy individual (Kara, 2004)

Although child abuse has appeared in various sources since the earliest periods of written history, humanity has only begun to pay significant attention to this issue in the last century (Jain, 1999; Sicher et al., 2000).

2. HISTORY OF CHILD ABUSE

The first description of child abuse in the medical literature was made by Auguste Ambroise Tardieu in 1860. Prior to this, the issue had been addressed in the novels of Charles Dickens and Victor Hugo (Practice Parameters, 1997; Tercier, 1998). John Caffey's association of long bone and rib fractures with subdural hematoma and child abuse in 1946 drew renewed attention to the issue. In later years, he introduced the concept of child abuse (Jain, 1999; Pressel, 2000; Tercier, 1998). With this development, numerous scientific studies addressing child neglect and abuse in all its aspects were conducted (Arthur, 1997; Powers et al., 1990). Subsequent studies began to include not only physically abused children but also those who were subjected to sexual or emotional abuse within their families or in society (Lynch, 1985).

In Turkish society, efforts aimed at protecting children began long ago through the foundation (waqf) system. During this period, it can be said that religious teachings and sacred beliefs played an important role. However, the establishment of institutional structures designed to meet the needs of modern society occurred much later compared to other nations (Osman, 1950; Polat, 2002).

After the end of the Ottoman Empire, the Republic of Turkey took its first step regarding children in need of protection through the Ministry of Education, and later transferred this responsibility to the Ministry of Health and Social Assistance. Immediately following this, the Regulation on Orphanages (Darüleytamlar) No. 2042 was enacted and put into practice on December 5, 1922 (Çavuşoğlu, 1999).

One of the most significant steps in this process up to the present day has undoubtedly been the United Nations Convention on the Rights of the Child, adopted in 1989 by the United Nations. 19th article of this convention establishes that children must be protected from all forms of maltreatment by those responsible for their care, and defines this protection as an obligation for the states that are parties to the convention (Oktay, 2000).

Turkey signed the United Nations Convention on the Rights of the Child, which had been approved by the United Nations General Assembly, on 14 February 1990. It was subsequently ratified by the Grand National Assembly of Turkey on 9 December 1994. The Convention on the Rights of the Child was published in the T.C. Official Gazette on 27 January 1995 and, through Law No. 4058, became part of domestic law and began to be implemented in Turkey (Lynch, 1985).

3. TYPES OF ABUSE

Child abuse takes four different forms: sexual, emotional, physical, and neglect (Powers et al., 1990).

3.1 Physical Abuse

Injuries in children may occur not only as a result of accidents but also due to parents' failure to protect them adequately or the use of excessive physical punishment. Although accidents are common in children, abuse should be suspected when injuries are not appropriate for the child's age or when the likelihood of them occurring accidentally is low. Physical punishment is a widely used and universal method for disciplinary purposes; however, when such corporal punishment is inflicted by those responsible for the child's care, it may constitute a significant risk factor for physical abuse. In such cases, if it is claimed that the injury was caused by another child, it should be carefully examined whether this is actually possible. Non-accidental trauma usually occurs when parents lose control or attempt to punish their children, and such cases should be investigated thoroughly (Çetin, 2014; First Istanbul Children's Congress, 2000; Tercier, 1998)

Findings associated with physical abuse include head trauma, bruises, fractures, dislocations, and contusions. In addition, cigarette burn marks on the body, partially healed fractures, and internal bleeding beneath the skull may also be detected. However, in some cases of physical abuse, there may be no visible injuries that disrupt the physical integrity of the body. For example, severe shaking of a child that results in brain damage may also constitute a form of physical abuse (Polat, 2006).

3.2 Sexual Abuse

Sexual abuse refers to the sexual exploitation of a child—whose psychological and sociological development has not yet been completed—by an adult or by another child who is older and physically stronger (Yaşar, 2007). Sexual abuse can manifest in various forms. For example, exposure to sexually explicit behaviors, obscene phone calls, verbal harassment, being forced to witness sexual acts, voyeurism, exposure to explicit or obscene publications, encouragement toward prostitution, sexual touching or rubbing of the body, and incestuous relationships can all be defined as forms of sexual abuse (Yakut, 2013).

3.3 Emotional Abuse

Emotional abuse is defined, according to social and scientific norms, as situations in which children and adolescents are exposed to negative attitudes and behaviors or are deprived of the appropriate attention, love, and care necessary for their well-being, leading to psychological harm. This type of abuse is generally carried out by individuals who hold power or authority in the child's environment.

Children who experience emotional abuse may display symptoms such as distancing themselves from their families, tension, dependency, feelings of worthlessness, maladjustment, and aggressive behavior. This condition may occur together with physical or sexual abuse or neglect, but it can also occur independently. The harm caused by emotional abuse can be as destructive as physical abuse; however, its effects often remain more hidden (Çetin, 2014; Ovayolu, 2007; Tercier, 1998).

3.4 Neglect

Neglect is defined as the failure of the person or persons responsible for a child's care to meet the child's basic needs—such as nutrition, health care, shelter, clothing, protection, and supervision—or, in a broader sense, the failure of the state to provide services such as health, education, social assistance, and security. Neglect may occur in different forms, including physical, emotional, educational, and medical neglect.

Physical neglect is frequently encountered in children who experience growth and developmental delays or injuries resulting from accidents. Compared to physical abuse, neglect is more common; however, it is often overlooked unless it results in death or serious injury, as it is more abstract in nature and less dramatic than physical or sexual abuse. Nevertheless, the effects of neglect on children can be as harmful as those of physical abuse. The most significant difference between abuse and neglect is that abuse involves an active behavior, whereas neglect represents a passive condition (Dubowitz, 2000, 2002; Jain, 1999; Ovayolu, 2007; Polat, 2002; Tercier, 1998; Theodore, 1999).Among the types of child abuse, neglect is the most commonly encountered; however, due to the difficulties in diagnosing it, it is often under reported (Dokgöz, 2002).

4. EFFORTS TO PREVENT CHILD ABUSE IN THE USA

Child abuse and neglect, as in the global context, also stand out in the United States as one of the significant problems threatening the social structure. Public administration, as with other social problems, is responsible for developing protective and preventive policies in this field and implementing the necessary interventions. As with every public issue, child abuse and neglect also impose serious costs on the national economy. Scientific studies have shown that preventive interventions are far less costly than the intervention and treatment processes carried out after an incident has occurred (Can, 2011).

Early home visits have been extensively examined as intervention strategies targeting pregnant women and newborn babies, and they have demonstrated significant positive effects in reducing factors associated with negative parenting risks such as abuse and neglect. In addition, various preventive approaches—such as school-based violence prevention programs, public awareness campaigns, training aimed at improving parenting skills, and structural reforms implemented in professional practices—have also produced promising results (Petersen et al., 2014: 265).

Preventive interventions constitute the foundation of a comprehensive initiative carried out by the United States Department of Health and Human Services. The main aim of this initiative is to promote the sharing of information about prevention programs that produce positive outcomes for children and families. In line with this vision, the Office on Child Abuse and Neglect (OCAN), operating under the Children's Bureau, launched the Child Abuse Prevention Initiative between 2003 and 2004 in order to increase public visibility of efforts to prevent child abuse. Recognizing the need to reduce the risks faced by vulnerable children has encouraged steps toward strengthening families, increasing their capacities, and enhancing their resilience within existing programs carried out through cooperation between the public and private sectors (Thomas et al., 2002: 1).

4.1 Programs to Improve Parenting Skills

Different intervention approaches have been designed to strengthen parenting skills and support healthy child development, thereby contributing to the prevention of child abuse and neglect (Fortson et al., 2016, p. 25). Efforts aimed at supporting parents, caregivers, and family members and improving parenting skills are considered a critical area of intervention in combating child abuse and neglect. Raising families' and caregivers' awareness of child development increases the likelihood of adopting positive discipline strategies and thereby contributes to reducing the risk of domestic violence (UNICEF, 2014: 12). A home visitation program implemented in the United States contributed to a 48% reduction in cases of child abuse and neglect over a 15-year period (UNICEF, 2014: 14).

4.2 Home Visiting and Other Family Support Programs

Home visiting practices, considered an effective strategy in combating child abuse and neglect, first gained prominence in the national policy agenda in the United States in 1991, when the Advisory Board on Child Abuse and Neglect recommended the universal expansion of such programs (Thomas et al., 2002, p. 12). Home visiting programs provide one-on-one parenting education and support services and are used as an effective method for reaching families who experience social isolation or have limited access to group-based interventions.

Implementing these programs as a targeted strategy for young children can contribute to reducing long-term costs while also supporting children's healthy social and emotional development in later life. Home visits provide families with direct information, guidance, and support, while also largely eliminating structural barriers—such as program limitations, transportation difficulties, and employment constraints—that may hinder access to services. Although these programs vary depending on their target populations and content, they generally include health services, parenting education, child abuse prevention, early intervention for infants and young children, and in some cases preschool education programs. The most common home visiting models focus on children's developmental processes and on how parents can support this development (Avellar & Supplee, 2013).

4.3 Public Awareness Activities

Public awareness initiatives are one of the fundamental components of a comprehensive strategy to combat child abuse and neglect. Such initiatives have the capacity to reach different target groups, including parents, future parents, children, and members of the broader community. During the development of preventive education programs and public information campaigns, institutions at the national, state, and local levels actively use various media tools to expand the reach of these activities (Hildyard & Wolfe, 2002, p. 1).

4.4 School Programs

Initiatives aimed at preventing child sexual abuse largely focus on educational interventions. Initially developed for children, these programs have gradually expanded to include families, teachers, youth service workers, and other adult groups who may potentially intervene. One of the primary aims of these interventions is to enhance children's ability to recognize risky situations and equip them with skills to prevent abuse.

These programs aim to teach children how to recognize boundary violations, identify unwanted physical contact, distinguish offenders' manipulation and desensitization strategies, and effectively say "no" to such approaches (Finkelhor, 2009: 179).

5. CHILD ABUSE PREVENTION EFFORTS IN TURKEY

5.1 Social Services and Child Protection

Within the operational framework of the child protection system in Turkey, the Social Services and Child Protection Agency serves as the primary executive body responsible for both ensuring the general welfare of all children and providing targeted support for children in need of protection. The central role of this institution stems from its capacity to offer continuous 24/7 care and supervision, as well as its ability to address protection requirements through various day-care service models (Ministry of Family and Social Services, 2023; Social Science Studies, 2019).

Social work encompasses planned social intervention processes that aim to support individuals, families, and communities in performing their social functions more effectively, enhance their quality of life, reduce their dependency on others by ensuring self-sufficiency, and strengthen family integrity. These services are carried out through systematic programs and practices conducted by professionals from various disciplines, particularly social workers (T.C. Official Gazette, 2005; Karataş, 2013).

5.2. Family-Based Care for the Child

The family-based care model stands out as one of the oldest and most human-centered approaches within child protection systems. This model is based on the premise that protecting a child within their natural environment—together with their biological family, particularly parents and close relatives—provides the most suitable setting for the child's development. This approach, adopted by various civilizations throughout history, continues to be regarded as one of the fundamental pillars of the child rights perspective today. The supportive role of family-based care in a child's emotional, social, and psychological development has been demonstrated by numerous scientific studies. In this context, supporting children within a family environment rather than through institutional care enables their basic needs, such as belonging, security, and identity development, to be met more effectively. In alignment with this understanding, the Constitution of the Republic of Turkey defines the protection, strengthening, and support of the family unit, as well as the protection of children, among the primary duties of the state. Article 41 of the Constitution emphasizes that 'Family is the foundation of Turkish society and is based on equality between spouses. The State shall take the necessary measures for the protection of the family and the best interests of the child," highlighting that social policies must be shaped within this framework (Constitution of the Republic of Turkey, 1982; Ministry of Family and Social Services, 2023; Tuncay, 2011).

5.3 In-Kind and Cash Assistance Services

Socio-economic poverty in Turkey disproportionately affects children more than any other social group. Problems arising from financial insufficiencies are often recognized late within the family unit, leading to an inability to adequately meet children's developmental, emotional, and physical needs. A lack of resources and attention within the family results in child neglect and, in some cases, can lead to consequences such as children working on the streets or being forced into street life. Indeed, a significant majority of children living or working on the streets originate from families with low socio-economic status (UNICEF, 2021).

Accordingly, social service policies have been developed to protect children within their family environment. One of these policies aims to lift children out of at-risk living conditions by supporting impoverished families through social assistance. In line with the principle of family-based protection, supporting children without separating them from their families is vital for both maintaining social cohesion and upholding child rights (Karataş, 2013).

Parallel to this understanding, the Social Services and Child Protection Agency (SHÇEK) Law defines the development and implementation of various services and programs to provide in-kind and cash assistance—within the limits of available resources—to individuals and families experiencing economic deprivation and severe difficulty in meeting basic needs as one of the agency's primary duties (T.C. Official Gazette, 2005).

6. DIFFERENTIAL DIAGNOSIS IN CHILD ABUSE FOR DENTISTS AND THE PHYSICIAN'S RESPONSIBILITIES

When encountering suspicious cases, clinicians must possess adequate knowledge and experience regarding accidental injuries to evaluate whether an incident truly resulted from an accident (Andressen et al., 2010).

6.1 Oral Findings in Physical Abuse

Tears of the labial and lingual frenulum, particularly in the labial frenulum region, are frequently encountered in cases of physical abuse. However, the presence of a labial frenulum tear alone is insufficient to diagnose physical abuse. When such a finding is accompanied by other clinical signs—especially in children under one year of age—the possibility of abuse must be strongly considered (Maguire et al., 2007; Thackeray, 2007).

A severe blow to the lower facial region may result in dental fractures, luxation (loosening), or complete avulsion (displacement) of the teeth. Nevertheless, such injuries are not exclusively indicative of abuse and can also occur as a result of accidents. Therefore, it is crucial to carefully evaluate the extent to which the sustained damage is consistent with the provided history

(Jessee, 1995; Owais et al., 2009).

Children subjected to physical abuse may present with lacerations, burns, bruises, or scars from previous injuries on the lips. Bruising may occur due to forced feeding. Burns on the

lips, as seen on the face and tongue, are often the result of physical punishment. Perioral bruising can develop as a consequence of violence applied to silence the child. Scarring on the lips serves as an indicator of past trauma and should prompt the clinician to consider the possibility of abuse (Christian, 2015; Peterson et al., 2003).

6.2 Oral Findings in Sexual Abuse

When a sexually transmitted infection (STI) or intraoral manifestations of such diseases are detected in a child, the possibility of sexual abuse must be strictly considered. If the child is under the age of two, there is a high probability that the infection was transmitted during birth or in utero. However, for children between the ages of 2 and 10, the likelihood of sexual abuse should be the primary consideration in the acquisition of such diseases (Yaşar & Akduman, 2007).

Semen residues or hairs may also be encountered within the oral cavity. When such findings are detected, necessary examinations should be conducted by taking samples from the tongue and buccal mucosa (Kellogg, 2005).

Similar to physical abuse cases, bite marks may also be observed in instances of sexual abuse. While these marks can be located on any part of the child's body, they are particularly likely to be found in the genital region. If the perpetrator is another child, marks typically occur on the cheeks and upper extremities. In humans, the intercanine distance (the distance between the two maxillary canines) varies between 2.5 and 4 cm. Therefore, when a bite mark is identified, measuring and evaluating the dimensions of the marks is critical for the diagnosis of abuse. If the intercanine distance in the bite mark is less than 2.5 cm, it is likely attributed to a child; if it is less than 3 cm, to a child or an adolescent; and if it exceeds 3 cm, it should be considered the work of an adult (Yaşar & Akduman, 2007).

6.3 Oral Findings in Emotional Abuse

Dentists should take into consideration that children subjected to emotional abuse may exhibit symptoms such as temporomandibular joint (TMJ) disorders, bruxism (teeth clenching), or teeth grinding due to violence and stress. Additionally, habits such as thumb sucking and nail-biting (onychophagia) may develop in these children. Such habits can predispose the oral and maxillofacial structure to both dental and skeletal malocclusions (Tirali et al., 2014).

6.4 Oral Findings in Dental Neglect

Dental neglect is defined as the failure to provide the necessary dental care to maintain oral health and the physical neglect of the oral cavity (Thomson et al., 1996). According to the American Academy of Pediatric Dentistry (AAPD), dental neglect is the willful failure by a parent or guardian to seek and follow through with treatment necessary to ensure a level of oral health essential for adequate function and freedom from pain and infection, even in the absence of acute symptoms (Kurt et al., 2019).

6.5 Responsibilities of the Physician

Physicians who encounter suspected cases of child abuse carry both ethical and legal responsibilities. In Turkey, since physicians are considered public officials, they are obligated under Article 279 of the Turkish Penal Code to report any crime discovered during the performance of their duties to the competent authorities. Failure to report constitutes a violation of both professional ethical principles and the law. Furthermore, the Child Protection Law No. 5395 assigns significant roles to healthcare professionals regarding the protection of children and the upholding of their rights. This obligation involves not only documenting the abuse but also intervening while prioritizing the best interests of the child (Child Protection Law, 2005; TPC, 2004).

The first step physicians must take in such cases is to meticulously document the situation by performing a detailed physical and psychological assessment of the child. Examination findings should be fully recorded in medical files, and particularly trauma signs, the child's narrative, and their psychological state should be reported in objective language. Subsequently, depending on the specifics of the case, a referral should be made to Child Monitoring Centers or a direct notification should be submitted to the Chief Public Prosecutor's Office. In this process, it is inappropriate for the physician to attempt independent investigations or confront the suspect; instead, they must ensure the commencement of legal proceedings (Erdoğan et al., 2021). Furthermore, it is of paramount importance for physicians to adopt a multidisciplinary perspective in their approach to child abuse. Within this framework, effective collaboration must be established with social workers, child development specialists, psychologists, guidance services, and judicial authorities. The physician should not only provide medical intervention but also contribute to creating suitable conditions for the child's protection, psychosocial support, and the prevention of re-traumatization. The World Health Organization (WHO) also identifies increasing the awareness levels and intervention capacities of first-contact healthcare personnel as a core strategy in combating child abuse (WHO, 2016). A physician's accurate, rapid, and sensitive intervention is vital for the preservation of the child's physical and mental health.

Consequently, the legal reporting obligation for physicians encountering child abuse is a necessity rather than a choice. This process must be evaluated alongside ethical responsibilities, the child's welfare, and a human rights perspective. The physician's sensitivity plays a critical role in ensuring the child's safety and preventing recurrent abuse.

REFERENCES

Andressen, J. O., Andressen, F. M., & Andersson, L. (2010). *Textbook and color atlas of traumatic injuries to the teeth: Child physical abuse* (4th ed.). London, England: Wiley-Blackwell.

Avellar, S., & Supplee, L. (2013). *Effectiveness of home visiting in child health and maltreatment reduction.* [Technical Report].

Can, M., Tırtıl, L., & Dokgöz, H. (2011). Physician responsibility in child abuse cases [Çocuk istismarı olgularında hekim sorumluluğu]. In S. Koç & M. Can (Eds.), *Forensic medicine in primary care* (2nd ed., pp. 181-191). Istanbul, Turkey: Istanbul Medical Chamber.

Çavuşoğlu, T. (1999). Child protection agency and the child in Turkey: 1921-1983 [Türkiye'de Çocuk Esirgeme Kurumu ve Çocuk: 1921-1983]. In B. Onur (Ed.), *Proceedings of the 2nd National Child Culture Congress* (p. 462). Ankara, Turkey: Ankara University CHUAM Publications.

Çetin, M. S. (2014). *The place and importance of child abuse and neglect in forensic dentistry* [Unpublished bachelor's thesis]. Ege University Faculty of Medicine, Izmir, Turkey.

Child Protection Law No. 5395. (2005). *Official Gazette of the Republic of Turkey*, 25876.

Christian, C. W., & Committee on Child Abuse and Neglect, American Academy of Pediatrics. (2015). The evaluation of suspected child physical abuse. *Pediatrics, 135*(5), e1337–e1354.

Constitution of the Republic of Turkey. (1982). Article 41: Protection of the family and children's rights.

Dokgöz, H., Şam, B., Ersoy, G., & Müsellim, N. T. (2002). A case of child neglect resulting in death [Ölümle sonuçlanan ihmale uğramış çocuk olgusu]. *Annual Forensic Medicine Meetings Book (No. 6)* (pp. 118-121). Antalya, Turkey: Forensic Medicine Institution Publications.

Dubowitz, H. (2002). Preventing child neglect and physical abuse. *Pediatrics in Review, 23*, 191-196.

Dubowitz, H., Giardino, A., & Gustavson, E. (2000). Child neglect: Guidance for pediatricians. *Pediatrics in Review, 21*(4), 111-120.

Finkelhor, D. (2009). The prevention of childhood sexual abuse. *The Future of Children, 19*(2), 169–194.

Fortson, B. L., Klevens, J., Merrick, M. T., Gilbert, L. K., & Alexander, S. P. (2016). *Preventing child abuse and neglect: A technical package for policy, norm, and programmatic activities* (p. 25). Atlanta, GA: Centers for Disease Control and Prevention.

Hildyard, S. D., & Wolfe, D. A. (2002). Child neglect: Developmental issues and outcomes. *Child Abuse & Neglect, 26*(6–7), 679–695.

Jain, A. M. (1999). Emergency department evaluation of child abuse. *Emergency Medicine Clinics of North America, 17*, 575-593.

Jessee, S. A. (1995). Physical manifestations of child abuse to the head, face and mouth: A hospital survey. *ASDC Journal of Dentistry for Children, 62*(4), 245–249.

Kara, B., Biçer, Ü., & Gökalp, A. S. (2004). Child abuse [Çocuk istismarı]. *Journal of Child Health and Diseases, 47*, 140-151.

Karataş, Z. (2013). Child protection applications in social services [Sosyal hizmetlerde çocuk koruma uygulamaları]. *Journal of Researches in Education and Teaching, 2*(3), 222–231.

Kellogg, N. (2005). Oral and dental aspects of child abuse and neglect. *Pediatrics, 116*(6), 1565–1568.

Kurt, A., Baygın, Ö., & Tüzüner, T. (2019). Dental neglect. *Yeditepe Dental Journal, 15*(1), 103–109.

Lynch, M. A. (1985). Child abuse before Kempe: An historical literature review. *Child Abuse & Neglect, 9*, 7-15.

Maguire, S., Hunter, B., Hunter, L., Sibert, J. R., Mann, M., & Kemp, A. M. (2007). Diagnosing abuse: A systematic review of torn frenum and other intra-oral injuries. *Archives of Disease in Childhood, 92*(12), 1113.

Ministry of Family and Social Services. (2023a). *Foster family services guide* [Koruyucu aile hizmetleri rehberi]. Ankara, Turkey.

Ministry of Family and Social Services. (2023b). *General Directorate of Child Services activity report* [Çocuk Hizmetleri Genel Müdürlüğü faaliyet raporu]. Ankara, Turkey.

Oktay, A. (2000). *Magic years of life* [Yaşamın sihirli yılları] (2nd ed.). Istanbul, Turkey: Şahinkaya Press.

Ovayolu, N., Uçan, Ö., & Serindağ, S. (2007). Sexual abuse in children and its effects [Çocuklarda cinsel istismar ve etkileri]. *Fırat Health Services Journal, 2*(4), 13-22.

Owais, A. I. N., Qudeimat, M. A., & Qodceih, S. (2009). Dentists' involvement in identification and reporting of child physical abuse: Jordan as a case study. *International Journal of Paediatric Dentistry, 19*(4), 291–296.

Petersen, A. C., Joseph, J., & Feit, M. N. (Eds.). (2014). *New directions in child abuse and neglect research* (p. 265). Washington, DC: National Academies Press.

Peterson, M. S., Durfee, M., & Coulter, K. (2003). *Child abuse and neglect: Guidelines for identification, assessment, and case management*. Volcano, CA: Volcano Press.

Polat, O. (2002a). *What are children's rights?* [Çocuk hakları nedir?]. Istanbul, Turkey: Analiz Publications.

Polat, O. (2002b). *Children and violence* [Çocuk ve şiddet]. Istanbul, Turkey: Der Publications.

Polat, O. (2006). Child abuse. In *Clinical forensic medicine applications* [Klinik adli tıp adli tıp uygulamaları] (pp. 129-176). Ankara, Turkey: Seçkin Publications.

Powers, J. L., Eckenrode, J., & Jaklitsch, B. (1990). Maltreatment among runaway and homeless youth. *Child Abuse & Neglect, 14*, 87-98.

Practice parameters for the forensic evaluation of children and adolescents who may have been physically or sexually abused. (1997). *Journal of the American Academy of Child and Adolescent Psychiatry, 36*, 37S-56S.

Pressel, D. M. (2000). Evaluation of physical abuse in children. *American Family Physician, 61*, 3057-3064.

Reynolds, A. J., Mathieson, L. C., & Topitzes, J. (2009). Do early childhood interventions prevent child maltreatment? A review of research. *Child Maltreatment, 14*(2), 182–206.

Sicher, P., Lewis, O., Sargent, J., et al. (2000). Developing child abuse prevention, identification and treatment systems in Eastern Europe. *Journal of the American Academy of Child and Adolescent Psychiatry, 39*, 660-667.

Social Services and Child Protection Agency Law No. 2828. (2005). *Official Gazette of the Republic of Turkey*.

Tercier, A. (1998). Child abuse. In J. A. Maer (Ed.), *Emergency medicine* (4th ed., pp. 1108-1118). St. Louis, MO: Mosby.

Thackeray, J. D. (2007). Frena tears and abusive head injury: A cautionary tale. *Pediatric Emergency Care, 23*(10), 735-737.

Theodore, A. D., & Runyan, D. K. (1999). A medical research agenda for child maltreatment. *Pediatrics, 104*, 168-177.

Thomas, D., Leicht, C., Hughes, C., Madigan, A., & Dowell, K. (2002). *Emerging practices in the prevention of child abuse and neglect*. Washington, DC: U.S. Department of Health and Human Services.

Thomson, W. M., Spencer, A. J., & Gaughwin, A. (1996). Testing a child dental neglect scale in South Australia. *Community Dentistry and Oral Epidemiology, 24*(5), 351–356.

Tirali, R., Yener, O., & Soydan, S. (2014). Oral findings of child abuse and neglect [Çocuk istismarı ve ihmalinin oral bulguları]. *Journal of Atatürk University Faculty of Dentistry, 24*(3), 154–157.

Tuncay, T. (2011). Definition, scope and principles of the social work profession [Sosyal hizmet mesleğinin tanımı, kapsamı ve ilkeleri]. *Society and Social Work, 22*(1), 5–20.

Turkish Penal Code No. 5237. (2004). Ankara, Turkey: Ministry of Justice Publications.

UNICEF. (2014). *Hidden in plain sight: A statistical analysis of violence against children*. New York, NY: UNICEF.

UNICEF. (2021). *Family-based care models and children's rights* [Aile temelli bakım modelleri ve çocuk hakları].

Yakut, H. İ., & Korkmaz, E. (2013). Sexual abuse in children [Çocuklarda cinsel istismar]. *Journal of Gynecology-Obstetrics and Neonatology, 10*(39), 1630-1632.

Yaşar, Z. F., & Gültekin Akduman, G. (2007). Child neglect-abuse and forensic dentistry [Çocuk ihmali-istismarı ve adli diş hekimliği]. *TSK Preventive Medicine Bulletin, 6*(5), 389-394.