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Cemento-Enamel Junction Identification Methods: A Narrative Review

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Abstract

The cemento-enamel junction (CEJ) serves as a critical anatomical landmark in both periodontal and restorative dentistry, guiding attachment level measurement, biologic width preservation, and restorative margin placement. However, accurate CEJ localization remains clinically challenging due to its anatomical variability, soft-tissue coverage, cervical wear, and technique-related limitations. Conventional clinical methods - visual inspection and tactile probing, remain essential but are limited by operator dependence and soft-tissue interference. Standardized intraoral radiographs, especially bitewings, improve reproducibility in interproximal CEJ–alveolar crest evaluation but fail to resolve buccal/lingual surfaces. This narrative review aims to summarize and critically evaluate current methods for identifying the CEJ, highlighting their diagnostic reliability, advantages, and limitations across clinical and imaging approaches.

Keywords: Cemento-enamel junction, Tooth morphology, Periodontal probing, Ultrasonography, Cone-beam computed tomography.

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1. Introduction

The cemento-enamel junction (CEJ) is the boundary between the anatomical crown and the root of a tooth, serving as a transition between two major dental hard tissues, cementum and enamel, providing a consistent landmark in clinical assessments (1). In healthy teeth, the CEJ is located 1 to 2 mm subgingivally (2). Microscopically, three primary CEJ configurations have been identified: cementum overlapping enamel (60%), edge-to-edge contact (30%), and a gap exposing dentin (10%) (1,3). Despite this relative consistency, variations in morphology, along with anomalies such as cervical enamel projections and enamel pearls, may exist, which predispose the tooth to plaque accumulation and localized periodontal destruction (4,5). After migration of the gingival margin apically (as a result of hard tooth brushing, periodontal disease, etc.), the CEJ is exposed in the oral cavity and can be visually identified. Clinically, the CEJ serves as a fixed, critical landmark with wide-ranging clinical relevance, including measuring CAL to distinguish between periodontal diseases, assessing periodontal disease severity, monitoring disease improvement after treatment, and detecting recurrence of periodontitis during the maintenance period (1,2,6,7). Moreover, its position dictates biologic width preservation and restorative margin evaluation in restorative dentistry, guides root coverage surgeries, and influences the design of regenerative therapies (1,8). Cairo and Pini-Prato (2010) demonstrated that combined periodontal and restorative techniques can reconstruct CEJ levels in recession defects, achieving improved esthetic and functional outcomes (7).

Nevertheless, accurate localization of the CEJ remains a challenge for many practitioners in both scenarios: (a) for CAL assessment when the gingival margin is coronal to the CEJ, and (b) in the presence of tooth cervical wear such as erosion (9). Misidentification of the CEJ in the first situation can result in erroneous CAL estimation and inappropriate periodontal diagnosis and treatment planning. Furthermore, in the second condition (cases of gingival recession with cervical wear), incorrect placement of restorative margins in relation to the CEJ may lead to gingival irritation, microbial leakage, and eventual treatment failure (1). Therefore, precise CEJ detection is essential not only for accurate diagnosis but also for long-term clinical outcomes (2,7).

Various methods exist to determine CEJ position, including visual, tactile, and imaging techniques; each of which has variable accuracy and shortcomings depending on anatomical and pathological conditions. This review aims to summarize and critically analyze current techniques for identifying the CEJ and to highlight their diagnostic reliability and clinical applicability.

2. Search strategy

2.1. Clinical assessment

2.1.1. Visual methods

Visual identification of the CEJ fundamentally depends on cervical tooth morphology (1). Histologic and scanning electron microscopy studies of both primary and permanent dentitions further confirm site-specific and age-related variability in CEJ form. Such variability can significantly influence the ease of clinical visualization (10). Therefore, morphology alone cannot ensure consistent CEJ identification across all teeth or patients (3,10).

Visual detection of the CEJ during clinical examination is strongly influenced by soft-tissue position and local surface conditions. In cases of gingival recession, the cervical tooth surface is exposed, and the CEJ may be identified visually (Figure 1A). However, clinical studies have reported only moderate inter-examiner agreement at partially exposed sites, with notable measurement deviations (11). Nevertheless, when the gingival margin lies at or coronal to the CEJ (as commonly seen in healthy individuals), visual localization is unreliable. It was indicated that in such cases of "negative gingival recession," the average coronal position of the gingival margin may be around 2 mm above the CEJ at mid-facial sites (12). This natural variation significantly limits visual localization, particularly in the absence of gingival inflammation or tissue shrinkage. Furthermore, visual identification is prone to intra- and inter-examiner variability due to masking by calculus, stain, or anatomical differences in cervical morphology (Figure 1B). In such cases, visual inspection should be complemented by adjunctive professional debridement to increase diagnostic accuracy (7). These limitations emphasize that visual inspection alone is insufficient and must be supplemented by tactile or imaging modalities for accurate CEJ localization in both healthy and diseased states (11,12).

Couso-Queiruga et al. demonstrated that supracrestal soft tissue dimensions are closely related to periodontal phenotype, including gingival thickness and keratinized tissue width. In patients with thick periodontal biotypes, this tissue morphology may obscure the CEJ and complicate visual detection. They confirm that CEJ visibility depends not only on tooth morphology and examiner skill, but also on population-specific periodontal phenotypes and disease prevalence (13).

In cases of gingival recession with non-carious cervical lesions, the CEJ may be altered or absent (Figure 1C); therefore, using a contralateral homologous tooth or an adjacent tooth (if the CEJ of the contralateral tooth is unidentifiable) may help in estimating the CEJ location (7). It was shown that reconstruction of CEJ by referencing the contralateral tooth was successful after a two-year follow-up (14). This approach facilitated accurate flap positioning and restoration alignment, resulting in stable soft-tissue coverage and harmonious gingival architecture over time (7,14,15). Overall, while visual evaluation of the CEJ can provide valuable information under favorable conditions, it should be considered only one part of a multimodal diagnostic strategy, and this method should always be corroborated with tactile probing and radiographic imaging (16,17).

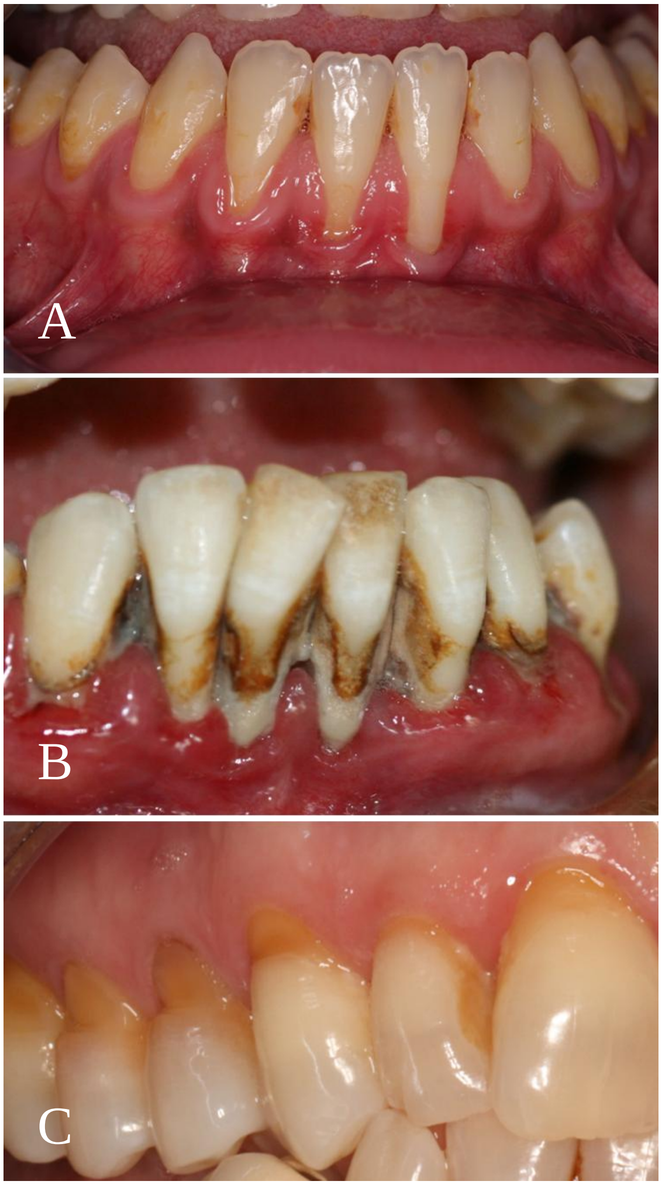

Figure 1. (A) In cases of gingival recession, the CEJ may be identified visually. (B) However, in some patients, the exposed CEJ is masked by calculus or staining. (C) CEJ may be altered or absent in cases of non-carious cervical lesions (the premolar area).

2.1.2. Tactile methods

Tactile methods for identification of the CEJ have long been regarded as an indispensable element of periodontal diagnostics (16,18). In the technique using tactile sense, a periodontal probe is inserted gently into the gingival sulcus or periodontal pocket to detect the irregular margin between the enamel and cementum (1). This method remains the clinical mainstay for CEJ detection, although its accuracy varies depending on tooth anatomy and location, gingival conditions, presence of bone loss, and operator experience. However, the type and the design of the periodontal probe, such as tip diameter, calibration markings, and force application, directly influence tactile sensitivity and measurement reproducibility. Inconsistent probe design can lead to systematic errors, particularly in detecting the CEJ in sites with inflammation, recession, or altered anatomy. Therefore, selecting a probe that provides controlled force, and precise gradation is essential for minimizing examiner-dependent variability and ensuring accurate longitudinal assessment in both clinical practice and periodontal research (17,19). Mokhagul et al. found that the accuracy of conventional CEJ detection (the tactile method) was improved when the sites were anesthetized. In addition, they reported a possible overestimation of CAL measurements at the sites without bone loss (2).

In terms of periodontal probe type, the evidence suggests a clear hierarchy of accuracy. The manual periodontal probes, such as the Williams probe, remain the most widely used due to their simplicity and accessibility, but they are subject to examiner variability and force inconsistency, with errors ranging from 0.5–1 mm depending on probe design and clinical conditions (17,20,21). Pressure-sensitive probes, exemplified by the True Pressure Sensitive (TPS) model, offer a hybrid solution (19,20). TPS probes offer improved tactile feedback and reduced variability compared to manual probes; however, they lack automated data recording and involve moderate costs (17). Digital or automated probing systems (eg, Florida electronic probe) improve reproducibility and reduce operator bias. Their superior accuracy in CEJ localization and PD/CAL assessment was shown in the studies (16,18). They offer the highest levels of accuracy, achieving reproducibility within 0.5 mm and substantial benefits for clinical trials and long-term monitoring. Despite their precision, they have drawbacks, including higher cost, calibration requirements, and the need for clinician training (18,21).

In clinical practice, tactile methods should not be applied in isolation. The moderate agreement rates, variability across probe types, and influence of biological confounders all argue for a multimodal approach, in which tactile probing is corroborated by visual inspection and radiographic imaging. By integrating these complementary methods, clinicians can achieve more reliable CEJ localization and ensure accurate assessment of periodontal attachment levels (2,21).

2.2. Imaging techniques for CEJ detection

Imaging techniques play a pivotal role in detecting the CEJ, especially when clinical methods are limited by gingival coverage, anatomical variations, or patient sensitivity. The evolution from conventional intraoral radiography to advanced three-dimensional imaging modalities has significantly enhanced diagnostic precision in periodontal evaluations (22,6).

2.2.1. Conventional intraoral radiography

Conventional intraoral radiographs, including periapical and bitewing techniques, are routinely employed in dental practice due to their accessibility and cost-effectiveness (23,24).

Periapical radiographs (PAs) remain a core tool for mesiodistal CEJ detection, providing detailed views of the root and surrounding alveolar bone, which enable indirect identification of the CEJ by assessing the contrast between enamel and cementum (Figure 2A). CEJ localization accuracy can vary significantly depending on image quality, angulation errors, and overlay of anatomical structures, such as restorations or calculus, which particularly obscure buccal and palatal aspects (11,25). A clinical assessment by Brezniak et al. highlighted moderate inter-examiner agreement in CEJ identification from standard PAs, emphasizing that diagnostic reliability depends heavily on clinicians' experience and radiographic conditions (11). A recent study using object detection algorithms on PAs of periodontitis patients showed over 90% accuracy, reducing examiner-related variability (25). While promising, AI performance still relies on proper imaging protocols, and both conventional and AI-based detection can be affected by overlapping restorations or poor angulation. Therefore, combining standardized radiography with AI provides the most reliable CEJ localization in clinical and research settings (11,25).

Bitewing radiographs (BWs) are intraoral images specifically designed to visualize the crowns and coronal roots of posterior teeth using a reproducible horizontal projection. Their strength lies in consistent image geometry, which allows clearer visualization of the interproximal CEJ and alveolar crest, making them particularly valuable in periodontal assessment (Figure 2B) (22,24). In conventional practice, BWs facilitate CEJ-to-crest distance measurements (22). Compared to periapical radiographs, bitewings are less susceptible to geometric distortion and often provide a more accurate assessment of the crestal bone levels in interproximal areas (22,26,27). BWs allow more consistent visualization of the CEJ–alveolar crest relationship. Therefore, when the primary objective is to locate the CEJ and evaluate interproximal bone levels, particularly in posterior teeth, BW radiographs are generally considered more reliable than periapicals, whereas periapicals remain valuable for comprehensive periapical assessments despite their technical limitations (22,26,27). Accurate identification of the CEJ on BW radiographs depends heavily on proper beam angulation and standardized radiographic techniques. It was demonstrated that even slight deviations in vertical X-ray beam angulation (as little as ±15°) can significantly alter the apparent distance between the CEJ and alveolar crest, leading to over- or underestimation of bone loss measurements (23). To minimize these discrepancies, Potter et al. emphasized the importance of reproducible beam alignment, showing that the use of standardized BW holders and consistent positioning greatly enhances image reliability and CEJ visibility by reducing horizontal and vertical angulation variability (24). Therefore, precise beam orientation and stabilization tools are essential to optimize BW radiographs for accurate CEJ detection and bone level assessment (23,24,28).

While BWs offer dependable interproximal assessments, their two-dimensional nature limits visualization of buccal and lingual CEJ surfaces. Moreover, diagnostic accuracy remains highly technique-sensitive; errors in angulation, tooth overlap, or patient movement can obscure critical landmarks (23,24,28). Nonetheless, under optimized conditions—including the use of digital sensors, standardized exposure parameters, cheek retraction, and AI support—bitewing radiographs remain a robust and reproducible method for evaluating the interproximal CEJ–bone crest relationship (24,29,30). The integration of artificial intelligence (AI) has further enhanced diagnostic consistency in BW radiography. In a recent study, an AI system (Denti.AI) demonstrated 65% sensitivity, 90% specificity, 76% overall accuracy, and a mean absolute error (MAE) of 0.499 mm in detecting radiographic bone loss, showing superior consistency compared with unassisted readings (29).

2.2.2. Panoramic radiographs

Panoramic radiography provides a comprehensive two-dimensional overview of both dental arches in a single exposure, making it a practical tool for full-mouth screening. However, several limitations—such as non-uniform magnification, structural superimposition inherent to two-dimensional imaging, and high sensitivity to patient-positioning errors (including tongue misplacement, anterior–posterior positioning errors, and head tilt or rotation) can impair accurate identification of anatomical landmarks, particularly the CEJ and the alveolar crest (31,32). However, recent advances in AI may overcome several limitations of panoramic radiography by automatically detecting and segmenting landmarks, standardizing CEJ-to-crest measurements, and reducing observer variability (33,34). For instance, a YOLO-based AI system achieved >98% accuracy in CEJ-to-crest measurement while shortening diagnostic time and minimizing variability (35). These findings highlight AI's potential for large-scale screening and routine follow-up where panoramic radiography is commonly used, though further validation is needed across diverse populations and imaging protocols (33,34,35).

2.2.3. Cone-beam computed tomography

Cone-beam computed tomography (CBCT) provides volumetric three-dimensional imaging of the dento-alveolar complex and allows direct visualization of tooth surfaces and alveolar bone in cross-sectional, sagittal, and coronal planes. Unlike conventional two-dimensional radiographs, CBCT overcomes the limitations of image superimposition and geometric distortion, enabling clinicians to visualize buccal and lingual alveolar bone plates, root morphology, and periodontal defects in greater detail. This capability is particularly valuable when the CEJ is partially obscured by restorations, anatomical variations, or overlapping structures. While the specific measurement error of the CEJ itself has not been directly reported, CBCT demonstrates high geometric accuracy and low linear measurement error in adjacent structures. Leung et al. reported mean errors below 0.6 mm for alveolar bone height and fenestration assessment (36). Similarly, phantom studies have shown absolute errors as low as 0.05 – 0.15 mm with optimized voxel sizes (37). Although direct CEJ measurement error data are lacking, the superior spatial resolution and three-dimensional clarity of CBCT, supported by both phantom and clinical studies, indirectly validate its use for more accurate CEJ localization in both clinical and research applications (Figure 2C) (38). Technical parameters critically modulate CBCT performance. Optimizing voxel size, field of view (FOV), and exposure settings is crucial for the reliable assessment of CEJ-related bone morphology (39,40,41). However, Beam-hardening and streak artefacts from metallic restorations, endodontic posts or implants, patient motion, and suboptimal positioning can obscure cervical tooth surfaces and adjacent bone, reducing confidence in CEJ localization. Algorithmic correction and emerging AI-based post-processing approaches are needed to overcome these problems (40,42).

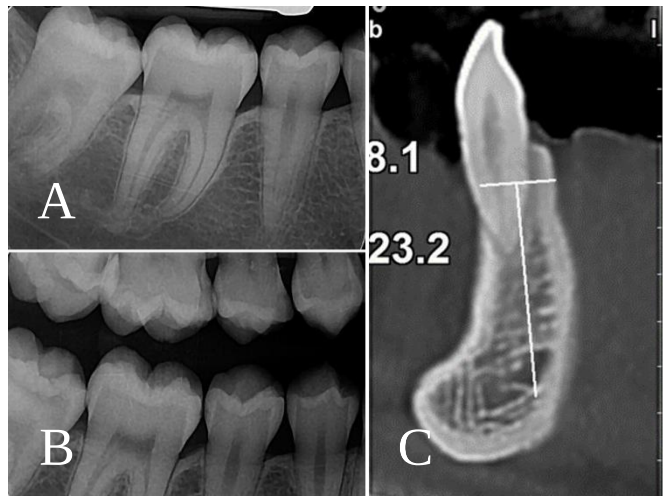

Figure 2. Radiographic assessment can provide detailed views of the root, which enable indirect identification of the CEJ. (A) Periapical radiography. (B) Bitewing radiography. (C) A cross-sectional view of Cone-beam computed tomography.

2.2.4. Ultrasound imaging

Ultrasound (US) imaging has recently gained attention as a promising non-invasive method for detecting the CEJ, offering a radiation-free and patient-friendly alternative to traditional diagnostic approaches. High-frequency dental ultrasound enables real-time visualization of periodontal structures, including gingiva, alveolar bone, and CEJ landmarks, without the discomfort of probing or the ionizing radiation inherent in radiography. Compared with conventional probing, ultrasound reduces patient discomfort and minimizes tissue trauma, while also providing cross-sectional visualization of both hard and soft tissues (43,44,45). Nevertheless, the technique is not free of challenges; operator dependency, variability in image interpretation, and reduced accuracy in anatomically complex regions remain important limitations (46,47).
In an ex vivo investigation, Qi et al. (43) imaged extracted human teeth with a 40 MHz transducer and compared ultrasound-derived CEJ positions to visual and tactile references. For about 80% of teeth with visually detectable CEJ and 76% of shallow cervical lesions, discrepancies

between ultrasound and clinical methods were within ±20%. The 95% confidence intervals of discrepancy extended up to 1.99 mm versus visual and 2.10 mm versus tactile methods in certain subgroups, suggesting that under favorable conditions, ultrasound may approach the accuracy of conventional clinical techniques (43). Complementing this, Fu et al. (44) demonstrated *in vivo* feasibility using a compact 9 MHz hockey-stick transducer, achieving agreement rates with manual probing within ± 0.5 mm. They also reported gingival margin–CEJ distances averaging –1.12 mm in mild disease and –0.56 mm in more advanced periodontitis, underscoring ultrasound's ability to capture subtle clinical changes in attachment level (44). Nguyen et al. (48) reported that ultrasound achieved comparable measurements of alveolar bone levels to CBCT, with mean differences ranging between 0.07–0.68 mm (1.6%–8.8%), although CBCT maintained slightly superior resolution for thin cortical plates (48). Furthermore, buccal and lingual cervical surfaces, which are often obscured in radiographic imaging, can be imaged directly with ultrasound (44,46).

Despite these strengths, several technical and anatomical factors may limit ultrasound's performance. Soft-tissue thickness, cervical surface curvature, and acoustic attenuation can reduce image contrast and obscure CEJ margins. Deeper cervical lesions introduced greater variance in ultrasound measurements relative to clinical methods, reducing reliability when the CEJ was masked or irregular (43). Similarly, restorations, metallic margins, or enamel irregularities may produce acoustic shadowing or reflections, complicating landmark identification (45). These findings emphasize that while ultrasound is highly promising, its accuracy is not uniform across all clinical scenarios (46,47).

One major avenue for improvement lies in computer-assisted detection. Nguyen et al. (49) achieved a mean error of 0.25 mm and reliability ≥ 0.98, while convolutional neural networks reached > 90% accuracy, reducing examiner bias and variability (50). Such AI-assisted methods can standardize imaging, minimize operator dependence, and enable automated monitoring (44,46,49,50).

Overall, current evidence suggests that ultrasound is best positioned as a complementary modality rather than a replacement for probing or radiography. Its non-ionizing nature, ability to image buccal/lingual cervical surfaces, and compatibility with AI-assisted analysis make it particularly attractive for repeated monitoring and for patients where radiation exposure should be minimized. Nonetheless, practical limitations, including operator skill, acoustic interference, and anatomical variability, necessitate standardized scanning protocols and continued refinement of automated detection systems. With ongoing advances in transducer technology, compact device design, and AI integration, ultrasound may eventually surpass both tactile probing and radiography in CEJ localization accuracy and reproducibility (44,49,50).

3. Conclusion

Conventional clinical methods (visual inspection and tactile probing) are essential but limited by anatomical variability, soft-tissue coverage, and examiner dependence. The evidence supports a multimodal diagnostic strategy: careful tactile and visual examination should be used as the first line, corroborated with optimized intraoral radiography for mesio-distal assessment. CBCT is also an accurate method; however, intraoral radiographs are often sufficient and involve lower dose and cost. Prospective, multicenter validation of AI-assisted ultrasound and harmonized imaging/probing protocols should be prioritized to establish evidence-based workflows for CEJ localization in both periodontal and restorative care.

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Using artificial intelligence (AI)

The authors declare that no generative AI or AI-assisted technologies were used to generate content, ideas, or theories during the writing process of this work.

Author contributions

Maryamsadat Mahdaviani: Methodology, Investigation Writing-Original draft, Writing-Review & editing.
Fazele Atarbashi-Moghadam: Supervision, Methodology, Investigation, Writing-Review & editing
Sajad Jahantigh: Data Curation, Writing-Review & editing.

Conflict of interest

The authors declare that they have no known competing interests that influence the work reported in this paper.

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