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The role of soft tissue analyses in orthodontic diagnosis and treatment planning: from conventional approaches to contemporary digital and artificial intelligence-supported evaluations: A review

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Abstract

Orthodontic diagnosis and treatment planning have traditionally relied on the evaluation of dental and skeletal relationships. However, contemporary orthodontic success is assessed not merely by achieving ideal occlusion, but also by maintaining or enhancing facial aesthetics, profile harmony, lip position, and soft tissue balance. Soft tissues are not passive coverings of hard structures; rather, they define facial perception, shape the boundaries of orthodontic intervention, and determine the aesthetic acceptability of treatment outcomes. Consequently, soft tissue analyses have evolved from being complementary assessments to becoming central elements in defining treatment objectives. This review discusses the historical development of soft tissue analyses, classical reference lines, the Arnett-Bergman approach, the influence of growth and ethnic variation, profile changes in extraction versus non-extraction treatments, three-dimensional facial analyses, and artificial intelligence-supported contemporary approaches. Current literature demonstrates that soft tissue analyses are critical not only diagnostically but also prognostically and aesthetically in orthodontic decision-making.

Keywords: Soft tissue analysis; Orthodontics; Facial aesthetics; Cephalometry; Arnett analysis; Lip position; Three-dimensional facial analysis; Artificial intelligence

1. Introduction

The historical development of orthodontic diagnosis and treatment planning reveals that early approaches were largely based on dental relationships, skeletal classifications, and cephalometric norms. The introduction of cephalometric radiography into orthodontics enabled craniofacial structures to be assessed using measurable and comparable parameters, marking a turning point in diagnostic methodology (1). Yet, approaches focused solely on correcting dental and skeletal norms proved insufficient in explaining the multidimensional nature of facial aesthetics.

Facial aesthetics are directly influenced by soft tissue thickness, tone, elasticity, age-related changes, lip morphology, nasal projection, chin prominence, and vertical-sagittal facial proportions. Recognition that soft tissue profiles do not correspond linearly to underlying skeletal structures triggered a paradigm shift in orthodontic diagnosis (2). Thus, soft tissues must be considered not merely as consequences of hard tissue changes but as independent and decisive structures in treatment planning.

In modern orthodontics, soft tissue analyses are regarded as fundamental diagnostic tools for decisions regarding extraction, camouflage treatment, orthognathic surgery planning, growth prediction, profile aesthetics, lip support, and patient expectation management (3). The aim of this review is to evaluate the evolution of soft tissue analyses from

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classical cephalometric approaches to contemporary digital and artificial intelligence-supported systems, and to discuss their clinical significance in orthodontic treatment planning.

2. Classical Soft Tissue Analyses and Reference Lines

The earliest focus in soft tissue analysis was the sagittal evaluation of lip position. Ricketts' aesthetic line (E-line), drawn between the nasal tip and soft tissue pogonion, assessed the position of the upper and lower lips relative to this reference, serving as a fundamental indicator of profile balance (4). Despite its clinical convenience, reliance on age-dependent landmarks such as the nasal tip and chin point necessitates cautious interpretation, particularly in growing individuals and across ethnic groups.

Steiner's S-line, defined between the nasal tip, the midpoint of the upper lip curvature, and soft tissue pogonion, sought to reduce nasal projection bias compared with the E-line, though it remained limited to two-dimensional profile evaluation (5). Burstone's B-line, extending from subnasale to soft tissue pogonion, provided a framework for assessing lip protrusion, retrusion, and sagittal profile balance (6).

Holdaway's soft tissue analysis, incorporating the H-line and H-angle, quantified relationships between the upper lip, soft tissue pogonion, facial angle, and profile convexity, offering predictive value for the impact of orthodontic tooth movement on soft tissue profiles (7). The concept of the visualised treatment objective (VTO) further enabled clinicians to anticipate post-treatment soft tissue outcomes (7). In orthognathic surgery, Legan and Burstone's soft tissue cephalometric analysis represented a milestone in planning surgical movements and their effects on facial aesthetics (8).

While these classical analyses facilitated quantitative evaluation of facial profiles, they were constrained by reliance on two-dimensional lateral cephalograms, age- and ethnicity-dependent reference points, and population-specific norms. Thus, they remain valuable but must be integrated into comprehensive facial assessments rather than used as absolute aesthetic determinants.

3. Arnett-Bergman Approach and the Evolution of Soft Tissue Cephalometry

Arnett and Bergman's facial keys approach marked a pivotal advance, positioning facial aesthetics as the starting point of treatment planning rather than a passive outcome of cephalometric measurements (9). By emphasising the combined evaluation of frontal, sagittal, and vertical facial components alongside clinical examination, this approach highlighted the limitations of decisions based solely on lateral cephalometric norms.

The central premise was that good occlusion does not necessarily equate to good facial balance. Each facial feature must be assessed in terms of current status, expected growth changes, the impact of orthodontic tooth movement, and the translation of surgical skeletal movements into soft tissue responses (10). This perspective strengthened clinical decision-making, particularly in borderline cases and orthognathic surgery planning.

Arnett's soft tissue cephalometric analysis systematised this face-centred approach, requiring natural head position, centric occlusion, and relaxed lips during evaluation. Metallic markers identified midfacial structures not clearly visible on cephalograms, and true vertical lines were used to assess anteroposterior positions of soft and hard tissue landmarks (11). Population-specific studies confirmed ethnic and cultural variability in Arnett's measurements (12), underscoring the need for individualised norms.

4. Growth, Age, Gender, and Ethnic Influences

Soft tissue analyses must account for age, gender, growth patterns, ethnicity, and tissue thickness. Age-related increases in nasal projection, for instance, can render lips more retrusive relative to aesthetic lines (13). Normative values should be interpreted as guiding ranges rather than rigid targets (14).

Ethnic differences are particularly significant: studies reveal variations in lip position, nasolabial angle, and aesthetic line relationships compared with Western norms (15). Research on Turkish populations demonstrates that malocclusion type, rest versus smiling posture, and growth stage influence soft tissue relationships (16). These findings support the creation of individualised treatment goals aligned with ethnic, age-related, gender-specific, and cultural characteristics.

5. Extraction Versus Non-Extraction Treatments

Soft tissue analyses are critical in extraction decisions. Premolar extraction can improve facial aesthetics in cases of dentoalveolar protrusion, lip incompetence, and crowding, but may reduce lip support and flatten profiles in patients with balanced or retrusive features. Studies using Holdaway's measures report reductions in H-angle and lip strain following extraction, alongside increases in nasal prominence (17).

Systematic reviews confirm associations between extraction treatments and lip retrusion, increased nasolabial angle, and altered profile convexity (18, 19). Yet, aesthetic interpretation depends on initial profile type, lip thickness, incisor retraction, nasal projection, age, and patient expectations. Long-term studies indicate continued post-treatment lip retrusion, with variability between extraction and non-extraction groups (20, 21).

6. Three-Dimensional Facial Analysis and Geometric Morphometrics

Traditional lateral cephalometry cannot fully capture three-dimensional facial morphology. Modern approaches such as geometric morphometrics analyse shape variation independently of size, enabling holistic evaluation of craniofacial and soft tissue structures (22). Anthropometry, photogrammetry, silhouette analysis, computer-assisted methods, and 3D imaging have evolved as complementary techniques (23).

Studies of aesthetic preferences highlight that facial attractiveness depends not only on normative measurements but also on cultural, social, and individual perceptions (24). Thus, 3D facial analyses are not merely technical improvements but patient-centred tools for realistic aesthetic evaluation.

7. Artificial Intelligence-Supported Cephalometry and Face-Driven Orthodontics

Artificial intelligence (AI) has rapidly advanced in orthodontic imaging, enabling automated landmark detection, cephalometric measurement, CBCT segmentation, facial analysis, growth prediction, treatment simulation, and patient monitoring. Pilot studies comparing AI-based and manual analyses report comparable reliability in some measures, though limitations remain regarding sample size, algorithm design, and validation (25).

Recent studies comparing AI-supported platforms with conventional digital methods reveal significant differences in certain angular and linear measurements, such as ANB, FMA, IMPA, and nasolabial angle (26). While AI offers advantages in standardisation and efficiency, caution is warranted regarding landmark accuracy, dataset variability, and clinical validation.

The concept of face-driven orthodontics emphasises that treatment goals must extend beyond dental alignment and occlusal correction to encompass facial balance, soft tissue harmony, profile aesthetics, smile design, and patient-specific expectations (27). AI applications hold promise in diagnosis, 3D reconstruction, simulation, and personalised planning, though heterogeneity of datasets and limited external validation remain challenges (28, 29).

8. Clinical Integration of Soft Tissue Analyses

For soft tissue analyses to be effectively incorporated into clinical practice, a multi-layered evaluative model should be adopted rather than reliance on a single analytical system. In the first stage, a detailed extraoral clinical examination must be performed, including assessment of facial symmetry, frontal proportions, profile convexity, nasal–lip–chin relationships, lip competence, mentalis muscle activity, smile line, gingival display, and lower facial height. In the second stage, lateral cephalometric analysis should be undertaken using systems such as Ricketts, Steiner, Burstone, Holdaway, or Arnett, thereby quantifying lip position and profile relationships. In the third stage, dental and periodontal boundaries, incisor positions, overjet, overbite, arch length requirements, malocclusion type, and growth pattern should be interpreted in conjunction with soft tissue findings.

In borderline cases, extraction decisions must not be based solely on crowding severity or incisor protrusion. Initial profile convexity, lip thickness, lip strain, nasolabial angle, nasal projection, chin prominence, growth direction, and patient aesthetic expectations must all be considered. Premolar extraction may enhance facial aesthetics in individuals with dentoalveolar protrusion and lip incompetence, yet in patients with initially flat profiles the same approach may yield unfavourable aesthetic outcomes. Accordingly, soft tissue analysis should serve not only as a diagnostic tool but also as a prognostic instrument in extraction decision-making.

In Arnett's analysis, attention to recording conditions such as natural head position, relaxed lip posture, and accurate determination of the true vertical line is essential for clinical validity. Forced lip closure, incorrect head positioning, or cephalometric evaluation without clinical examination may lead to misdiagnosis in cases presenting with lip incompetence, maxillary retrusion, mandibular prognathism, or midfacial deficiency. Thus, soft tissue analyses must not be confined to radiographic measurements alone, but should be supported by clinical facial examination, photographic analysis, and, where possible, three-dimensional records.

9. General Evaluation

The principal contribution of soft tissue analyses in orthodontics lies in shifting treatment planning away from exclusive reliance on occlusal correction and cephalometric norms, towards an emphasis on facial aesthetics and individual harmony. Classical hard tissue analyses remain indispensable for evaluating skeletal and dental relationships, yet they are insufficient to predict the true impact of treatment on facial appearance. In patients with thick lips, incisor retraction may produce only limited changes in lip position, whereas in those with thin lips or high lip strain, more pronounced soft tissue responses may occur. Consequently, identical dental movements can yield divergent aesthetic outcomes across individuals.

Similarly, the effects of extraction therapy on facial profile cannot be standardised due to individual variability. In patients with dentoalveolar protrusion, extraction may improve lip competence, reduce profile convexity, and balance mentalis muscle activity. Conversely, in patients with retrusive lips or flat profiles, the same mechanics may diminish lip support and accentuate age-related flattening of the profile. Therefore, average values of lip retraction reported in the literature should not be applied as direct predictions for every patient.

Digital and artificial intelligence-supported analysis systems offer significant opportunities in soft tissue evaluation. Automated landmark identification, measurement standardisation, time efficiency, record management, and patient communication can streamline clinical workflows. Nevertheless, datasets used to train AI systems may be limited in terms of ethnicity, age distribution, malocclusion type, and imaging protocols, restricting their accuracy across diverse populations. Hence, AI-based analyses should be regarded as supportive tools for clinician decision-making, not substitutes for clinical examination, professional experience, and individualised patient assessment.

10. Conclusion

Soft tissue analyses constitute fundamental components of modern orthodontic diagnosis and treatment planning. The aesthetic success of orthodontic therapy cannot be achieved solely through ideal tooth positioning or correction of skeletal norms; lip position, nasal–lip–chin relationships, profile convexity, facial proportions, soft tissue thickness, and patient-specific aesthetic expectations must play a central role in defining treatment objectives. Classical analyses such as those of Ricketts, Steiner, Burstone, and Holdaway provide valuable contributions to profile evaluation, while the Arnett–Bergman approach integrates soft tissues into a face-centred system combined with clinical examination. Contemporary three-dimensional facial analyses, geometric morphometrics, and AI-supported cephalometry further enhance comprehensiveness. Yet, no single analytical system can guarantee absolute aesthetic outcomes. The most appropriate strategy is an individualised treatment plan that integrates classical cephalometric analyses, clinical facial examination, population-specific norms, digital technologies, and clinician expertise.

Compliance with ethical standards

Disclosure of conflict of interest

The author declares no conflict of interest.

Author contribution

İdris Onur YALÇIN is the sole author and was responsible for conceptualization, literature evaluation, manuscript drafting, critical revision, and final approval of the manuscript.

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