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AGE-RELATED SOFT TISSUE CHANGES IN ORTHODONTIC DIAGNOSIS AND TREATMENT PLANNING: A NARRATIVE REVIEW

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ABSTRACT Orthodontic diagnosis has traditionally centered on hard-tissue and dental relationships, yet clinical success is ultimately judged by the face patients see in the mirror. Over the past three decades, a soft tissue paradigm has emerged, recognizing that the lips, cheeks, chin, and perioral musculature govern facial esthetics as much as, or more than, the underlying skeleton. This narrative review synthesizes current evidence on facial soft tissue anatomy, contemporary assessment techniques (clinical examination, cephalometry, three-dimensional imaging, and photography), and the age-related changes that alter soft tissue behavior across the lifespan. The influence of soft tissue morphology on treatment decisions in Class I, II, and III malocclusion is discussed, along with the role of interdisciplinary collaboration and post-treatment stability. Because soft tissue response to tooth movement and growth is inherently variable and difficult to predict with precision, individualized, multimodal assessment integrating digital tools with clinical judgment is essential. Incorporating soft tissue evaluation into every stage of orthodontic care—from diagnosis through retention—allows clinicians to achieve outcomes that are functionally stable, esthetically durable, and responsive to the natural aging process.

KEYWORDS : Soft Tissue Assessment; Facial Esthetics; Orthodontic Diagnosis; Craniofacial Growth; Aging; Treatment Planning

1. INTRODUCTION

Orthodontics has historically emphasized correction of dental and skeletal discrepancies, with treatment success measured through cephalometric norms and occlusal indices. However, patients rarely evaluate their treatment in these terms; they judge outcomes by how their face and smile appear.[1] The soft tissue envelope skin, subcutaneous fat, muscle, and connective tissue draped over the craniofacial skeleton determines the external, visible expression of any underlying hard-tissue correction.[2] Two individuals with near identical skeletal patterns can present strikingly different facial profiles depending on lip thickness, tonicity, and drape, underscoring that skeletal normalcy does not guarantee esthetic success.[3]

This recognition has driven a paradigm shift from a purely hard-tissue-based diagnostic model toward one that integrates soft tissue behavior into every decision: incisor positioning, extraction versus non-extraction planning, camouflage versus orthognathic surgery, and retention strategy.[4] Soft tissue assessment is particularly critical because cephalometric skeletal norms often fail to predict how the overlying tissues will respond to tooth movement, and because the soft tissue profile continues to evolve with growth and, later, with aging a dimension frequently neglected in treatment planning.[5] This review summarizes the anatomical basis, clinical and digital methods of soft tissue evaluation, the trajectory of age-related soft tissue change, and their combined influence on orthodontic diagnosis, treatment planning, and long-term stability.

2. Anatomy and Functional Role of Orofacial Soft Tissues

Facial soft tissue landmarks provide reproducible reference points for cephalometric, photographic, and three-dimensional analysis (Table 1). Midline points such as glabella, soft tissue nasion, subnasale, labrale superius/inferius, stomion, soft tissue pogonion, and menton define vertical proportion and sagittal profile.[6] Together these points construct the esthetic triangle (nasal tip, subnasale, pogonion), which underlies the perceived convexity or concavity of the profile.

Beyond serving as passive landmarks, orofacial soft tissues are functionally active. The lips, cheeks (via the buccinator), and tongue maintain the dentition within a dynamic neutral zone; imbalance in this equilibrium from mouth breathing, tongue thrust, or lip incompetence can produce or perpetuate malocclusion.[7] Lip competence, defined as passive contact of the lips without muscular strain, protects against relapse and mentalis hyperactivity, while smile dynamics (smile arc, gingival display, buccal corridors) are governed largely by upper lip length and mobility rather than by tooth position alone.[8] Consequently, soft tissues must be regarded as primary determinants not passive coverings of treatment direction, particularly in borderline extraction and camouflage-versus-surgery decisions.

Table 1. Key Facial Soft Tissue Landmarks Used in Orthodontic Assessment

Landmark	Location	Clinical relevance
Glabella (G)	Most prominent point between the eyebrows	Anchors upper facial third; vertical proportion analysis
Soft tissue nasion (N′)	Concavity between glabella and nasal bridge	Alters perceived profile convexity
Subnasale (Sn)	Junction of columella base and upper lip	Defines nasolabial angle
Labrale superius/ inferius (Ls/Li)	Most anterior points of upper/lower lip	Lip protrusion; reference for E-line/S-line
Stomion (Sto)	Midpoint of gently closed lips	Vertical lip height, lip strain
Soft tissue pogonion (Pog′)	Most anterior point of soft tissue chin	Lower facial projection; profile convexity
Menton (Me′)	Lowest point of soft tissue chin	Vertical facial proportion
Cheilion (Ch)	Lateral commissure of the lips	Smile width, symmetry, occlusal canting
Zygion (Zy)	Most lateral point of zygomatic arch	Transverse facial width

3. Techniques for Soft Tissue Assessment

Modern soft tissue diagnosis relies on a combination of complementary tools rather than any single modality (Table 2).

Clinical examination remains the foundation of assessment, evaluating facial thirds and fifths, lip seal at rest, nasolabial angle, and dynamic function during speech and smiling. Its strength lies in capturing real-time, functional information that static records cannot, though it is inherently subjective and examiner-dependent.[9]

Cephalometric analysis, pioneered by Broadbent and later extended to soft tissue by Arnett and Bergman, remains central to quantifying lip position and chin projection using reference lines such as Ricketts' E-line and Steiner's S-line.[10] Its principal limitation is that it compresses a three-dimensional structure into a single sagittal plane and exposes patients to radiation.

Three-dimensional imaging—cone-beam computed tomography (CBCT), stereophotogrammetry, and laser surface scanning—overcomes these limitations by capturing volumetric soft tissue data, enabling precise assessment of asymmetry, surgical outcome simulation, and radiation-free longitudinal growth monitoring.[11] Artificial-intelligence-assisted landmark detection and soft tissue prediction software are increasingly integrated into these platforms, though cost, technical training requirements, and motion artifact remain barriers to universal adoption.

Standardized photography offers a low-cost, reproducible method for documenting facial proportions, smile dynamics, and serial treatment changes, and is particularly valuable for capturing gingival display and smile arc, parameters not readily assessed on cephalograms.[12]

Table 2. Comparison of Soft Tissue Assessment Modalities

Modality	Key strengths	Key limitations
Clinical examination	Real-time, dynamic, low cost, no equipment	Subjective, examiner-dependent, not quantifiable
Cephalometric analysis	Standardized, quantifiable, longitudinal tracking	Two-dimensional, radiation exposure, landmark reproducibility issues
CBCT / 3D imaging	Volumetric, high precision, surgical simulation	Expensive, technique-sensitive, limited accessibility
Stereophoto-grammetry / laser scanning	Radiation-free, reproducible, ideal for growth monitoring	High initial cost, motion artifact
Standardized photography	Inexpensive, captures dynamic smile esthetics, easy serial comparison	Two-dimensional, sensitive to posture/lighting variation

4. Age-Related Changes in Soft Tissues

Craniofacial soft tissues are not static; they mature in parallel with, but not always synchronously to, skeletal growth, and continue to remodel throughout adulthood (Table 3).

During growth and adolescence, the neurocranium completes most of its development by 6–7 years, while the viscerocranium and the overlying soft tissues continue maturing through the pubertal growth spurt and into the postpubertal phase.[13] Sexual dimorphism is notable: females generally complete growth 1–2 years earlier than males. Hormonal influences shape sex-specific soft tissue patterns estrogen promotes perioral fat deposition, while testosterone favors muscular definition and a more angular jawline.[14] Lip thickness increases in absolute terms during adolescence but is frequently outpaced by skeletal forward growth, while nasal projection and the nasolabial angle continue to change into the third decade of life well beyond the completion of skeletal maturity.

In adulthood and aging, intrinsic collagen and elastin loss (approximately 1% dermal collagen reduction per year after the third decade) combined with extrinsic photoaging leads to reduced skin elasticity, while sarcopenia of the orbicularis oris, mentalis, and buccinator muscles diminishes perioral support.[15] Clinically, this manifests as lip thinning and elongation, flattening of the nasolabial angle, deepening of the mentolabial sulcus, and descent of the soft tissue chin pad—a trajectory documented longitudinally by Bishara et al. from ages 5 to 45.[16] These changes influence how adult patients will respond to incisor retraction, since redundant or inelastic skin does not always "drape" favorably over a repositioned dentoskeletal base.

Table 3. Age-related Soft Tissue Changes Relevant to Orthodontic Planning

Life stage	Predominant soft tissue changes	Clinical implication
Infancy–early childhood (0–5 yr)	Voluminous, elastic tissue; prominent fat pads	Convex "baby face" profile; limited diagnostic reliability
Prepubertal (6–10 yr)	Gradual reduction in facial fat; slow perioral maturation	Early habit correction (mouth breathing, thumb sucking) most effective
Pubertal growth spurt (10–16 yr)	Rapid mandibular growth; lip thickness increases but lags skeletal growth	Optimal window for growth-modification appliances
Postpubertal (17–25 yr)	Continued nasal and upper-lip maturation; muscle tone stabilizes	Soft tissue profile may still shift after skeletal maturity
Adulthood (>30 yr)	Collagen/elastin decline (~1%/yr), sarcopenia, fat redistribution	Conservative retraction; realistic esthetic expectations
Older adulthood (>50 yr)	Lip thinning, nasolabial flattening, chin pad descent, skin laxity	Adjunctive esthetic therapies may be needed alongside orthodontics

5. Impact of Soft Tissue Changes on Orthodontic Treatment: Evidence and Critical Appraisal

The soft tissue response to tooth movement differs meaningfully across malocclusion classes and dictates both mechanics and long-term expectations (Table 4).

5.1 Class I Malocclusion. Lip competency and smile-line position are the principal diagnostic variables. Proclined incisors producing mentalis strain often warrant retraction, but the degree of retraction must be tempered by lip thickness thin lips show a disproportionately large response, risking a flattened, prematurely aged appearance, whereas thick lips tolerate greater retraction with minimal esthetic consequence.[17] Upper lip retraction averages approximately 40% of maxillary incisor retraction, and lower lip retraction approximately 80% of mandibular incisor retraction, though these ratios vary with lip morphology. A cross-sectional analysis of extraction cases further showed that incisor retraction produced significantly greater lip-base thinning and vermilion retraction in patients with pre existing lip incompetence than in those with competent lips, while thicker lips lengthened more than thinner lips for the same amount of tooth movement[18] evidence that pretreatment soft tissue phenotype, not incisor position alone, should guide the extent of anterior retraction.

5.2 Class II Malocclusion. Facial convexity and lip strain dominate the clinical picture. The G–Sn–Pog ʹ angle is typically more acute, and mentalis overactivity accompanies attempts at lip closure. Timely use of functional appliances (Twin Block, Herbst) during the pubertal growth spurt can reduce convexity by advancing the mandible and improving lower lip support, whereas adult camouflage relies on premolar extraction and controlled retraction, with orthognathic surgery reserved for severe skeletal discrepancy.[19]

5.3 Class III Malocclusion. Soft tissue compensation can mask or exaggerate the underlying skeletal discrepancy: a hyperactive, everted lower lip and deepened mentolabial sulcus often accompany mandibular excess. Camouflage through incisor decompensation risks worsening lower lip strain, while orthognathic surgery maxillary advancement, mandibular setback, or both—achieves more predictable soft tissue correction, with soft tissue typically following hard tissue movement at a ratio of 0.6–0.8:1.[20]

Table 4. Soft Tissue Considerations by Malocclusion Class

Malocclusion class	Characteristic soft tissue finding	Primary treatment consideration
Class I	Lip incompetence, mentalis strain, variable smile line	Extraction/retraction decisions guided by lip thickness and tone
Class II	Increased facial convexity, lower lip strain	Growth modification in adolescents; camouflage or surgery in adults
Class III	Facial concavity, everted lower lip, deep mentolabial sulcus	Cautious camouflage vs. orthognathic surgery; soft tissue follows hard tissue at ~0.6–0.8:1

5.4 Quantifying the Soft Tissue Response: evidence synthesis. A 2018 systematic review and meta-analysis pooling more than 1,400 patients across 24 studies found that extraction treatment, compared with non-extraction treatment, produced a mean additional lower lip retraction of 1.96 mm, upper lip retraction of 1.26 mm, and nasolabial angle increase of 4.21°, with a small but measurable gain in profile pleasantness[21] quantitative confirmation that soft tissue change tracks extraction decisions, but with effect sizes modest enough that individual variation can easily outweigh the group average. This variability is precisely what limits chairside prediction: identical incisor movements can yield markedly different lip responses depending on baseline lip competence, thickness, and vermilion tone, underscoring why population-derived ratios (e.g., the oft-cited 40%/80% upper/lower lip rule) should be treated as starting estimates rather than patient-specific guarantees.

5.5 Digital and AI-based Prediction: Progress and Limitations. Software-based visualized treatment objectives and, more recently, deep-learning models have been developed to forecast individual soft tissue response. A 2024 comparative study of 887 adults found that an AI model trained on 78 cephalometric landmarks outperformed conventional statistical prediction specifically for soft tissue landmarks with high biological variability, though conventional methods remained competitive overall, suggesting a hybrid approach may be optimal[22]. A 2023 scoping review of AI-generated facial change prediction after orthodontic treatment found an overall low certainty of evidence, with the lower lip and chin identified as the least predictable regions even for AI-based systems[23]. Similarly, scoping reviews of AI applied to orthognathic and face-driven orthodontic prediction consistently report promising accuracy alongside recurring methodological weaknesses small, single center samples, heterogeneous datasets, and a near-absence of external validation that currently restrict routine clinical adoption[24,25].

5.6 Is there a Need for Improvement? Taken Together, the Evidence Supports a Clear Answer: yes. Three gaps stand out. First, predictive precision remains inadequate at the individual level meta-analytic effect sizes and regression models explain only part of the variance in lip and chin response, so current clinical rules of thumb (fixed retraction ratios, generic E-line targets) are, at best, population averages rather than reliable patient-specific forecasts. Second, the evidence base is fragmented: studies use inconsistent landmarks, imaging modalities, ethnic samples, and follow-up durations, which limits pooling of data and the development of validated, generalizable norms. Third, AI and 3D simulation tools though rapidly maturing have not yet been validated in large, multi-center, prospective, multi-ethnic cohorts with independent external testing, meaning their outputs should currently support, not replace, clinical judgment. Addressing these gaps will require standardized soft tissue documentation protocols, larger longitudinal and multi-ethnic datasets, pre-registered validation of AI models against real (not merely simulated) outcomes, and closer integration of dynamic/functional imaging that captures soft tissue behavior during speech and expression rather than only at rest (Table 5).

Table 5. Evidence Gaps and Priorities for Improving Soft Tissue Assessment

Current gap	Consequence	Suggested improvement
Population-derived retraction ratios applied to individuals	Poor person-level prediction accuracy	Patient-specific models incorporating lip thickness, tone, and competence at baseline
Heterogeneous study protocols and landmarks	Difficult to pool data or build validated norms	Standardized, consensus-based soft tissue documentation protocols
AI/3D prediction models with limited external validation	Uncertain generalizability outside training cohorts	Large multi-center, multi-ethnic, prospective validation studies
Static (rest-position) imaging predominates	Misses functional/dynamic soft tissue behavior	Routine incorporation of dynamic and video-based smile/speech analysis
Few long-term (>10 year) longitudinal soft tissue datasets	Aging-related change poorly incorporated into planning	Prospective longitudinal cohorts spanning growth through adulthood

6. The Soft Tissue Paradigm and Interdisciplinary Management

Contemporary orthodontics increasingly begins treatment planning with facial soft tissue analysis rather than cephalometric norms alone, since soft tissue parameters nasolabial angle, lip prominence, lip strain correlate more strongly with perceived attractiveness than skeletal classification.[26] This has elevated interdisciplinary collaboration to a central role. Coordination with periodontics manages gingival biotype, recession risk, and augmentation before or during tooth movement; prosthodontics relies on orthodontically guided gingival architecture for optimal emergence profiles and papilla preservation; oral and maxillofacial surgery reshapes the soft tissue envelope through orthognathic and genioplasty procedures; and myofunctional/speech therapy addresses tongue thrust, mouth breathing, and lip incompetence that can undermine both function and stability.[27] Digital smile design and three-dimensional simulation tools now facilitate synchronized planning and improved patient communication across these disciplines.

7. Post-Treatment Soft Tissue Stability

Soft tissue stability after active treatment depends on tissue thickness and elasticity, biomechanical control during tooth movement, and patient habits such as tongue posture and lip competence.[28] Retention protocols must therefore address soft tissue as well as dental relapse: fixed retainers help sustain anterior lip support, while functional (myofunctional) retention retrains perioral musculature to accommodate the new dental position. Because aging continues to alter lip length, nasolabial angle, and chin projection long after treatment concludes, periodic follow-up—supported by serial photography or three-dimensional scanning allows early identification of undesirable changes and, where appropriate, adjunctive minimally invasive esthetic therapies.[29]

8. Remaining Limitations and Future Directions

Beyond the evidence gaps identified in Section 5.6, soft tissue behavior remains considerably less predictable than skeletal growth at the level of basic biology. Variability in tissue thickness, muscular tone, and individual response to identical mechanical forces limits the precision of any single predictive model, and cephalometric norms derived from specific population samples do not generalize across ethnicities.[30] Long mandibular growth in males and continued soft tissue maturation into the third decade further complicate long-term forecasting. Population-specific normative databases and dynamic (functional) imaging offer promise for narrowing this predictive gap, but, as discussed above, longitudinal, multi-ethnic studies with standardized soft tissue documentation protocols are needed before digital and AI-based tools can be considered reliable for routine clinical decision-making.

9. CONCLUSION

Soft tissue assessment has moved from an adjunctive consideration to a foundational pillar of orthodontic diagnosis and treatment planning. Facial landmarks, multimodal assessment techniques, and an understanding of age-related soft tissue trajectories together allow clinicians to anticipate not merely react to the esthetic consequences of tooth movement. Because soft tissues continue to evolve well beyond the completion of active treatment, integrating growth- and aging-aware planning, interdisciplinary collaboration, and individualized retention strategies is essential for achieving orthodontic outcomes that remain functionally stable and esthetically harmonious over a patient's lifetime.

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