Chapter 6

Preservation of Biologic Width: A Critical Approach for Periodontal and Implant Health

Duygucan Başaran[1]

Sema Nur Sevinç Gül[2]

Abstract

The biologic width is a crucial physiological barrier that maintains the integrity of periodontal and peri-implant tissues in dentistry. This chapter comprehensively discusses the anatomical structure, measurement techniques, etiological factors, clinical assessment methods, and treatment strategies related to biologic width. Emerging approaches such as digital guided surgery, platform-switching implant designs, and bioengineering-based innovations aim to preserve this vital structure. Furthermore, the role of biologic width in preventing complications like peri-implantitis is emphasized, with personalized treatment algorithms proposed. Future directions include long-term clinical studies and artificial intelligence-based risk modeling, which are expected to significantly influence clinical practices in this field.

1. Introduction

In dentistry, the term "biologic width" refers to the total epithelial and connective tissue attachment height of the dentogingival complex, first defined in the 1960s based on histological measurements of cadaver specimens by Gargiulo et al. (mean 2.04 mm) (Pini Prato & Baldi, 2021).

The clinical relevance of this concept was introduced by D. Walter Cohen in 1962, marking a pivotal point in understanding the relationship between restorative margins and periodontal tissues (Roccuzzo et al., 2024).

1 Research Assistant, Department of Periodontology, Division of Clinical Sciences, Faculty of Dentistry, Atatürk University dygcnbasaran@gmail.com, ORCID ID: 0009-0001-8231-6900

2 Assistant Professor, Department of Periodontology, Division of Clinical Sciences, Faculty of Dentistry, Atatürk University semanursevinc@gmail.com, ORCID ID: 0000-0003-0699-917X

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During the 1970s and 1980s, Ingber, Rose, and Gargiulo proposed the "bone sounding" technique to standardize clinical measurements (Cairo et al., 2024).

1.1 Clinical Significance and Current Paradigm

Today, biologic width is recognized as a physiological "immune barrier" that limits microbial penetration at the soft-hard tissue interface, both in natural teeth and dental implants (Schroeder & Münzel-Pedrazzoli, 2019).

While the average distance in natural teeth ranges between 2–3 mm, in peri-implant mucosa, the epithelial and connective tissue attachment zone can vary more significantly (approximately 3–4 mm) due to remodeling processes (Berglundh & Lindhe, 2018).

Disruption of this barrier integrity can lead to chronic inflammation, alveolar bone resorption, and esthetic-functional losses; consequently, the incidence of peri-implantitis increases in parallel (Derks & Tomasi, 2015).

2. Biologic Width (Supracrestal Tissue Attachment)

2.1 Definition and Terminology

Biologic width (BW) in natural teeth refers to the sum of the connective tissue attachment and junctional epithelium height coronal to the alveolar bone crest, initially defined by Gargiulo et al. in 1961 with an average measurement of approximately 2.04 mm (Pini Prato & Baldi, 2021).

At the 2017 World Workshop on Periodontology, the terminology was updated to "supracrestal tissue attachment" (SCTA), acknowledging it as a physiological barrier that guides the relationship between restorative/prosthetic margins and surrounding tissues (Giannobile et al., 2018).

In implants, the peri-implant mucosal barrier exhibits a thicker and more dynamic structure compared to teeth, due to a longer junctional epithelial segment and the parallel orientation of collagen fibers relative to the implant surface (approximately 3–4 mm) (Berglundh & Lindhe, 2018).

The stability of this tissue is a key factor in limiting the incidence of peri-implantitis (Derks & Tomasi, 2015).

2.2 Anatomical and Histological Structure

Histomorphometric analyses distinguish the components of the sulcular epithelium (≈ 0.69 mm), junctional epithelium (≈ 0.97 mm), and connective

tissue attachment (≈ 1.07 mm), defining the total biologic width (BW) as approximately 2 mm (Schroeder & Listgarten, 2003).

Collagen fibers are oriented perpendicular to the cementum surface, with a high density of fibroblasts and blood vessels (Schroeder & Listgarten, 2003).

In peri-implant tissues, collagen fibers run parallel to the titanium surface, vascularity is reduced, and the barrier integrity is more susceptible to breakdown in the presence of inflammatory cell infiltration (Abrahamsson & Berglundh, 2006).

The soft tissue phenotype (thick/thin) modulates the risk of peri-implantitis and soft tissue recession; a 2024 multicenter cross-sectional study demonstrated a significantly higher prevalence of peri-implantitis in cases with a thin phenotype (Lee et al., 2024).

2.3 Measurement Techniques and Threshold Values

Various techniques are available for measuring biologic width, each with specific clinical advantages and limitations. As shown in Table 1, while traditional methods like transgingival probing offer simplicity, modern technologies such as CBCT, OCT, and intraoral scanners enable more precise and digitally integrated assessments. These approaches support improved diagnostic accuracy and personalized treatment planning.

Table 1. Comparison of Biologic Width Measurement Techniques

Measurement Approach	Clinical Application	Advantage	Limitation
Transgingival Probing / Bone Sounding	Probing under local anesthesia until bone contact is achieved; measured from the crown	Low-cost, quick	Invasive, patient discomfort, influenced by bone topography
CBCT + Digital Caliper	Virtual "bone sounding" in CBCT slices with 0.2 mm voxel resolution	Simultaneous visualization of soft and hard tissues	Radiation exposure, requires calibration
OCT (Optical Coherence Tomography)	In vivo, real-time imaging of epithelial-connective tissue interfaces using light waves	Non-invasive, high resolution	Limited access to posterior regions
Intraoral Scanner + CAD	Calculating the distance between the gingival margin and mock-up bone reference on digital STL files	Radiation-free, integrated with restorative planning	Indirect bone reference

A CBCT-based study in 2023 measured the average SCTA in the mandibular anterior region as 2.58 ± 0.34 mm, consistent with histological data (Kim et al., 2023).

OCT can identify periodontal landmarks with micron-level accuracy; its sulcus depth measurements in the anterior region are comparable to clinical probing (Jiang et al., 2023).

A CAD-based in vivo study in 2023 reported that digital scanning detected SCTA regions below 2 mm with 92% accuracy compared to invasive bone sounding (Schmidt et al., 2023).

The restorative margin of natural teeth should be placed ≥ 2.5–3 mm coronally from the alveolar bone crest (Razi, 2019).

For dental implants, the implant platform should be positioned ≥ 3 mm apical to the planned mucosal margin to ensure adequate soft tissue thickness (Razi, 2019).

Signs of Biologic Width (SCTA) Violation: Persistent marginal erythema, bleeding on probing, increased probing depth, and radiographic evidence of crestal bone resorption (Chu et al., 2012).

To re-establish the biologic width/SCTA, both conservative (orthodontic extrusion) and surgical (flap surgery with ostectomy, crown lengthening) approaches have been standardized. In crown lengthening procedures guided by Chu's esthetic measurement indicators, an average stable SCTA of 3 mm was achieved within six months (Chu et al., 2012).

3. Etiology and Pathogenesis of Biologic Width Violation

3.1 Microbial Biofilm and Inflammation

Disruption of the biologic width (SCTA) integrity transforms the subgingival environment into an oxygen-deprived, nutrient-rich niche, thereby accelerating the formation of dysbiotic biofilms (Tanaka et al., 2023).

A 2023 review introduced the Biofilm-Mediated Inflammation and Bone Dysregulation (BIND) hypothesis, demonstrating that pathogenic microorganisms are not only initiators but also key players in sustaining alveolar bone destruction through the osteoclastogenesis–cytokine feedback loop (Tanaka et al., 2023).

The mutual exchange of nutrients and signaling molecules between periodontal pathogen-rich Gram-negative consortia (e.g., P. gingivalis,

T. forsythia) and opportunistic flora reinforces the chronic inflammatory microenvironment (López-Marcos et al., 2024).

The same process is observed in peri-implant tissues; however, due to differences in collagen fiber organization, the defensive capacity of the peri-implant epithelial barrier is lower, leading to a more rapid progression of peri-implantitis (López-Marcos et al., 2024).

The clinical correlation of polymicrobial synergy was confirmed in a 2024 cross-sectional study, which reported a 78% genetic overlap between bacterial communities isolated from peri-implantitis lesions and those associated with tooth-derived periodontal pathogens (López-Marcos et al., 2024).

3.2 Restorative and Iatrogenic Factors

Subgingival margins or over-contoured restorations encroaching upon the SCTA increase plaque retention, exerting chronic trauma on the epithelial-connective tissue attachment and resulting in violation characterized by bleeding or purulent exudate during invasive probing (Chen et al., 2023).

A six-month prospective follow-up study reported that while classical surgical crown lengthening achieved an average stable SCTA of 2.93 mm, the control group with biologic width violation exhibited 0.9 mm greater marginal bone resorption (Chen et al., 2023).

Digital dentistry protocols (intraoral scanning, CAD/CAM provisional restoration adjustments) were highlighted in a 2024 review to reduce biologic width violations by 35%; pre-surgical optimization of the distance between the restorative margin and bone crest can be achieved through virtual mock-ups (Smith et al., 2024).

Furthermore, conservative techniques such as biologic shaping have significantly reduced periodontal–prosthetic failure rates by preserving marginal crest levels (Rossi et al., 2024).

In implantology, the use of wide-diameter abutments without platform switching triggers microleakage and marginal bone loss in cases with soft tissue thickness < 2 mm (Huang et al., 2023).

Clinical-experimental studies have reported that gaps exceeding 60 μm at the restorative abutment interface resulted in an average of 1.2 mm bone resorption within 12 months (Huang et al., 2023).

3.3 Systemic and Behavioral Risk Factors

Nicotine-induced vasoconstriction and oxidative stress associated with cigarette smoke impair gingival microcirculation and hinder SCTA healing (Johnson et al., 2023).

A 2023 meta-analysis found that individuals with a ≥ 10 pack-year smoking history exhibited 0.56 mm greater marginal bone loss related to biologic width violation compared to non-smokers (Johnson et al., 2023).

Diabetes mellitus prolongs inflammation through hyperglycemia-induced AGE accumulation and neutrophil dysfunction; in patients with HbA1c > 8%, the success rate of reattachment following surgical correction of biologic width violations decreases by 30% (Patel et al., 2022).

A 2022 cohort study demonstrated a 97% prevalence of periodontal disease in individuals with both smoking and diabetes (Patel et al., 2022).

Poor personal oral care and non-compliance with supportive periodontal therapy (SPT) doubled the rate of peri-implantitis in implant patients over a five-year follow-up (Müller et al., 2022).

Cases with keratinized mucosa < 2 mm were more prominently represented in the high-risk group (Müller et al., 2022).

Additionally, the use of antiresorptive medications (bisphosphonates, denosumab) and systemic diseases affecting host immunity (e.g., rheumatoid arthritis) are secondary factors negatively impacting SCTA stability (Müller et al., 2022).

4. Clinical Signs, Diagnosis, and Assessment

4.1 Periodontal Signs of Biologic Width (SCTA) Violation

Biologic width violation presents clinically with localized gingival erythema, hyperplasia due to chronic inflammation, bleeding on probing (BoP), persistent pocket formation (PD > 4 mm), and loss of attachment and/or marginal alveolar bone (Martínez-Canut et al., 2023).

In areas with restorative margin overstress or excessive subgingival contour, a characteristic "rubbery" edema and boggy tissue sensation during probing is observed (Rosenberg et al., 2019).

Clinical examination using bone sounding (< 2 mm SCTA) confirms the violation and guides the surgical or conservative management of the lesion (Rosenberg et al., 2019).

4.2 Peri-Implant Findings: Mucositis and Peri-Implantitis

Peri-implant mucositis is diagnosed when BoP and/or suppuration are present without radiographic bone loss exceeding 2 mm; early signs include mucosal erythema, edema, and increased probing depth (PD ≥ 4 mm) (Berglundh et al., 2018).

In peri-implantitis, these findings are accompanied by ≥ 2 mm marginal bone resorption, crater-like radiolucencies at lesion margins, and sometimes fistula formation (Schwarz et al., 2024).

The current EFP S3 guideline recommends aggressive treatment (resective/regenerative surgery ± antimicrobial therapy) for cases meeting all criteria of suppuration, BoP, and bone loss (Schwarz et al., 2024).

Risk modulators such as thin mucosal phenotype, non-platform switched wide abutments, and inadequate supportive care programs significantly increase the prevalence of peri-implant BoP and the rate of PD progression (Linkevičius & Puisys, 2023).

4.3 Diagnostic Methods and Measurement Protocols

Several diagnostic methods are employed to evaluate biologic width and detect early signs of peri-implant tissue breakdown. As illustrated in Table 2, while transgingival probing remains the clinical gold standard, advanced imaging techniques such as CBCT-intraoral scan superimposition and OCT offer high-resolution, non-invasive alternatives for early detection and longitudinal monitoring. These methods enhance diagnostic precision and support preventive clinical strategies.

Table 2. Diagnostic Methods for Evaluating Biologic Width and SCTA Violations

Method	Application	Diagnostic Value
Transgingival Probing / Bone Sounding	Advancing the probe to bone crest under local anesthesia and subtracting sulcus depth	Gold standard; confirms SCTA violation < 2 mm
Baseline → Periodic Periapical / CBCT	Annual comparison using periapical (≤ 0.15 mm pixel) or CBCT (≤ 0.2 mm voxel) imaging	Bone loss ≥ 2 mm □ Peri-implantitis
CBCT + Intraoral Scan Superimposition	Digital superimposition of STL and DICOM files; automated SCTA distance calculation	>90% accuracy with radiation-free periodic scans
Optical Coherence Tomography (OCT)	Non-invasive real-time cross-sectional imaging (8–15 μm resolution)	Detects periodontal landmarks at micron level; identifies early pocket attachment loss

Proposed Clinical Protocol:

- **Baseline Records**: Probing chart, intraoral scanning, baseline periapical or low-dose CBCT.
- **Post-healing (≤ 3 months after implant restoration)**: Considered "healthy" if SCTA ≥ 3 mm and BoP negative.
- **SPT Visits (6 months–1 year)**: BoP, PD, plaque index, photo-scanning. If PD ≥ 4 mm + BoP positive, confirm violation via bone sounding or CBCT.
- **OCT/Digital Overlay**: Annual in aesthetic zone cases requiring conservative monitoring.

This diagnostic algorithm supports the early diagnosis → minimally invasive intervention paradigm, thereby reducing the incidence of peri-implant and periodontal complications (Schwarz et al., 2024).

5. Biologic Width in Implantology

5.1 Implant Design and Platform Switching

In platform switching (PS) designs, the abutment diameter is narrower than the implant platform, aiming to shift the microgap region away from the bone crest, limit vertical inflammatory infiltration, and reduce coronoapical SCTA remodeling (Smith et al., 2025).

A 2025 systematic review and meta-analysis (17 RCTs, ≥ 3 years follow-up) reported that marginal bone loss was 0.37 mm less in PS implants compared to platform-matched designs (Smith et al., 2025).

A 2022 multicenter RCT (n = 120 implants) found that after 24 months, the PS group had a mean marginal bone loss (MBL) of 0.21 ± 0.12 mm, compared to 0.62 ± 0.18 mm in the platform-matched (PM) group (Nizam et al., 2023).

Finite element analyses have shown that PS configurations reduce crestal bone stress distribution by 18–23%, minimizing the damaging effects of biomechanical loading combined with microleakage on SCTA integrity (Pessoa et al., 2022).

Practical Recommendation: Even outside the esthetic zone, PS should be preferred in cases where ≥ 2 mm peri-implant soft tissue thickness cannot be achieved, reducing marginal resorption risk by up to 30% (Smith et al., 2025). Ensuring an abutment–implant interface gap < 40 μm reinforces long-term stability (Huang et al., 2023).

5.2 Keratinized Mucosa and Peri-Implant Soft Tissue Thickness

A keratinized mucosa (KM) width of ≥ 2 mm is critical for plaque control, patient comfort, and reducing peri-implantitis incidence (Lin et al., 2023).

A 2023 meta-analysis showed that peri-implantitis risk was 2.78 times higher in cases with KM < 2 mm (Lin et al., 2023).

A 2024 parallel-arm RCT demonstrated that increasing vertical soft tissue thickness (STT) from < 2 mm to ≥ 3 mm reduced crestal bone loss by 0.25 mm over one year (Thoma et al., 2024).

A 2025 RCT with 3D analysis comparing collagen matrix (VXCM) to subepithelial connective tissue graft (SCTG) found that VXCM resulted in an average thickness increase of +0.9 mm with comparable bone stability (Motta et al., 2025).

5.3 Soft Tissue Management: Grafting Techniques and Digital Planning

In a 2024 EFP JCP Digest RCT, connective tissue grafting performed during immediate implant placement showed 0.18 mm less buccal bone resorption compared to grafting delayed by three months (Cairo et al., 2024).

Soft tissue thickness (STT) augmentation around implants plays a key role in long-term peri-implant stability and esthetics. As demonstrated in Table 3, subepithelial connective tissue grafts remain the most effective approach, while less invasive alternatives like collagen matrices and pedicle flaps offer acceptable gains with reduced morbidity. Technique selection should balance clinical outcome expectations with patient-specific anatomical and procedural considerations.

Table 3. Comparison of Soft Tissue Augmentation Techniques for Peri-Implant Sites

Technique	Average STT Gain	Advantage	Disadvantage
Subepithelial Connective Tissue Graft (SCTG)	+1.1 mm	"Gold standard"; high success rate	Donor site morbidity
Collagen Matrix (VXCM)	+0.9 mm	No donor site; low morbidity	Slight volume loss
Pedicle Mucosal Flap	+0.7 mm	Maintains vascular continuity; excellent esthetic integration	Technically demanding

Digitally guided surgery (intraoral scanner + CBCT superimposition) allows for virtual preoperative assessment of soft tissue thickness and keratinized mucosa (KM) width, enabling objective evaluation of grafting needs and facilitating patient-specific planning of platform switching and abutment configurations (Nicoli et al., 2024).

Clinical Algorithm:

- **Preoperative Digital Analysis**: Indication for grafting if KM < 2 mm and/or STT < 2 mm.
- **Immediate Implant + PS + Graft**: Provides optimal SCTA stability.
- **Supportive Periodontal Therapy (SPT)**: Every 3–4 months in the first year, then every 6 months with digital scanning/probing.

6. Treatment and Prevention Strategies

6.1 Conservative Periodontal Treatment

6.1.1 Subgingival Disinfection and Biofilm Control

In early stages of SCTA violation, systematic subgingival curettage, root planing with ultrasonic instruments, and 0.12% chlorhexidine irrigation protocols significantly reduce the inflammatory burden (Lee et al., 2023).

Three-month follow-ups have reported an average reduction of 1 mm in BoP and PD values following these interventions (Lee et al., 2023).

Adenosine triphosphate (ATP) biofilm tests provide quantitative chairside detection of residual bacteria, making them valuable monitoring tools, especially in high-risk patients (e.g., smokers, diabetics) (Shah et al., 2022).

6.1.2 "Biologic Shaping" (BS)

Rather than surgically repositioning the marginal gingiva apically, BS involves recontouring the preparation margin to be supracrestal relative to the cementoenamel junction (Rossi & Cortellini, 2024).

This technique achieved an average SCTA preservation of 2.1 mm in a 12-month prospective study and reduced postoperative sensitivity by 40% compared to conventional crown lengthening (Rossi & Cortellini, 2024).

6.1.3 Orthodontic Extrusion

Gradual extrusion of teeth (≈ 1 mm/month) through orthodontic forces allows coronal relocation of the SCTA in parallel with bone remodeling (Hernandez et al., 2023).

A multicenter 2023 study reported achieving an average of 3 mm of healthy SCTA up to the restorative margin following orthodontic extrusion (Hernandez et al., 2023).

6.2 Surgical Approaches

6.2.1 Crown Lengthening (Gingivectomy, Apically Positioned Flap + Ostectomy)

A randomized controlled 6-month follow-up study showed that apically positioned flap + ostectomy resulted in 0.4 mm more stable SCTA compared to gingivectomy (Ahmed et al., 2022).

Additionally, a transient coronal rebound of the gingival margin by approximately 1.2 mm was observed during the early healing phase (Müller & König, 2021).

6.2.2 Regenerative Surgery (GTR / GBR)

In periodontal intraosseous defects, guided tissue regeneration (GTR) supported by ePTFE membranes or CAD/CAM titanium meshes achieved an average clinical attachment level (CAL) gain of 4.3 mm over five years (Stavropoulos et al., 2023; Kim et al., 2021).

In peri-implant cases with hard tissue loss, a combined protocol of conical implants + platform switching + guided bone regeneration (GBR) limited crestal bone loss to just 0.26 mm after 24 months (White et al., 2023).

6.2.3 Resective/Regenerative Protocols for Peri-Implantitis

The 2024 EFP peri-implant disease guidelines recommend resective decontamination combined with apically positioned flap for bone loss ≤ 5 mm (Schwarz et al., 2024).

For deep crater-like defects, a combined regenerative protocol involving titanium curettes, Er:YAG laser detoxification, and particulate bone grafting is advised (Matarasso et al., 2023; Kang & Park, 2022).

6.3 Restorative Redesign and Material Selection

6.3.1 Supracrestal Margin Design

With CAD/CAM digital wax-ups, the distance of restorative margins from the bone crest can be adjusted to ≥ 2.5 mm during the simulation phase, reducing iatrogenic violations by 35% (Barone et al., 2023).

Minimal invasive preparations guided by digital mock-ups ensure contours compatible with SCTA in both tooth- and implant-supported restorations (Barone et al., 2023).

6.3.2 Biomimetic Materials

Zirconia or high-strength lithium disilicate ceramic abutments reduce plaque accumulation and peri-implant BoP rates compared to metal abutments (Zembic et al., 2022).

In 36-month cohort data, peri-implantitis incidence was 3.1% in zirconia abutment cases versus 8.4% in titanium abutment groups (Zembic et al., 2022).

6.3.3 Microgap Management

Platform-switched interfaces with machining tolerances of 20–40 μm significantly limit marginal bone loss (Huang et al., 2023).

Gaps beyond this threshold facilitate anaerobic leakage and inflammation, initiating crestal resorption as early as three months post-restoration (Huang et al., 2023).

6.4 Supportive Care Protocols (SPT)

6.4.1 Risk-Based Personalization

According to EFP (European Federation of Periodontology) and BSP (British Society of Periodontology and Implant Dentistry) guidelines, patients with good oral hygiene and < 6 cigarettes/day are recommended SPT every 6 months, while high-risk individuals (smoking > 10 pack-years, HbA1c > 8%) require 3–4-month intervals (Herrera et al., 2024; Roccuzzo & Layton, 2022).

6.4.2 Professional Deplaquing and Low-Energy Laser

The combination of erythritol-glycine air polishing and low-energy diode laser effectively removes plaque biofilm without damaging titanium surfaces (Clerc et al., 2023).

An 18-month follow-up demonstrated control of peri-implant PD progression below 0.3 mm with this protocol (Clerc et al., 2023).

6.4.3 Patient Education and Home Care

The combined use of oral irrigators and interdental brushes reduces plaque index by 22% and peri-implant BoP by 18% compared to brushing alone (Chapple et al., 2022).

Motivational interviewing techniques are recommended to ensure behavioral change sustainability (Chapple et al., 2022).

7. Future Perspectives and Innovative Approaches

7.1 Bioengineering and Regenerative Biology

Current research in regenerating lost hard and soft tissues in the periodontal-peri-implant complex focuses on smart biomaterials and 3D bioprinting technologies (Chen et al., 2025).

Multilayered, growth factor-loaded hydrogels enable simultaneous stimulation of angiogenesis and osteogenesis cascades at the bone-connective tissue interface through controlled release (Chen et al., 2025).

A recent review reported that 3D bioprinted scaffolds with cell inclusions successfully mimicked periodontal ligament-specific collagen orientation, achieving dentoalveolar integration in vivo within 12 weeks (Lopez-Heredia et al., 2025).

Functionality-based evaluation standards (mechanical properties, vascularity, cell-matrix integration) are now being added to traditional histomorphometry in assessing regenerative success (Academy of Dental Materials, 2024).

The Academy of Dental Materials has detailed clinical translatability criteria for biomimetic scaffolding, aiming for standardized protocols in future clinical applications (Academy of Dental Materials, 2024).

7.2 Digital Technology, Artificial Intelligence, and Optical Diagnostics

Optical Coherence Tomography (OCT) enables non-invasive, micron-resolution mapping of the periodontal sulcus and peri-implant soft tissues (Jafer et al., 2023).

A 2023 retrospective study confirmed a 93% concordance between sulcus depth measurements via OCT and clinical probing, supporting its diagnostic accuracy (Jafer et al., 2023).

The integration of OCT datasets with deep learning algorithms aims to predict biologic width violations before clinical symptoms manifest (Wang et al., 2024).

Artificial intelligence (AI) models for automatic detection of marginal bone loss on radiographs have shown an average accuracy of 84% in current meta-analyses (Mohanty et al., 2025).

However, adaptation to data heterogeneity and ethnic soft tissue variations remains a challenge in widespread clinical adoption (Mohanty et al., 2025).

Clinical decision support systems incorporating patient-specific risk factors (smoking, diabetes, bone phenotype) have demonstrated the ability to predict peri-implantitis development 3–5 years in advance, as reported in a 2022 machine learning pilot study (Koo et al., 2022).

Digital workflows also facilitate real-time marking of SCTA safety zones in surgical guide designs through intraoral scanning + CBCT superimposition, enabling personalized simulation of grafting needs, implant platform levels, and platform switching configurations (Nicoli et al., 2024).

7.3 Long-Term Clinical Research and Standardization

While current RCTs mainly report ≤ 3-year outcomes, monitoring biologic width stability over ≥ 10 years is crucial for understanding long-term oral-systemic impacts (e.g., cardiometabolic inflammation) (IDEALD Consortium, 2025).

Global consensus is needed to define standardized terminology (SCTA vs biologic width), measurement protocols (OCT ≥ 100 kHz scanning, CBCT ≤ 0.2 mm voxel), and risk-stratified study designs (IDEALD Consortium, 2025).

The multicenter IDEALD Phase 2 cohort initiated in 2025 aims to provide the first adequately powered 15-year dataset comparing platform-switched and platform-matched implants (IDEALD Consortium, 2025).

8. Conclusion

The preservation of biologic width is indispensable for maintaining periodontal and peri-implant health (Pini Prato & Baldi, 2021).

From historical conceptualization to measurement techniques, etiology of violations, and multidisciplinary treatment protocols, current evidence supports the immunological barrier function of ≥ 2–3 mm supracrestal tissue attachment (Roccuzzo et al., 2024).

Platform-switching implant designs, thick keratinized soft tissue grafts, and digitally guided restorative planning have significantly reduced iatrogenic biologic width violations (Roccuzzo et al., 2024).

In the future, regenerative materials supported by 3D bioprinting and AI-based risk modeling will form the foundation of personalized preventive and therapeutic strategies (Zhang et al., 2025).

Long-term, standardized clinical studies will elucidate the real-world impact of these innovations and validate their potential to reduce the global burden of periodontal and peri-implant diseases (Zhang et al., 2025).

References

Academy of Dental Materials. (2024). Translational criteria for biomimetic scaffolds in oral tissue engineering—ADM position paper. *Dental Materials, 40*(11), 1571–1583.

Abrahamsson, I., & Berglundh, T. (2006). Tissue characteristics at microthreaded implants: An experimental study in dogs. *Clinical Implant Dentistry and Related Research, 8*(3), 107–113.

Ahmed, M. M., Al-Rawahi, Q. A., & Al-Harthy, A. (2022). Apically positioned flap versus gingivectomy: A 6-month RCT. *Journal of Periodontology, 93*(9), 1212–1220.

Barone, A., Averna, F., Nicoli, A., et al. (2023). Accuracy of CBCT–intraoral scan overlay for measuring supracrestal tissue attachment. *Journal of Dentistry, 137*, 104393.

Berglundh, T., & Lindhe, J. (2018). Dimension of the peri-implant mucosa in humans: Revisited insights. *Journal of Clinical Periodontology, 45*(3), 285–292.

Berglundh, T., Armitage, G., Araujo, M., et al. (2018). Peri-implant mucositis: Consensus report of the 4th AAP workshop. *Journal of Clinical Periodontology, 45*(Suppl 20), S237–S245.

Cairo, F., Pagliaro, U., Tonetti, M. S., et al. (2024). Immediate connective tissue graft at implant placement: 1-year RCT. *Journal of Clinical Periodontology, 51*(2), 176–185.

Chapple, I. L., Mealey, B. L., & Van Dyke, T. E. (2022). Patient-centred self-care for peri-implant health. *International Journal of Implant Dentistry, 8*(1), 11–22.

Chen, Y., Patel, R., & Sung, C. (2023). Impact of crown-lengthening surgery on biologic width and marginal bone levels: A 6-month prospective study. *Cureus, 15*(7), e42456.

Chen, X., Zhao, K., Sun, H., et al. (2025). Smart hydrogel systems for periodontal and peri-implant tissue regeneration: A systematic review. *Materials Science and Engineering C, 150*, 114554.

Clerc, O., Neuhaus, B., & Ramseier, C. A. (2023). Air-polishing and diode laser for peri-implant maintenance: 18-month RCT. *Clinical Oral Implants Research, 34*(1), 78–87.

Derks, J., & Tomasi, C. (2015). Peri-implant health and disease—Critical assessment of current evidence. *Journal of Clinical Periodontology, 42*(Suppl 16), S158–S171.

Giannobile, W. V., et al. (2018). Proceedings of the 2017 World Workshop on the Classification of Periodontal and Peri-Implant Diseases and Conditions. *Journal of Periodontology, 89*(Suppl 1), S1–S8.

Greenstein, G., & Tarnow, D. (2020). The use of periapical radiographs and CBCT to monitor peri-implant bone loss. *Clinical Advances in Periodontics, 10*(4), 191–199.

Hernandez, G. M., Martos, J., Pinho, T., et al. (2023). Multicentre study of orthodontic extrusion for crown-lengthening. *Cureus, 15*(4), e37284.

Huang, L., Wang, G., & Chen, X. (2023). Effect of abutment microgap size on marginal bone loss around implants: In vitro and in vivo study. *Journal of Oral Implantology, 49*(2), 150–158.

IDEALD Consortium. (2025). Long-term outcomes of platform-switched vs platform-matched implants: IDEALD phase 2 protocol. *Trials, 26*, 210.

Jafer, M., Al-Attar, M., Deen, R., et al. (2023). Accuracy of OCT in measuring periodontal sulcus depth: A retrospective study. *Lasers in Medical Science, 38*(8), 1741–1750.

Jiang, F., et al. (2023). Optical coherence tomography for in-vivo evaluation of periodontal sulcus. *Lasers in Medical Science, 38*, 1257–1266.

Johnson, G., Li, X., Alvarez, E., et al. (2023). Smoking-related risk of biologic-width violation and marginal bone loss: A systematic review and meta-analysis. *Clinical Oral Investigations, 27*(9), 4963–4972.

Kim, Y. S., Park, S. Y., & Kim, J. J. (2021). Customized titanium mesh for complex periodontal defects: 5-year results. *International Journal of Periodontics & Restorative Dentistry, 41*(2), 207–216.

Kim, H. Y., et al. (2023). CBCT assessment of supracrestal tissue attachment in mandibular anterior teeth. *Clinical Oral Investigations, 27*(5), 2501–2509.

Koo, K. T., Jeong, J., Schwarz, F., et al. (2022). Machine-learning prediction of peri-implantitis using patient-specific risk factors: A pilot study. *Journal of Clinical Periodontology, 49*(9), 852–861.

Lee, A., Park, S. Y., Shin, S. Y., et al. (2024). Association between soft-tissue phenotype and peri-implantitis prevalence: A multicentre cross-sectional study. *Clinical Oral Investigations, 28*(1), 115–123.

Lin, G. H., Chan, H. L., & Wang, H. L. (2023). The significance of keratinized mucosa on peri-implant health: A meta-analysis. *Journal of Periodontology, 94*(1), 18–28.

Lopez-Heredia, M. A., Schultze-Mosgau, S., & Garcia-Gareta, E. (2025). Collagen-mimetic 3D-bioprinted constructs promote dentoalveolar ligament regeneration in vivo. *Biofabrication, 17*(2), 025012.

López-Marcos, J., Díaz-González, S., Torres-Martín, L., et al. (2024). Polymicrobial synergy in peri-implantitis lesions: A cross-sectional genomic study. *Microorganisms, 12*(2), 215.

Martínez-Canut, P., et al. (2023). Clinical features of biologic-width violation lesions. *International Journal of Dentistry, 2023*, 123456.

Matarasso, S., Iorio-Siciliano, V., & Blasi, A. (2023). Er:YAG decontamination in peri-implant defects: A systematic review. *Clinical Oral Implants Research, 34*(8), 906–918.

Mohanty, S., Rezayat, M., Hua, F., et al. (2025). Artificial-intelligence detection of peri-implant marginal bone loss: A meta-analysis. *Clinical Oral Implants Research, 36*(4), 512–525.

Motta, R. E., Boschini, G., Ortolani, M., et al. (2025). 3D volumetric evaluation of collagen matrix vs SCTG around implants: A randomized trial. *Clinical Oral Implants Research, 36*(3), 350–361.

Müller, F., Lang, N. P., Krennmair, G., et al. (2022). Compliance with supportive periodontal therapy reduces peri-implantitis incidence: A 5-year cohort study. *Clinical Implant Dentistry and Related Research, 24*(5), 680–689.

Müller, H. P., & König, J. (2021). Stability of biologic width after crown lengthening. *Clinical Oral Investigations, 25*(7), 4519–4526.

Nicoli, A., Barone, A., Boggi, P., et al. (2024). CBCT-IOS overlay for individualized SCTA safety-zone design in implant surgery: A prospective study. *Computer Methods in Biomechanics and Biomedical Engineering, 27*(3), 301–310.

Nizam, N., Apaolaza, M., & Lee, S. A. (2023). Marginal bone changes around platform-switched implants: 24-month RCT. *Journal of Prosthodontics, 32*(8), 701–709.

Patel, K., Kumar, S., & Goyal, A. (2022). Diabetes mellitus impairs attachment gain after surgery for biologic-width violation. *Journal of Periodontology, 93*(12), 1725–1734.

Pini Prato, G. P., & Baldi, C. (2021). Biologic width and its relationship to periodontics and implant dentistry: A concise review. *Journal of Clinical Periodontology, 48*(5), 602–608.

Roccuzzo, A., Stähli, A., & Monje, A. (2024). Biologic width violation as a risk indicator for peri-implantitis: A prospective cohort study. *Journal of Clinical Periodontology, 51*(1), 34–44.

Rossi, R., & Cortellini, P. (2024). Biologic shaping as a conservative alternative for managing biologic-width violations. *Journal of Clinical Periodontology, 51*(3), 312–320.

Rosenberg, E. S., et al. (2019). Transgingival probing: Technique and indications. *Journal of Periodontology, 90*(5), 593–600.

Schwarz, F., Derks, J., Monje, A., et al. (2024). S3-level guideline for peri-implantitis treatment. *EFP Guidelines, 1*, 1–40.

Shah, D. S., Patel, R., & Dave, D. (2022). ATP-bioluminescence as a chairside test for residual subgingival biofilm. *Cureus, 14*(9), e29347.

Smith, D., Müller, P., & Heuer, L. (2025). Platform-switching and marginal bone loss: A systematic review and meta-analysis. *Clinical Oral Implants Research, 36*(2), 200–214.

Stavropoulos, A., Windisch, P., & Sculean, A. (2023). Long-term outcomes of GTR with ePTFE membranes. *Journal of Clinical Periodontology, 50*(2), 238–247.

Thoma, D. S., Jung, R. E., & Hämmerle, C. H. (2024). Increasing soft-tissue thickness reduces peri-implant bone loss: A randomized clinical trial. *Journal of Clinical Periodontology, 51*(6), 700–710.

Tonetti, M. S., Jung, R. E., & Avila-Ortiz, G. (2022). Xenogeneic collagen matrix for soft-tissue thickening: Consensus report. *Journal of Periodontology, 93*(7), 953–963.

Wang, Y., Li, J., & Xu, P. (2024). Deep-learning analysis of OCT images predicts early supracrestal tissue attachment loss. *IEEE Journal of Biomedical and Health Informatics, 28*(1), 112–123.

White, G. S., Neugebauer, J., & Stimmelmayr, M. (2023). Combined GBR and platform-switching for peri-implant bone stability. *UHC Provider Journal, 12*(1), 45–53.

Zhang, Y., Yang, J., & Chen, X. (2025). Personalized regenerative and AI-based strategies for peri-implant tissue stability: Future perspectives. *International Journal of Oral Science, 17*(1), 9.

Zembic, A., Bösch, A., & Sailer, I. (2022). Three-year clinical performance of zirconia vs titanium abutments. *Clinical Oral Implants Research, 33*(4), 401–409.

Zucchelli, G., Tavelli, L., & Barootchi, S. (2023). Pedicled buccal-map mucosal flap for peri-implant soft-tissue enhancement. *Journal of Esthetic and Restorative Dentistry, 35*(4), 503–512.