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The Role of Digital Dentistry in Reducing Biologic Width Violations

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Abstract
In today's world there is an ever increasing focus on providing a patient with the most aesthetic restorations and prosthesis. To achieve such perfection most dentists rely heavily on a subgingival margin which often leads to biologic width violation due to marginal inaccuracy of the restoration. This violation of the attachment apparatus results in inflammation and dysregulation of the immune pathways, which lead to initiation of bone loss. The end stage of this violation is, initiation of the pathology of chronic periodontitis. The use of a digital workflow can help in increasing the marginal adaptation of the prosthesis hence reducing the iatrogenic biologic width violations while maintaining the aesthetic demands of the patients and providing more reliable results. Digital impressions can help in reducing the finish line errors both in the clinics and the laboratories. Hence by avoiding biologic width violation we can help in maintenance of the periodontal hygiene of the patient.

Keywords
Biologic Width
Width Violation
Chronic Periodontitis
Digital Impressions
CAD CAM
3D Printing
Bone loss

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I. Introduction

As it was stated by Neville et al *"It would indeed be ironic if, in the process of restoring teeth affected by Dental Caries, Dentistry in any way contributed to the causation of periodontal disease, thereby threatening the longevity of the tooth."* [1]Fifty years have passed since this statement and the fight still continues. Our restorative techniques and sciences still continue to persevere against the never-ending challenge to find a biomimetic material and highlight the approach that can prevent any iatrogenic damage to periodontium as a side effect.[2]The prime focus is yet on the restorative marginal interphase which till date is the muse of aesthetic and restorative dentistry. [2, 3] A high number of restorative and prosthetic failures yet continue to cite marginal failure as a reason and moreover show weakened periodontium post removal of the irritant which worsens the prognosis of the tooth.[3] These high numbers of failures and increased compromise of the periodontium can be attributed to biologic width violations.[4]

The first breakthrough discovery of biologic width came from the pioneering research presented by Gargiulo et al in 1961 where he reported:

- Sulcus depth of 0.69 mm
- Epithelial attachment of 0.97 mm
- Connective tissue attachment of 1.07 mm

Hence the total epithelial and connective tissue attachment would be 2.04 mm up to the crest of the alveolar bone. These observations along with the observations of Vacek et al in 1994 had one common conclusion that the length of the connective tissue attachment remains relatively constant on all the tooth surfaces in all the cadavers for which they were measured. This attachment apparatus is known as the "Biologic Width".[4,5,6] The sulcus epithelium also known as the junctional epithelium is a collar-like band of stratified squamous non-keratinising epithelium 2-3 layers thick in early life and shows an increase in the number of

layers later in life to 10 or 20 layers.[5] It originates from the unison of the oral epithelium and the reduced enamel epithelium.[5] It is attached to the tooth via the internal basal lamina which includes the lamina densa adjacent to the enamel of the tooth and the lamina lucida attached to the hemidesmosomes.[5] Laminin that is secreted by the cells plays a key role in adhesion. This epithelium undergoes constant turnover due to mitotic activity daily; with morning times showing the highest and evening times showing the lowest rate of cell division.[5] The daughter cells constantly migrate in the coronal direction simultaneously providing a continuous attachment to the tooth surface.[5] This mitotic activity is seen to be on the rise in diseased states such as gingivitis with an increase in the number of the layers as a result of increased plaque accumulation and inflammation.[5]

The gingival tissue which forms the other and the most important half of this attachment is a complex of ground substance with connective tissue elements.[5] The gingival connective tissue also known as the lamina propria consists of two layers:

1. Papillary layer
2. Reticular layer

The ground substance mainly consists of glycosaminoglycans and proteoglycans consisting mainly of hyaluronic acid, chondroitin sulfate among others.[5] The collagen fibers seen in the gingiva are mainly composed of Type 1 collagen.[5] The unique ability of the gingival tissue lies in its ability of healing which allows it to not only repair but also to regenerate, which is a direct factor in width violation which we shall later review.[5]

The deep attachment apparatus of the teeth while being one of the most evolutionarily advanced organs is also the most researched aspect of the oral anatomy.[5,7] The multitude of evidence converges to the point that the soul of the attachment remains in the Alveolar bone that is connected to the teeth via the periodontal ligament.[5,4,7] The basic structure of the bone consists of the bundle bone which comes in immediate contact with the fibers.[5] The most important factor is the presence of a rich neurovascular network which plays an important role in all the infections of the tooth whether periapical or periodontal in nature.[5]

In a healthy individual, this attachment apparatus along with the entire masticatory system helps in performing the regular day-to-day functioning provided the balance of these structures comprising the attachment remains unhindered.[5]

For patients with indications of the subgingival margin for tooth preparation, this attachment apparatus serves the real challenge.[4,7] Any disturbance in the physiology of this system can trigger a chain of events, the end product of which can lead to the patient landing up with severe periodontal pathologies.[4] This is where width violation is comfortably pushed aside due to the increased aesthetic demands today and the dentist's trying to provide a restoration that would last longer than be functionally effective. The impact of this width violation is not just local but also systemic as it leads to reduced masticatory functions which can be detrimental to digestion and also trigger an unnecessary increase in the inflammatory markers of the patient.

EXAMINATION OF BIOLOGIC WIDTH

The examination of Biologic Width can be undertaken by various methods. Biologic width evaluation can be completed as a part of the routine periodontal examination.[8]Any discomfort experienced during probing with a periodontal probe should be further evaluated especially for teeth that exhibit bleeding on probing and those that may be restored.[8] Running the periodontal probe through the margin serves the purpose of evaluating any violation. [8]

Another method for evaluating the biologic width is bone sounding or transgingival probing under local anesthesia that helps in evaluating the length of the attachment, which if found to be more than 2 mm confirms width violation.[8]

Radiographic examination of the teeth, when undertaken, can help in evaluating the interproximal bone height of which the clinical probing depth should be subtracted to calculate the biologic width.[7,8] Over the years, authors have also recommended that different angles should be used to record the width in different areas.[7] In the last decade the use of parallel profiling radiography has gained some importance due to its increased accuracy in measuring not just the length but also the thickness of the width.[9]

ETIOLOGY OF WIDTH VIOLATION

Biologic width lies close to the gingival attachment of the tooth which is an area that is generally prone to wear and tear and hence its violation occurs commonly during routine dental procedures, especially those that are more commonly associated with a subgingival location.[5,10] Violation is observed more often in patients who have undergone prosthetic and restorative treatment.[10] The increasing expectation of a highly aesthetic smile and the perfect emergence profile has led to a significant increase in the shift, from the more favorable equigingival margin to a highly challenging subgingival margin and hence the number of patients showing width violation post completion of their treatment in follow-ups has also increased due to increased plaque retention.[8,10] Over

preparation and overextension of the preparation is often seen as the most common factor in width violation but more often than not the fault may not just lie in the selected margin design but also with margins or surfaces of the final restoration, which may not be perfectly finished and polished.[3,11] This being established it is not necessary that the above-stated data may be the only causative factor in prosthetics that may lead to width violation. The effect of mechanical retraction and the chemical reaction to impression materials can often result in width violation and an increase in inflammation of the subgingival tissue which may eventually lead to bone loss if not treated and finally resulting in failure of an otherwise good prosthesis or restoration.[2,12]

Overhanging restorations have been stated by studies as the leading cause of alteration of the subgingival flora due to width violation and can often lead to increased bone loss and inflammation in the gingiva and periodontium adjacent to the tooth restored.[1,13] But restorative and prosthetic procedures are not the only factors involved in width violation.

Food lodgment and impaction has also been demonstrated as an etiology of width violation due to the mechanical wedging effect and due to the presence of a foreign body in the tissue.[14] Trauma from occlusion may also serve to aggravate any pre-existing attachment violation and also has been demonstrated in increasing the subgingival tissue inflammation due to its pumping effect on the subgingival calculus and given the fact that bone defects and loss of lamina dura have been observed more for cases with TFO.[15] Routine periodontal instrumentation such as scaling and root planning may also lead to deep subgingival trauma which may result in width violation.[16] Mechanical trauma apart from iatrogenic factors can also weigh into width violation such asmasochistic habits and physical injuries.[16] There may also be some other etiologies such as orthodontic treatment and appliances which may at times result in unintentional width violation.[16]

Apart from width violation, biologic width also undergoes alteration in its length throughout our lifetime as part of the natural aging process.[5] This weighs in due to the loss of alveolar bone with increasing age which leads to increased length of connective tissue attachment and at times also manifests clinically as gingival recession. [5] This reduced length of the alveolar bone can prove detrimental to the dentogingival supporting apparatus.[5]

The end result of all biologic width violations has always been observed to summate into the accumulation of subgingival plaque which may later move on to forming subgingival calculus which serves as the initiation of a long silent illness - chronic periodontitis; which has to be treated by major clinical intervention.[8,10,16]

SEQUELAE OF WIDTH VIOLATION

Patients with subgingival margins, apically positioned retainers, and overextended restorations have shown a higher tendency to demonstrate bleeding and worsening gingival index scores which points toward the clinical sequelae of width violation which the patient may often report of.[8] But the pathology that follows biologic width violation is not a single step, but a cascade of reactions to it. Following width violation, the increased tendency for plaque accumulation promotes a shift in the microflora of the subgingival niche which triggers a series of inflammatory reactions. [8,10,17] Studies have stated that there is a statistically significant difference in the subgingival microflora count post placement of restorations within the area. [17] The predominant species that was observed was Alpha hemolytic Streptococci followed by rods and spirochetes.[17,18] The PCR studies of the subgingival genome supports the above-mentioned evidence along with demonstrating secondary colonization of Leptotrichia, Fusobacterium, Neisseria, Actinomyces, Haemophilus, Prevotella, Capnocytophaga, Rothia, Gemella, Veillonella, Campylobacter, Peptostreptococci, and Aggregatibacter species following primary colonization by streptococci.[18] This shift of subgingival flora marks the onset of chronic periodontitis in patients.[18] As per Shi et al the probing depth has not been demonstrated to have any correlation with the microbiome of the subgingival environment.[18] The change in the diversity leads to a marked change in the pH, temperature, and mainly the oxygen tension which facilitates an anaerobic bacterial load higher than that seen in healthy gingiva.[19] The difference between healthy and diseased gingiva has also been cited to be only in the dominant microbial composition.[19] The inflammation resulting from this ecological shift due to width violation has been shown to cause dysregulation of the innate immune-mediated pathways that facilitate increased periodontal destruction.[20,21]

Studies by Flores de Jacoby et al, Tarnow et al and Sorensen et al in the past have demonstrated the significant effect that the location of the margin can increase the subgingival microbial colonization due to increased plaque which can have long term effects on periodontal health. [22,23,24] Secondary factors such as smoking, alcohol, betel nut chewing, mechanical trauma, abstinence from maintaining oral hygiene, and drug-related complications have also been shown to contribute to the subgingival microflora makeover.[17] As per the observations of Lang et al, it was also noted that overhanging restoration margins on the proximal surface lead to a spike in the black-pigmented Bacteroides even before the placement of the overhanging margins. [13] This indicates that even in conditions where the margin is within physiologic limits the subgingival flora still undergoes major alteration when a subgingival margin is used.[13] Neville et al had also stated similar findings

and also stated that higher periodontal index scores were noted for patients with overhanging restoration margins. [1]

PRESERVATION AND CORRECTION OF BIOLOGIC WIDTH

The basics of biologic width cannot be completely understood without understanding the healing and regeneration that occurs in the periodontal ligament and gingival attachment area. The healing of the periodontal ligament and the biologic width attachment is unlike the events of healing that are generally noticed in any wound healing, it is also governed by the factors involved in regeneration.[5,25,26,27] The presence of the undifferentiated mesenchymal cells in the periodontal ligament makes it the only organ capable of regenerating the connective tissue attachment that exists between the tooth and the bone. [5,25,26] But the downward migration of the epithelium and covering of the tooth surface by epithelium while making the tooth less susceptible to resorption makes it permanently incapable of developing an attachment with bone. [5,25,26] As it was clearly stated by Karring et al in his observations that of the root pieces that were implanted in bone, periodontium, and epithelium, the root piece that was associated to periodontium showed the development of a ligament attachment hence stating that cells of the periodontium is essential to regeneration and plays an important role in the repair of the attachment apparatus including the biologic width. [5,25,26]

As it was stated above in the sequelae of width violation when the violation of the space occurs due to any etiologic factor it is followed by inflammation and tissue injury.[4,5,25] This tissue injury and inflammation sets in motion a cascade of steps that lead to irreversible bone loss hence leading to gingival recession and formation of periodontal pockets, healing of which only occurs by the epithelium attaching to the cementum (even after surgical intervention in most cases) and not the connective tissue which eventually leads to worsening of periodontal support; progressing to chronic periodontitis. [4,5,8,25]

Traditional methods involving the correction or the prevention of biologic width violation involve crown lengthening surgeries, surgical osseous resection, gingivectomy, apically repositioned flap surgeries with or without osseous resection, and rapid or slow orthodontic intervention with or without fibrotomy to supplement it. [4,7,8] The advantage of these surgical procedures is that the biologic width is adequately preserved in most cases and hence the solution is long-lasting along with the added benefit of being time tested and well documented. [4,7,8] But the disadvantage of these methods is that they are time-consuming and require a long period of healing which is suggested to be anywhere between 4-6 months after the procedure to initiate the restorative and prosthetic treatment. [4,7,8] Even the surgeries done with the finest level of expertise can still not give absolutely predictable outcomes due to the multitude of natural factors involved in healing and hence after the surgical procedure the patient is kept under observation until a new gingival crevice is developed. This new attachment apparatus that develops may or may not be as effective as planned and may again require an alteration by the clinician in the treatment protocol which may often lead to burnout of patients.[4,7,8] A patient with an aesthetic dissatisfaction may not be able to put in the amount of time and patience that these conventional procedures may warrant. In a few cases performing an elective procedure may also carry the added risk of initiating a pathology that doesn't exist; which is a valid concern amongst most patients considering periodontal plastic surgery procedures.[4,7,8]

IMPORTANCE OF DIGITAL WORKFLOWS IN IMPROVING THE PRESERVATION OF BIOLOGIC WIDTH

The first digital impression in dentistry was put forth in the 1980's and today 40 years later dentistry has made huge leaps and bounds in going digital.[2,3] Our research in developing the most comfortable, bio-friendly, and accurate method of fabrication of restoration has taken us towards CAD-CAM technology and dental scanners. [2,3,28] Today a multitude of companies have invested in and developed various dental scanners whose efficiency and accuracy still remain a hot topic amongst researchers. Besides reducing the laboratory workload, the advances when effectively utilized have made it easier for us to preserve the marginal integrity of our restorations and have brought us closer to visualizing the subgingival domain that we would only have to judge or imagine. [2,3,28]

The first step in the fabrication of the prosthesis requires a good focus on tooth preparation but an immense focus on making an accurate impression. The negative replica sent by the clinician is the only reference used in the laboratory for the fabrication of the prosthesis. In 1997 a survey conducted by Winstanley et al evaluated 290 dental impressions sent to the laboratory for further processing and around 36% of them showed some of the other defect.[29]A similar in vitro evaluation done by Albashareih et al in 1999 showed defects in around 50% of the impressions and the dies that were evaluated in total.[30] In 2005 Samet et al conducted a similar study and found that around 89% of the total impressions evaluated showed at least 1 appreciable error.[31] The common citing in all these studies was the observation that the majority of the defects were in the marginal area with poor gingival displacement cited as one of the major causes. [29,30,31] This can

directly be related to the high amount of errors in the marginal adaptation of the prosthesis often. [29,30,31] Clayton et al stated in his survey, where he evaluated 1157 dental impressions sent to different laboratories, of which around 86% of them showed at least one appreciable error where the cervical finish lie and marginal inaccuracy accounted for error in 55% of all the cases.[32] Of all the cases evaluated by Clayton et al 15% were soiled with blood which may suggest that biologic width attachment violation might have occurred in a significant number of these cases which were ignored.[32] Studies have also stated that the use of rigid impression materials may also lead to increased tray failure leading to the opening of the restoration and marginal inaccuracy. [32,33,34,35] A significant correlation was stated by Clayton et al and Seelbach P et al in their studies between dual impression techniques and finish line errors, and both of them have advocated improper use of the technique as a major etiology for the errors. [32,36] Another interesting finding that Clayton et all reported was that the lab only repeated work in 3-4% of the total cases showing an error in the impressions; which shows that the percentage of erroneous prosthesis fabrication is so much higher. [32] Taking all these errors into account a digital workflow may be considered to add standardization to these steps.[36] In an in-vitro evaluation by Seelbach et al, the marginal accuracy for impressions made with digital scanners was found to show a scope of error less than those made with a single step and two-step putty wash techniques; with the best internal fit for the prosthesis that was fabricated using LAVA and COS scanners.[36] But an important point to be taken into consideration is that in-vitro evaluations are free of influence by secondary factors that may make a clinical step rather tedious such as saliva, limited access, infra-gingival finish lines, etc. These studies are also free from errors that often occur in laboratories such as shrinkage error, sintering changes, and human errors in the process of fabrication. [36] In a similar in-vivo evaluation by Pradies G et al it was stated that the observed mean marginal gap was approximately 20 microns less for digital impressions.[3] But it was also stated that if an intra-oral scanners were to be used, its accessibility becomes critical in its success.[3] An in-vitro study by Ender A et al compared the trueness and precision of full-arch scans and conventional impressions and concluded that intraoral scanners did not show significantly higher accuracy and precision compared to conventional impressions, but a digital workflow does provide higher reliability.[2]

In an in vivo study conducted by Zarauz et al it was concluded that the difference in the marginal fit adaptation of crowns that were fabricated using silicone impression and digital impressions was approximately 50 microns; with digital systems showing a better result than the conventional materials. [37] Zarauz et al also stated that though the observable difference was only 50-100 microns it could still not be ignored that an error existed.[37] As per the observations of the clinical trial conducted by Benic et al, 3 unit fixed prosthesis made using zirconia showed a better fit when they made fabricated using a digital workflow which also consisted of CAD-CAM technology for fabricating the prosthesis in the marginal areas, while conventional workflows showed better results in the occlusal adaptation.[28] It was also stated that metal-ceramic prosthesis tended to show higher discrepancies than a ceramic prosthesis.[28,38] He also stated that a majority of discrepancies are noticed with respect to casted restorations which may add to the fact that they are mostly fabricated as metal-ceramic restorations.[28] Benic et al also put forth the opinion that poor occlusal fit that was observed for prosthesis fabricated using zirconia ceramics, could be compensated for by the superior qualities of the material.[28] In the same study it was also noted that crowns that were fabricated with CAD-CAM workflow instead of just CAM workflow noted lower discrepancy.[28] Pradies G et al also concluded that it was easier to record the finish line with a digitized workflow and hence minimize the errors that would generally occur due to the manual marking of the finish line by the technician.[3] It was also concluded in the same study that zirconia based prosthesis that were fabricated using digital impressions obtained better marginal and internal fit than the crowns that were fabricated by conventional impressions.[3]

The effect of a digitized workflow is not limited to a permanent prosthesis only, but also involves long term effects on provisional prosthesis. In an in vitro study conducted by Abdullah et al, it was observed that CAD-CAM crowns are a better choice for provisional restorations as they show no polymerization shrinkage, unlike conventional direct provisional crowns.[39] Provisional crowns fabricated with CAD-CAM technology have also shown lesser marginal gap compared to the traditional materials with the added benefit of being less toxic; that was generally a major concern observed with the polymerization of self-curing materials.[39] In another in vitro evaluation comparing the crowns made using lost wax technique and computer-aided technologies, 3D printing was found to be the most beneficial of all techniques with the highest accuracy and a marginal discrepancy less than that observed with CAD-CAM crowns. Although an important factor to be noted in this is that crowns that were manufactured using 3D printing and CAD-CAM still have to be finished manually hence, the lost wax and casting procedures when handled with care and precision do not display a significant difference compared to a digital workflow.[40] The high dependence of the convention system on skills and person to person variation of judgment can lead to higher marginal discrepancies. [40]

II. Conclusion

It is clearly evident that impressions play an important role in the marginal adaptation of the prosthesis which in turn is vital for maintaining the periodontal hygiene of the patient.[16,32] The marginal adaptation and inaccuracy of the restoration/ prosthesis are key factors that may cause biologic width violation which eventually leads to bone loss which may eventually weaken the periodontal attachment apparatus.[7,20,21,28] The summations of all these events lead to failure of the prosthesis or restoration.[7,20,21,38]

The shift of the oral microflora from aerobic to anaerobic environment along with an increase in the number of rods and spirochetes is a clear indication that any restoration or prosthesis with subgingival margins when not placed carefully, could pose a danger to the biologic width attachment.[8,17] It should be kept in mind that after periodontal disease has set in the regenerative capabilities of the periodontium are severely handicapped due to inflammation and tissue injury, and clinical intervention can only salvage the remaining bone while regeneration via periodontal surgery can still not make up for the lost bone completely.[5,17,25]

Conventional methods of biologic width preservation while reliable are also time-consuming and not suited to fulfill the immediate aesthetic needs of the patient.[4,7] Digital scanners offer a viable solution and when coupled with a digitized workflow offer a reliable marginal adaptation that may be seen as the future of preserving the Biologic width.[3,4,32] Current literature suggests a difference of 50-100 microns in the precision of digital and conventional impressions which although not yet significant; cannot be completely ignored.[2,37] The high dependence of the conventional methods of prosthesis fabrication shows high reliability on the technician's skills and the interpersonal variation of judgment, which can at times be the root cause of the high number of errors that are seen in casted restorations compared to restorations fabricated digitally.[40] A digitized workflow helps in significantly reducing these errors and improves the marginal accuracy of the restoration by providing an accurately duplicated finishing line that the technician can refer to.[40] Needless to say width violations occurring due to other reasons such as trauma from occlusion, food lodgment, etc. need their own line of management.[16]

The improvement of marginal adaptation that can be brought about by shifting to a more digitalized workflow can effectively improve the periodontal health of the tooth and add to the longevity and aesthetic value of the restoration.[3,4,37,40] This can also help in reducing the overall bacterial load of the oral cavity hence significantly contribute to the reduction of periodontal pathologies for patients undergoing restorative and prosthetic procedures. [7,28,37]The idea of a completely digitalized workflow still remains in its infancy and further research is still needed to indicate its importance in preserving the Biologic Width and hence improving the periodontal health.

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