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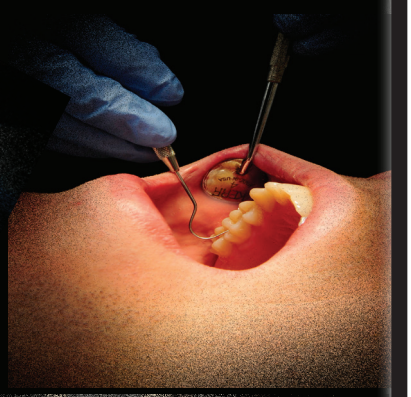

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Note from the Editor...

This issue of *The Medical Journal* is dedicated to all things related to Dentistry. Submissions received from the field were exemplary and covered a broad spectrum, to include treating military working dogs. We are also proud to include the top two winners of the 2021 Joseph L. Bernier Dental Research Award Competition.

Named after the 14th US Army Dental Corps Chief, Major General (MG) Joseph L. Bernier instituted a preventative dentistry program across the Army and organized Oral Pathology as a recognized specialty. His early years included serving as a researcher and educator at the former Army Dental School preparing civilian dentists to become combat dentists. The first Advanced Education of General Dentistry residency at Fort Hood, TX, began under MG Bernier's service as Dental Corps Chief. Specifically, this award embraces the future of Army Dentistry by advancing the pursuit of knowledge, education, and research.

Consisting of a consolidated category for graduating or recently graduated dental residents for research conducted by US Army Dental Corps officers, the competition receives a wide-range of submissions, such as retrospective studies, laboratory studies, literature reviews, and descriptive case studies.

Submission winners, US Army Dental Corps officers, demonstrate research that is well-designed, properly executed, relevant to military dentistry, and worthy of publication. The Bernier Dental Research Award Competition dates back to at least 1991, when it was administered by the former US Army Institute of Dental Research, which ultimately merged with the US Army Institute of Surgical Research.

Typically, the Bernier Dental Research Award Competition's initial Call for Submissions goes out in December in *The Dental Corps Bulletin*. Deadline for submission is in the spring of each year. To view the announcement of this year's winners, visit *https://www.dvidshub.net/video/799662/dental-corps-2021-bernier-award-announcement*, and congratulations to all the 2021 Bernier Dental Research Award Competition winners.

Tooth Wear in Patients Undergoing Sleep Studies: A Blinded Observational Study

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Thomas Beltran

Abstract

Objectives: Obstructive sleep apnea (OSA) is a common health problem that remains an underdiagnosed issue. Screening tools and clinical markers are needed from a variety of providers to determine patients at risk for OSA. Tooth wear could be a good potential identifier of patients at risk of having OSA.

Methods: This is an ambidirectional observational cohort. Participants were identified as retrospectively having undergone a sleep study and then tooth wear data was prospectively collected at patients' annual dental exam. The participants also completed an anonymous questionnaire to determine correlations with possible confounding factors.

Results: A total of 107 individuals were included in the analyses. No significant differences in wear were found between participants with an Apnea-Hypopnea Index (AHI) <5 and those with AHI ≥5 for any of the teeth examined (all $P > 0.05$). Overall, both groups had median tooth wear scores of 2 (IQR 1). Similarly, no differences in tooth wear were found between participants based on their body mass index (BMI) classification or consumption data (all $P > 0.05$).

Conclusion: Sleep is a complicated entity with many possible confounding factors. There is no correlation between AHI and tooth wear in the selected military cohort. Dentists should screen patients for possible medical and dental conditions whenever tooth wear is detected. Further research is needed to determine if tooth wear could be used as a potential identifier of patients at risk for OSA.

Introduction

Obstructive sleep apnea (OSA) is associated with an increased risk of many health problems, such as atrial fibrillation, depression, congestive heart failure, stroke, hypertension, coronary artery disease and diabetes.[1] It has been estimated that 82-95% of the population with OSA remain undiagnosed and therefore go without treatment.[2,3] Screening tools and clinical markers are needed for providers to determine patients at risk for OSA.

The diagnosis of tooth wear is immediate, inexpensive, and can be made based on the clinical examination of tooth surfaces. Tooth wear is a consequence of bruxism, or teeth grinding, a symptom which has been frequently associated with obstructive sleep apnea.[4-6] These characteristics make tooth wear a good potential identifier of patients at risk of having OSA.

In a recent review of the literature, two studies regarding OSA and tooth wear specifically (as opposed to bruxism) were found. In 2015, a small prospective study recruited patients (N=30) with various stages of tooth wear and sent them for a sleep study. While the severity of tooth wear was associated with the severity of OSA, in their patient sample, over 80% of patients had lost 10 or more teeth.[7] Anitua, et al. retrospectively examined a combination of dental casts and clinical photographs of teeth to evaluate tooth wear in patients who had undergone a sleep study. While the severity of tooth wear was associated with the severity of OSA, they recommended that in future prospective studies, intraoral inspection of the patient should be included.[8]

These outcomes justify the performance of prospective and controlled clinical studies to evaluate the association between tooth wear and OSA, to identify confounders that may influence this association and potentially determine if unexplained tooth wear is an appropriate cause to refer patients for sleep studies. To our knowledge, no study has prospectively evaluated tooth wear at dental visits in patients with sufficient dental health access, who have already undergone a sleep study.

The incidence of OSA in military personnel has increased more than 500% since the early 2000s.[9,10]

Figure 1. Smith and Knight's simplified scoring criteria.

Score	Description
0	No visible wear
1	Wear confined to enamel, no wear into dentin
2	Dentin just visible or dentin exposed for less than a third of the surface
3	Dentin exposure greater than a third of the surface
4	Exposure of pulp or secondary dentin

Non-adherence is high in this population, especially so in military personnel who have been also been diagnosed with post-traumatic stress disorder.[11,12] OSA is also a leading cause of US Army aircrew waivers,[13] and of cases newly diagnosed in 2015, 48.1% were diagnosed in the last year of service. This is attributed to medical separation, increased diagnoses in aging, or service members delaying diagnosis to avoid medical separation/permanent profile.[14]

Evidence suggests that service members who are adherent to therapy experience improved sleep quality, energy, emotional well-being and fewer depressive symptoms.[11] Increasing the number and variety of screening tools may allow for undiagnosed patients to be more easily identified and referred for treatment, thereby improving the well-being and health of US service members.

The primary objective of this study is to assess if the severity of tooth wear (as measured by the 5-point Smith and Knight tooth wear index scale) in US service members is associated with the severity of OSA (as measured by the Apnea-Hypopnea Index) in patients who have already undergone a sleep study. Secondary objectives include adjusting the primary objective for potential confounding factors, such as demographics, comorbidities, diet and current treatments for those patients already with diagnosed OSA. The purpose is to estimate the severity of tooth wear in patients with obstructive sleep apnea and to assess a potential clinical marker available to dentists in the identification of patients at risk of obstructive sleep apnea syndrome. The null hypothesis would be that there is no correlation between severity of tooth wear and severity of OSA. An additional null hypothesis would be that there are no associations with OSA and multiple extraneous factors.

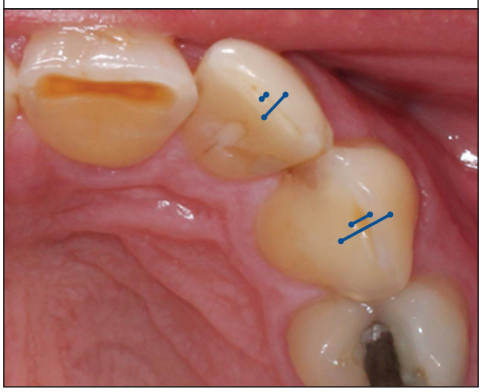
Methods

This is an ambidirectional observational cohort. Participants were identified as retrospectively having undergone a sleep study and then tooth wear data was prospectively collected at patients' annual dental exam. The participants also completed an anonymous questionnaire to determine correlations with possible confounding factors at the same time as tooth wear data was collected.

Table 1. Respondent characteristics.

Characteristic	n	AHI <5 %	AHI >5 %
Gender			
Male	97	35.1	64.9
Female	10	70.0	30
BMI			
Underweight	0	-	-
Normal weight	22	68.2	31.8
Overweight	53	30.2	69.8
Obese	31	29.0	71.0
		M (SD)	M (SD)
Sleep, hrs	107	5 (1)	5 (1)
Stress level	107	6 (2)	6 (2)

Figure 2. Intraoral tooth wear measurements.



Active duty patients who had undergone an overnight in-lab polysomnogram at Womack Army Medical Center or Cape Fear Valley Medical Center were offered inclusion in the research. Potential participants were reached by telephone within 1 month of their polysomnogram to ask if they would be interested in participating in the research at the same time as their military required annual dental exam. If participants were not interested then they received their annual dental exam at their home dental clinic on Fort Bragg according to standard operating procedure. If they agreed to participate then they received their annual dental exam at the same time as participation in the research.

The investigator was blinded as to what the patient's diagnosis/AHI score was before their annual exam and participation in the study. All participants presented to the dental clinic within 3 months of having their overnight polysomnogram. Upon arrival to the dental clinic, the patient was given the consent form and privacy statement and given the option to participate in the study. All patients who presented to the clinic consented to participate in the study.

One dental provider collected all tooth wear data. Anterior tooth wear was scored using Smith and Knight's tooth wear index (Figure 1).[15] The incisal surfaces were the only ones scored. The incisal surface was scored in the buccal-lingual direction. The incisal wear classification was modified so that dentin wear was consistent with the other surface classifications and could be measured in an objective way. A score of 2 is defined as "Loss of enamel exposing dentin for less than one third of surface" instead of "Loss of enamel just exposing dentin." A score of 3 is defined as "Loss of enamel exposing dentin for more than one third of surface" instead of "Loss of enamel and substantial loss

Table 2. Median tooth wear by group.

Median Tooth Wear by Group, Mdn (IQR)		
Location	AHI <5, %	AHI >5, %
T6 - T11	2 (1)	2 (1)
T22 - T27	2 (1)	2 (1)
T19 and T30	2 (1)	2 (1)

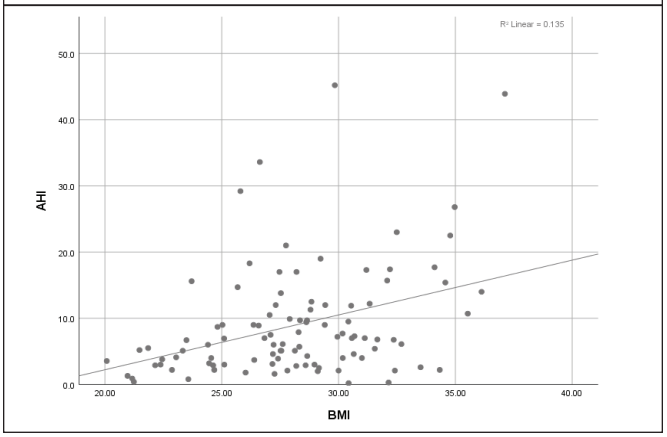
of dentin." Whether dentin was exposed for more than one third of the surface was determined using a UNC 15 periodontal probe and measuring from the incisal view in the buccal-lingual dimension (Figure 2). It was measured in the area of greatest dentin exposure. In Figure 2, #9 would be measured as a score of 4, #10 as a score of 2, and #11 as a score of 3. If a tooth was heavily restored or missing and tooth wear data could not be collected it was annotated. #19 and #30 occlusal tooth wear was also included for comparison.

The participants all got their routine annual dental exam according to standard operating procedure. The tooth wear data was recorded during the annual exam. Clinical data was collected in the dental records for treatment purposes as part of standard clinical care. The participants also completed an anonymous questionnaire to determine correlations with possible confounding factors. The short questionnaire asked about confounding factors such as age, sex, stress, gastroesophageal reflux disease (GERD), dietary patterns (diets rich in food or drinks containing a variety of acids, especially citric and phosphoric acids), smoking, alcohol, caffeine, temporomandibular joint issues, sleep position, sleep arousal, headaches, use of an occlusal nightguard and use of a positive airway pressure (PAP) device. Information for the research was collected without any identifiers but each patient was assigned a patient study ID for tracking purposes. This concluded the participant's part of the study.

The patient's AHI data and body mass index (BMI) were collected after the annual dental exam and data collection from the patient's medical records. Patients with Apnea Hypopnea Index<5 serves as a control group. Those with AHI ≥5 were examined as a group as well as stratified by AHI quartile. The Centers for Disease Control's (CDC) guidelines for BMI were used to pool BMI into categories.[16] All data were compiled and analyzed.

The Shapiro-Wilk test was used to assess the normality of the data distributions. Consequently, measures of central tendency and dispersion for AHI are reported as medians with

Figure 3. Body mass index (BMI) and apnea-hypopnea index (AHI) scatter plot.

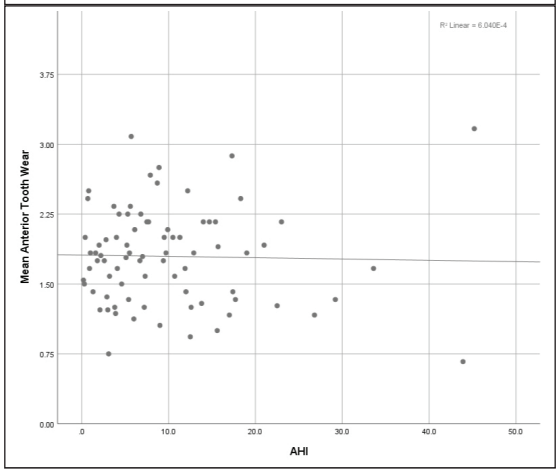


associated interquartile ranges (IQR). Age and BMI are summarized using means with associated standard deviations. The Kruskal-Wallis test to examine the relationship between tooth wear and AHI. Chi-square tests of independence was used for pairwise comparisons. Significance was declared at P<0.05 for all tests. All data were analyzed using standard statistical software.

Results

A total of 109 individuals were recruited for this study. Excluded from the analyses were two individuals lacking AHI data, leaving only 107 participants to be included in the analyses. The majority of participants were male (n= 97; 90.7%). The average age of the sample was 36 years (standard deviation=7). Participants with elevated AHI were found to be older than the control group (median =34, standard deviation=7; and median=37, standard deviation=7 respectively), P=0.03. Sample characteristics are summarized in Table 1 by group. There was a positive relationship (P<0.001) between BMI and AHI. BMI and AHI results are plotted on Figure 3.

Figure 4. Tooth wear and apnea-hypopnea index (AHI) scatter plot.



Teeth were examined in aggregate as well as by location (Table 2). No significant differences in wear were found between participants with AHI <5 and those with AHI ≥5 for any of the teeth examined (all P>0.05). Overall, both groups had tooth wear scores of 2 (IQR 1). Tooth wear and AHI are plotted on Figure 4. Similarly, no differences in tooth wear were found between participants based on their BMI classification, consumption data, or self-reported medical conditions (all P>0.05). Consumption information for

the sample is summarized in Table 3. Self-reported medical conditions for the sample are summarized in Table 4.

Table 3. Consumption frequency.

Item	Daily	Weekly	Monthly	Rarely or Never
Cigarettes	2.8	0.9	0.0	96.3
Vaping	3.7	1.9	0.0	94.4
Chewing Tobacco	10.3	3.7	2.8	83.2
Beer	3.7	27.1	20.6	48.6
Wine	0.9	14.0	13.1	72.0
Liquor	0.0	17.8	23.4	58.9
Coffee	57.0	6.5	9.3	27.1
Diet Soda	5.6	8.4	3.7	82.2
Non-diet Soda	4.7	10.3	11.2	73.8
Sweet Tea	3.7	11.2	15.9	69.2
Unsweet Tea	0.0	4.7	15.9	79.4
Juice	7.5	23.4	19.6	49.5
Energy Drinks	10.3	14.0	10.3	65.4
Caffeine Pills	0.9	0.9	0.9	97.2
Candy	1.9	20.6	21.5	56.1
Sugary Foods	9.3	29.9	19.6	41.1
Acidic Fruits	3.7	14.0	18.7	63.6

To check whether the non-significant difference in tooth wear could be due to a lack of statistical power, a post hoc power analyses was performed with power (1-β) set at 0.80 and a two tailed α=0.05. Results of this analysis showed us that sample sizes would have to increase from our existing sample size of 107 to 4,676 in order for group differences to reach statistical significance at the .05 level. Thus, it is unlikely that our negative findings can be attributed to a limited sample size and in fact represent a true lack of relationship between AHI and tooth wear.

Discussion

The null hypothesis that there is no correlation between severity of AHI and severity of tooth wear was accepted. The additional null hypothesis that no associations with OSA and multiple extraneous factors was also accepted.

This patient population could be at higher risk for tooth wear. These participants had already undergone a sleep study. All had a reason for undergoing the sleep study in the first place. This could range from poor sleep quality to history of traumatic brain injury (TBI) or other medical reason. Bruxism is more frequently observed in depressed, anxious, and emotionally stressed individuals.[17] Military personnel are at high risk of exposure to traumatic events with subsequent associated psychological distress and mental health problems including depression, family violence, substance abuse, and post-traumatic stress disorder (PTSD), which may threaten occupational functionality.[18] Only 38-41% of people in this study reported they did not think they have PTSD, anxiety, or frequent headaches (Table 4).

This study has the benefit of direct observation of the teeth when scoring tooth wear. Anitua, et al. only used photos and casts.[8] Due to minor color or surface changes between dentin and enamel on some patients, it would be difficult to fully measure or detect the changes without direct observation in the mouth.

Table 4. Self reported medical conditions by percentage.

Frequency Assessment	GERD	Acid Reflux	Anxiety	PTSD	Frequent Headaches	TMD
Yes, and I am currently being treated for it	9.3	11.2	31.8	25.2	40.2	6.5
Yes, but I am not currently being treated for it	0.0	3.7	8.4	8.4	14.0	5.6
No, but I think I might have it	6.5	13.1	15.0	15.0	5.6	11.2
No, and I don't think I have it	78.5	65.4	41.1	42.1	38.3	58.9
I don't know	5.6	6.5	3.7	9.3	1.9	17.8

Many people classify tooth wear as mild, moderate, or severe without quantifying these measurements. By using Smith and Knight's tooth wear index, we were able to quantify the tooth wear in a repeatable way. Each tooth must be scored in order to determine an average or a generalized tooth wear score. We were only looking at anterior tooth wear because it has been hypothesized that bruxism and protruding the mandible are protective functions during sleep.[19] Prospective evaluations and case studies of sleep bruxism and apnea indicate that bruxism events may be directly correlated to apnea episodes.[20] While a causal relationship cannot be made, OSA has been called the highest risk factor for tooth grinding during sleep.[21] Many people do not have anterior tooth guidance in excursive movements or can have an open bite that will minimize any tooth wear. This was not controlled for in this study.

It is not known whether tooth wear observed in this population was due to sleep bruxism or some other etiology. There are three broad categories of wear etiology: functional, erosive, and parafunctional.[22] Tooth structure can also be missing due to trauma, caries, resorption, or genetic defects. The etiology of tooth wear or missing tooth structure was not investigated in this study.

All of the participants in this study are required to get dental care on an annual basis. The overall health of the teeth were excellent. None of the participants were missing any anterior teeth. None of the patients had more than 3 anterior teeth that could not get an incisal wear score due to being heavily restored.

There was a positive correlation ($P<0.001$) between BMI and AHI in this study. No differences in tooth wear were found between participants based on their BMI classification ($P>0.05$). Only 3 patients had an AHI greater than 30. The active duty military population in this study is overall a healthy, physically fit group. This could explain the lack of severe AHI patients and the lack of correlation between tooth wear and AHI in this study. It is possible for an individual to have an elevated BMI due to increased muscle mass instead of body fat. Service members with high

standards of fitness and physical readiness may be classified as overweight or obese according to BMI despite having healthy or even low levels of body fat. A study of service members by Heinrich and colleagues,[23] showed that non-obese military men can be misclassified as obese using the BMI categories compared to using body fat testing. However, Heinrich's study showed that categorizing obesity based on measured BMI actually underestimated the prevalence of obesity.

A suggested format for a future study could be screening patients for tooth wear and then sending them for a sleep study like the pilot study done by Durán-Cantolla, et al.[7] Standard operating procedures in the military health care system precluded this study design without further research.

Conclusion

Sleep is a complicated entity with many possible confounding factors. There is no correlation between AHI and tooth wear in the selected military cohort. Dentists should screen patients for possible medical and dental conditions whenever tooth wear is detected. Further research is needed to determine if tooth wear could be used as a potential identifier of patients at risk for OSA.

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Comparison of Opioid Prescription Pattern Trends amongst DENTAC and Selected Departments of the Carl R. Darnall Army Medical Center, Fort Hood, TX, from 2010 to 2017

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Abstract

Purpose: The purpose of this Observational Retrospective Cohort is to compare opioid prescription pattern trends from 1 January 2010 to 31 December 2017 amongst the Dental Health Activity (DENTAC), Obstetrics/Gynecology (OBGYN), Emergency Room (ER), and Family Medicine departments assigned to the Carl R. Darnall Army Medical Center, Fort Hood, TX. In addition, as a secondary outcome, the type of opioids prescribed will be explored during the same time frame.

Methods: An Observational Retrospective Cohort Longitudinal Archival Medical Chart Review was executed by a report collection from the Pharmacy Data Transaction Service (PDTS). Data analysis was developed with a Repeated Measures Analysis of Variance (ANOVA) in order to compare means across multiple variables based on repeated observations. By utilizing a mix of factors model, variables within each department (Test of Within-Subjects Effects) and between departments (Test of Between-Subjects Effects) were analyzed.

Results: The statistical analysis demonstrated no significant differences within the number of pills dispensed from the DENTAC and OBGYN departments. A moderate decrease in prescription patterns at the Emergency Department and extreme decrease at the Family Medicine Department was reported. No significant differences between the number of patients and number of prescriptions dispensed were found within each department over the 8-year period. The statistical analysis showed significant differences between the Family Medicine and Emergency departments in comparison with the DENTAC and OBGYN departments. From 2010-2016, Family Medicine and Emergency Departments demonstrated a substantial decrease in opioid prescribing. The DENTAC and OBGYN departments showed a constant linear factor from 2010 to 2016 indicating minimal changes in number of pills dispensed and revealing a small decrease of pills dispensed during 2017. The most common types of opioid medication prescribed in the four departments from 1 JAN 2010 to 31 DEC 2017 were Morphine Sulfate and Hydromorphone HCL.

Conclusions: In this study, the DENTAC AND OBGYN departments did not show a significant decrease in number of opioid pills and number of prescriptions dispensed compared to the Family Medicine and ER departments. Overall, the Family Medicine department showed the most drastic change in opioid prescription patterns from 1 JAN 2010 to 31 DEC 2017 at the Carl R. Darnall Army Medical Center, Fort Hood, TX. The most common types of opioid medication prescribed in the same period of time within the four departments were characterized by morphine and hydromorphone components.

Introduction

The opioid crisis in the US was declared a public health emergency in 2017.[1,2,3] In the last few decades, the treatment of chronic pain has expanded to the primary care setting. Many primary care providers have had little specific training in pain medicine and addiction and are unsure about how to safely prescribe opioids. In addition, the high prevalence of psychiatric comorbidity in those who abuse prescription drugs contributes to the complexity in treating pain.[4] In 2012, US healthcare providers wrote more than 259 million prescriptions for opioids, twice as many as in 1998.[5] The non-therapeutic use of opioid analgesics increased markedly over the

past 15 years, to the point where it is now regarded as a major public health concern.[6]

In 2015, approximately 12.5 million people misused prescription opioids, and approximately 2 million people demonstrated prescription opioid use disorder because of the high rates of opioid abuse, overdose, and death. In 2016, the total number of opioid prescriptions in the US was approximately 214.9 million, with an annual opioid prescribing rate of 66.5 prescriptions per 100 people.[3]

Chronic pain conditions and prescription drug abuse are an increasingly prevalent public health issue. Population-based studies reveal that more than 75 million Americans (about 25% of the entire population) have chronic or recurrent pain. Of these, 40% report the pain as having moderate to severe effect on their lives.[7] It is estimated that 90-95% of long-term opioid therapy is prescribed for non-cancer pain conditions (NCPC), and it has been previously reported that approximately 3% of the US general population without cancer uses opioids regularly for a month or more per year.[8]

Between 1980 and 2000, opioid prescribing at outpatient visits for chronic musculoskeletal pain doubled from 8% to 16% with the use of more potent opioids increasing from 2% to 9%.[9] Among Medicaid fee-for-service enrollees, the overall use of opioid pain medication increased 3-fold from 1996 to 2002, and varied widely from state to state.[9,10] Documented increases in treatment admissions, morbidity, and mortality related to opioids correlate with national increases in overall consumption levels of opioids.[10,11] Opioids are also frequently for short-term pain management in emergency and clinical settings.[4]

The data available from the National Survey on Drug Use and Health indicates that approximately 4.5 million people 12 years or older reported nonmedical use of pain relievers, including taking more pills than prescribed and combining with other substances.[1] In 2005, 1.5 million of the 108 million emergency room visits were associated with drug misuse or abuse, with most visits (55%) involving multiple drugs. Of these visits, more than one-third involved the non-medical use of prescription or over the counter (OTC) drugs.[4] Opioids are the most prescribed medication of any drug category in the US, exceeding 250 million prescriptions annually. Legitimate prescriptions, and the diversion (intentional or unintentional) of those prescriptions, constitute a major source of abuse.[12]

Besides the drastic increases in the number of prescriptions written and dispensed, several other factors have likely contributed to the severity of the current opioid abuse problem, including lack of standards among healthcare professionals for prescribing opiates, greater social acceptability for using medications for different purposes, and aggressive marketing by pharmaceutical companies.[13]

The availability of prescription drugs has contributed to a dramatic increase in nonmedical use and abuse of these medications. Clinician awareness is essential in helping reduce prescription drug abuse while continuing to provide effective treatment.[4] Hall et al reported that 44% of persons dying from an opioid-related overdose had obtained their medications from a physician.[14]

Former President Donald Trump's Commission on Combating Drug Addiction and the Opioid Crisis entered this battle, making 56 recommendations to include The Research Act (to promote research on innovative non-addictive pain medications), The Combat Addition Act (to train providers in acute pain management skills), The Creating Opportunities Act (to support drug monitoring programs), the Securing Opioids and Unused Narcotics Act (to safely dispose any unused medications), the Comprehensive Opioid Recovery Centers Act (to provide recovery support services) among others.[15,16] Additionally, hundreds of local, regional, state, and federal interventions have been implemented.[17] The US Office of National Drug Control Policy responded to the epidemic with numerous recommendations, including the need to evaluate current databases that measure the extent of prescription drug use, misuse, and toxicity.[18] Key topics addressed present and future strategies to combat drug abuse to include prescription drug monitoring programs, reducing prescriptions, public education, eliminating internet drug pharmacies, and the development of future drugs that are not only tamper resistant but also non-addictive.[7,18]

National interventions to control the opioid crisis have been also considered in dentistry. The American Dental Association (ADA) partnered with the National Institute of Health (NIH) to accelerate science that will lead to solutions to the opioid crisis through the NIH's Helping to End Addiction Long-Term Initiative.[19]

Also, the ADA expressed support for several proposals that complement the ongoing efforts to keep prescription opioid pain medications from becoming a source of harm. On March 26, 2018, the ADA announced a new interim policy on opioids that includes mandatory continuing education, prescribing limits on opioid dosage and duration of no more than seven days for the treatment of acute pain, and mandated dentists to register with and utilize prescription drug monitoring programs.[15]

National surveillance data suggest that dentists follow primary care physicians as the second-leading prescribers of immediate-release opioids and, as such, dentists have been identified as having an important role in opioid abuse prevention efforts.[20] Researchers of previous studies have noted that dentists are often the first source of exposure to opioids for adolescents and young adults. Easy access to prescription opioids among these age groups can increase the likelihood of prescription opioid misuse.[3] Providers need training on how to treat oral and dental pain with an opioid and this includes several factors, such as healthcare provider experience, professional guidelines, the patient's own pain perception, communication regarding the pain experience between patient and the treatment team, and individual pain assessment.[21]

Thanks in part to policies on opioids and treating dental pain adopted by the ADA, the rate of opioid prescriptions written by dentists has decreased considerably in recent years. In 1998, dentists were the top specialty prescribers of immediate-release opioids, accounting for 15.5% of all immediate-release opioid prescriptions. By 2009, the amount of opioid prescriptions written by dentists decreased to 8% of all opioid prescriptions in the US, and by 2012, the latest year for which data is available, dentists prescribed 18.5 million prescriptions, accounting for 6.4% of all opioids prescribed in the US.[2,19,22]

Multiple studies compare and analyze opioid prescription patterns among different medical specialties to include dentistry. Chandrashekar and colleagues identified specific characteristics that would create differences in opioid prescription patterns. They found that the type of health care provider diagnosing dental issues is an important factor, concluding that nurse practitioners prescribed an opioid after a dental diagnosis for approximately 1 in every 4 patients receiving Medicaid.[21] Findings from a 2006 National Ambulatory Medical Care Survey study showed a comparable opioid prescribing pattern between nurse practitioners and medical specialists and found similar results.[11] Volkow et al studied multiple characteristics in opioid prescriptions during 2009 by analyzing medical and pharmacy Medicaid claims from data reports and concluded that dentists, unlike their primary care physician (28.8%), internist (14.6%), and orthopedic (7.7%) colleagues, prescribed opioid medication only 8% of the time.[23]

Similar results were found by Niodita et al in opioid prescribing practices from 2010 through 2015 among dentists in the US. The analysis of prescription rates and dosages, type of opioid drug prescribed, and type of dental visit concluded that dentists more frequently prescribe opioids in a large sample of people who are privately uninsured in the US.[2]

In 2013, a Pew Research Center survey showed that only 16% of Americans believed that the US was making progress in reducing prescription drug-abuse.[10] Multiple studies compare opioid prescription trends amongst different medical departments, but they have largely relied on self-reported opioid drug use,[17] non-representative samples, and have been non-characteristic of the military population.[13]

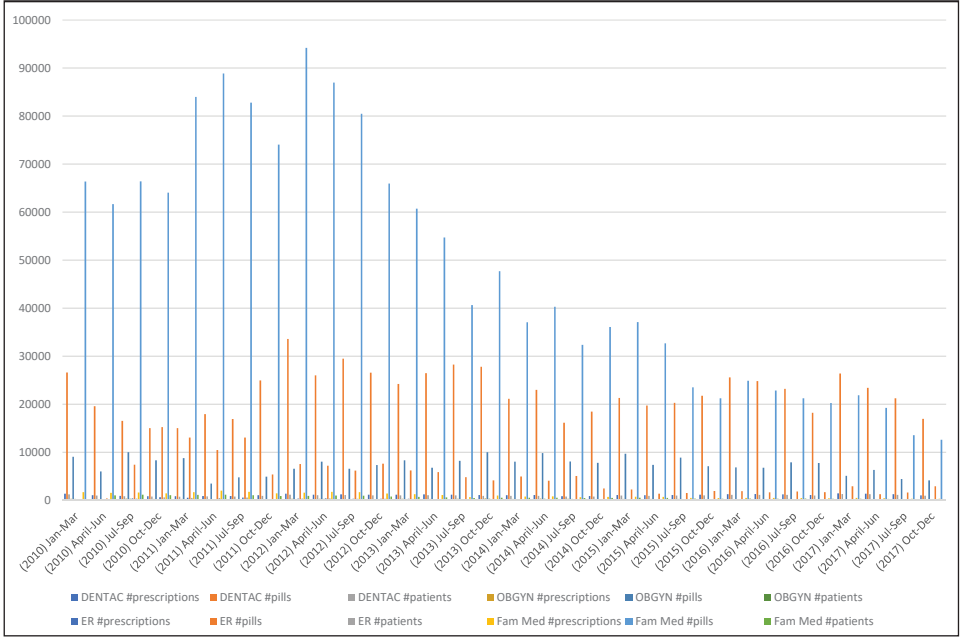
The use and abuse of prescribed controlled substances are of concern to the Department of Defense (DoD) because of their potential impact on military readiness, the health and well being of military personnel and their families, and associated health care costs. Opioids are used in treating military veterans with post-traumatic stress disorder, mental health, and substance abuse diagnoses and pain conditions, like lower back pain and migraine headaches.[24] The growing rate of opioids prescribed to younger veterans has also been documented.[25] Unfortunately, the information on prescription drug use and abuse among active duty service members (ADSM) is scarce in contrast to the increased literature focused on opioid use and abuse in the civilian population.[26]

The observation and evaluation of opioid prescription patterns within the DENTAC department and its comparison to opioid prescription trends with other departments (OBGYN, ER and Family medicine) is extremely useful in acquiring significant data that will provide a general assessment of opioid prescriptions patterns over an extended period of time. By comparing these figures within departments and between departments, we can evaluate the effectiveness of measurements from our government, dental associations and local efforts in order to control pain in the safest way possible. As healthcare providers, our responsibility is to ensure that our service members receive the best treatment that maintains them in a high level of mental and physical health in order to remain deployable while successfully fulfilling mission requirements.

HYPOTHESES: The purpose of this study is to compare opioid prescription patterns trends from 1 January 2010 to 31 December 2017 among the DENTAC, OBGYN, Emergency Room, and Family Medicine departments assigned to the Carl R. Darnall Army Medical Center, Fort Hood, TX.

Primary research question: Did opioid prescriptions decrease at the Fort Hood DENTAC department from 2010 to 2017?

Figure 1. Opioid prescription trends by quarters from 1 January 2010 to 31 December 2017.



Secondary research question: How did opioid prescription trends from the Fort Hood DENTAC department compare to the Fort Hood OBGYN, ER and Family Medicine departments from 2010 to 2017?

Null Hypothesis #1: There are no changes in opioid prescription trends at the Fort Hood DENTAC department from 2010 to 2017.

Null Hypothesis #2: There are no significant differences between opioid prescription trends between the Fort Hood DENTAC department and the Fort Hood OBGYN, ER and Family Medicine departments from 2010 to 2017.

In addition, as a secondary outcome, the type of opioid prescribed will be explored from 1 January 2010 to 31 December 2017 amongst the DENTAC, OBGYN, Emergency Room, and Family Medicine departments. This finding will provide a baseline to determine which opioids were mostly prescribed during this period of time.

Materials & Methods

STUDY DESIGN: An Observational Retrospective Cohort Longitudinal Archival Medical Chart Review was executed by a report collection from the Pharmacy Data Transaction Service (PDTS), a centralized information repository that builds a common patient medication profile for all DoD and that includes specific data from the Pharmacy Department of the Carl R. Darnall Army Medical Center at Fort Hood, TX.

DATA ACQUISITION & MANAGEMENT: Only authorized personnel from the General Dynamics Information Technology Department of the Pharmacy Analytics Support Section located in San Antonio, TX, were granted access to the Composite Health Care System and Armed Forces Health Longitudinal Technology data repository system. These personnel were not part of the study team.

The information collected was a raw data summary obtained by a provider's Medical Expense and Performance Reporting System (MEPRS) codes search, and it was limited to number of pills, number of prescriptions, and number of patients without including any personal identifiable information (PII). The data was arranged in a spreadsheet format, by Grouping Variable using the specific providers MEPRs codes and classified in the corresponding departments: DENTAC, ER, OBGYN and Family Medicine. The repeated measurement variables (number of prescriptions, number of pills and number of patients) were displayed and collected every three months (quarterly) from 1 January 2010 to 31 December 2017 (Figure 1). This spreadsheet document was kept on a government computer assigned to the pharmacy personnel. The computer was password and common access card (CAC) protected, and the system was firewall protected. There were no planned linkages with external databases. Data was transferred by the pharmacy personnel to the principal investigator by encrypted email and secured against intentional or unintentional loss of confidentiality, integrity, or availability.

STATISTICAL ANALYSIS: The data analysis was conducted by the principal investigator in conjunction with the biostatistics analysis department at the Carl R Darnall Hospital. Data from the spreadsheet document was imported into statistical software for data analysis.

Table 1. Repeated measures analysis of variance (ANOVA) mix of factors model.

Between-Subjects Factors			
		Value Label	N
Departments	1	DENTAC	32
	2	OBGYN	32
	3	Family Medicine	32
	4	Emergency Room	32

Within-Subjects Factors	
Measure:	MEASURE_1
Charac	Dependent Variable
1	Prescriptions
2	Pills
3	Patients

Data analysis was developed with a Repeated Measures Analysis of Variance (ANOVA) in order to compare means across multiple variables based on repeated observations from the four different departments: DENTAC, OBGYN, ER and Family Medicine (Table 1). By utilizing a mix of factors model or split-plot, a factorial repeated measure of variance is determined by the combination between subjects and within subjects, while statistical assumptions of homogeneity of inter-correlations within factors are established.

Table 2. Test of within-subjects effects.

Source of Variation		Sum of Squares	DF	Mean Square	F	P
Factor	Sphericily assumed	1336.200	3	445.400	50.52	<0.001
	Greenhouse-Gelsser	1336.200	1.174	1138.414	50.52	<0.001
	Huynh-Feldt	1336.200	1.255	1065.113	50.52	<0.001
Group x Factor Interaction	Sphericily assumed	156.200	3	52.067	5.91	0.004
	Greenhouse-Gelsser	156.200	1.174	133.079	5.91	0.033
	Huynh-Feldt	156.200	1.255	124.510	5.91	0.03
Residual	Sphericily assumed	211.600	24	8.817		
	Greenhouse-Gelsser	211.600	9.39	22.535		
	Huynh-Feldt	211.600	10.035	21.084		

The within-subjects effects analysis (Table 2) displays the variation attributed to factor (#prescriptions, #patients, and #pills) in relationship with the group (DENTAC, OBGYN, ER and Family Medicine Departments) and their residual variation. The factor and group (P value) is low (P<0.05), concluding that there is significant difference within the subjects. The Sphericity value determines the variances of differences, and it has been adjusted by two methods, Greenhouse-Geisser (Epsilon: 0.391) and Huynh-Feldt (Epsilon: 0.418) in order to correct the univariate results.

Table 3 displays the within-subjects factors analysis (1=#pills, 2=#prescriptions, 3=#patients). The mean, standard error and confidence interval have been determined. A Bonferroni correction for multiple comparisons is applied for confidence interval adjustment (95%).

Table 3. Within-subjects factors analysis.

			95% Confidence Interval	
Charac	Mean	Std. Error	Lower Bound	Upper Bound
1	649.508	25.963	598.120	700.895
2	20629.148	1159.079	18329.007	22917.289
3	508.516	17.163	474.545	542.487

TREND ANALYSIS: The within-subjects analysis demonstrated no significant differences within the number of pills dispensed from the DENTAC and OBGYN departments. A moderate decrease in prescription patterns at the ED ($p<0.05$) and an extreme decrease at the Family Medicine Department ($p<0.05$) was reported. No significant differences between the number of patients and number of prescriptions dispensed were found within each department over the 8-year period. (Figure 1).

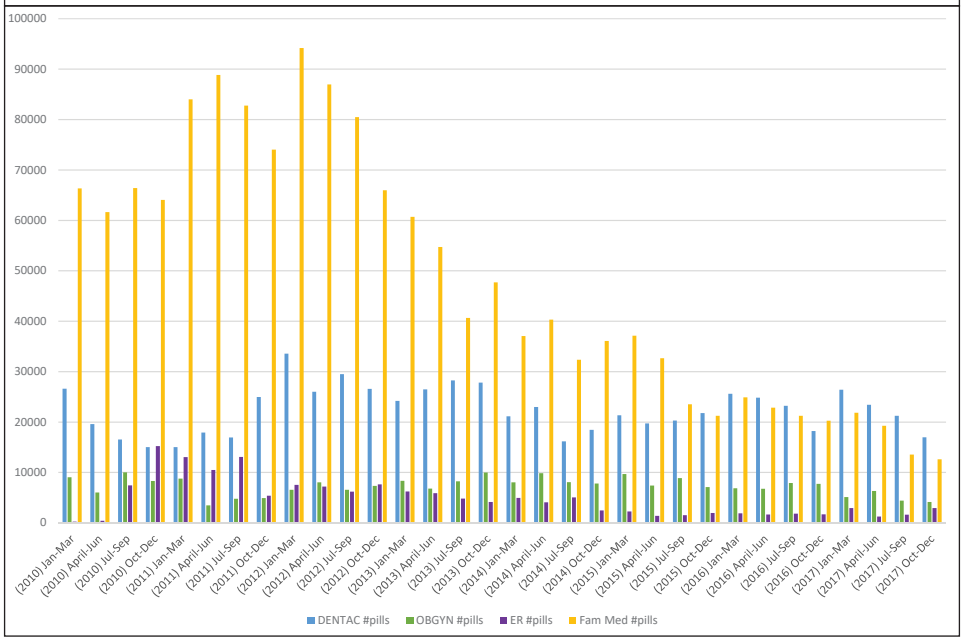
The between subjects analysis indicates significant differences between Family Medicine and ED in comparison with the DENTAC and OBGYN departments ($p<0.05$). A substantial decrease in opioid pills dispensed has been proved in Family Medicine and ED (95% confidence interval). The DENTAC and OBGYN departments showed a constant linear factor from 2010 to 2016 indicating minimal changes in number of pills dispensed and revealing a small decrease of pills dispensed during 2017 (Figure 2).

Results

The samples collected in this study demonstrated no significant differences within the number of pills dispensed from prescriptions generated by the DENTAC and OBGYN departments during the study period. On the contrary, a substantial decrease in opioid pills dispensed was detected in Family Medicine and ED. A moderate decrease in prescription patterns at the ED and an extreme decrease at the Family Medicine was identified. No significant differences between the number of patients and number of prescriptions dispensed were found within each department during the 8-year period.

The most common types of opioid

Figure 2. Opioid pill prescription trends by quarters from 1 January 2010 - 31 December 2017.



medication prescribed in the same period of time ·within the four departments were characterized by morphine and hydromorphone components (Figure 3).

Discussion

In October 2017, the US Department of Health and Human Services declared the opioid crisis a public health emergency[27] with more than 100 opioid-related overdose deaths occurring daily and more than 11 million people misusing prescription opioids, an estimated cost to the US of $506 billion annually.[28]

The impressive response to the epidemic is heartening, but the effect of programs to control the crisis is not yet known, especially in the military population.[10] Some local and state interventions have described a reduction in the abuse and diversion of prescription opioids after the enactment of state legislation.[18] Navigating the complexity of treatment guidelines provided by the Federation of State Medical Boards, the US Drug Enforcement Agency (DEA), and other health organizations can be confusing and intimidating. The difficulties in measuring pain, fear of regulatory issues, and legal risks are additional barriers to providing appropriate pain management.[7]

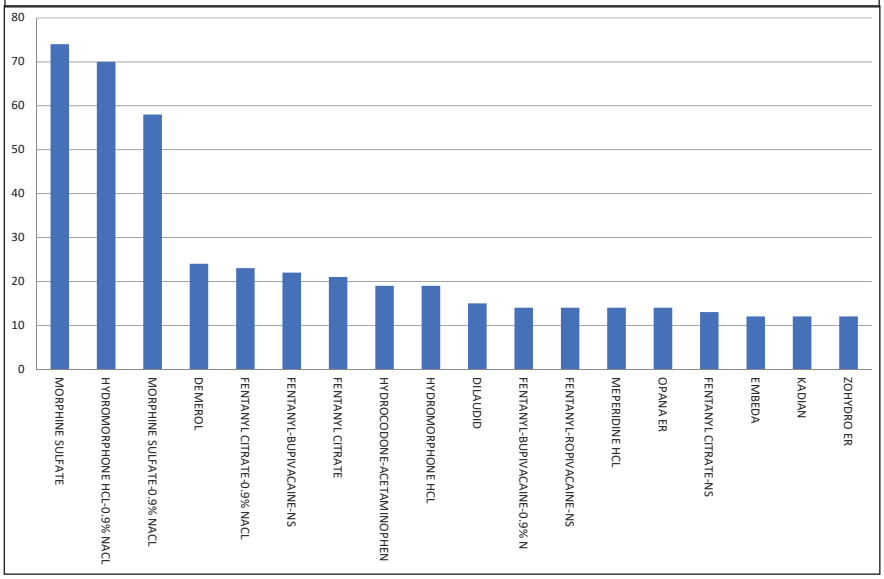
One aspect of the 5-part US Department of Health and Human Services Opioid strategy is to increase the availability of "better data" that will improve our understanding of the opioid epidemic. Consequently, dental researchers have sought to understand the factors related to opioid prescribing by oral health care professionals.[1,2]

According to the ADA, in the late 1900s dentists were the top specialty prescribers of opioids, accounting for 15.5% of all US opioid prescriptions. In 2012, this had been reduced to 6.4%. However, this was probably because of the nature of dental practice where there is a predominance of short-term, lower dose prescribing. When specifically compared with family physicians, dentists had higher odds of prescribing an opioid for short term pain.[29]

In this study, the DENTAC did not show a significant decrease in number of opioid pills and number of prescriptions dispensed compared to the Family Medicine and ED. In agreement with the ADA report, the DENTAC accounted for the most opioid prescriptions dispensed at the Carl R. Darnall Army Medical Center at Fort Hood, TX.

The ADA policy recommends prescription limits and continuing education for dental professionals with prescribing authority. Specifically, in this policy the ADA supports mandatory continuing education for prescribing opioids and other controlled substances, statutory limits on opioid dosage and duration and dentists registering with and use of Prescription Drug Monitoring Programs (PDMPs) to promote the appropriate use of opioids and to deter misuse and abuse.[29] This study shows that although these policies have been implemented, the DENTAC has not decreased the number of

Figure 3. Opioid drug class (DENTAC, OBGYN, FAM Med, ER departments) from 1 January 2010 - 31 December 2017.



opioid prescriptions and pills dispensed during the analyzed period of time. This could be explained by the fact the study only includes prescription trends from 2010 to 2017, excluding possible drastic changes in later years by applications like the use of long-acting anesthetic agents and non-dependent pain-controlled substance prescription programs.

In this study, the most common types of opioid medication prescribed within the four departments from 1 JAN 2010 to 31 DEC 2017 were characterized by morphine and hydromorphone components. In 2011, it was reported that dentists (including dental specialties) prescribed 12% of immediate-release opioids that also contain acetaminophen (e.g. Vicodin, Percocet and Tylenol 3) behind only family physicians, who prescribed 15% of immediate release opioids.[1,2] Immediate release opioid analgesics are the most commonly misused prescription opioids with 5% through 23% of dispensed doses used non-medically.[11]

McCauley et al described hydrocodone and acetaminophen as the predominant opioid prescribed by dentists in their study, accounting for 76% of all prescriptions, followed by oxycodone and acetaminophen (12%) and codeine and acetaminophen (7%).[30] Further studies that analyze specific DENTAC opioid drug class prescription patterns are recommended.

The results achieved in this study are not without limitations. Since the information collected was a raw data summary obtained by a provider's MEPRs codes search by departments, this does not account for the fact that providers from a specific department may prescribe opioids while rotating through other departments. At the same time, there was no specification in the proportion of opioid prescriptions provided based on specific diagnoses or difference between pre-procedural and post-procedural prescriptions. Also, the population is not identified by patient age, sex, race and ethnicity, making this an especially important area of future research.[21]

Conclusion

In this study, the DENTAC was the largest opioid prescriber followed by the OBGYN department. These departments did not show a significant decrease in number of opioid pills and number of prescriptions dispensed compared to the Family Medicine and ED segments. Overall, the Family Medicine department showed the most drastic decrease in opioid prescription patterns from 1 JAN 2010 to 31 DEC 2017 at the Carl R. Darnall Army Medical Center, Fort Hood, TX. This study suggests there is progress in combating the abuse of prescription opioid analgesics. Although significant differences were found between departments, all of them showed decrease in opioid prescription trends over the studied period of time.

The most common types of opioid medication prescribed in the same period of time within the four departments were characterized by morphine and hydromorphone components.

The opioid prescribing practices of dental professionals is an understudied area of research that merits greater attention. A greater understanding of the depth and complexity of the issues of opioid prescribing will enable knowledge translation to facilitate the construction of more effective policies and eventual solutions to the opioid crisis problem.

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Clinical Advantages of Angled Screw Access Channels for Implant-Supported Restorations in the Esthetic Zone

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Abstract

Introduction: Retained cement following delivery of an implant-supported crown is strongly associated with peri-implant mucositis and peri-implantitis, and screw retention is a strategy for avoiding this problem entirely. In the esthetic zone, screw retention compromises esthetics unless the screw access in the crown is concealed to the palatal of the incisal edge. To avoid positioning the implant platform excessively toward the palate, practitioners can design an angled screw access channel in the crown.

Case Presentation: A healthy 22-year-old patient with nonrestorable tooth #9 received extraction and immediate implant placement with immediate provisionalization. The screw access channel for the provisional restoration involved the incisal edge. Rather than placing a custom abutment and cementing the definitive restoration, an angled screw access channel was employed. The implant-supported restoration exhibited favorable esthetics, and the possibility of retained cement was avoided.

Conclusion: Up to a point, positioning maxillary anterior implants toward the palate is favorable. When the long axis of the implant is directed between the incisal edge and the cingulum of adjacent teeth, the implant-supported crown can be screw retained without compromising esthetics. In immediate implant situations, such positioning also increases the distance between the implant and the facial alveolar bone and encourages a favorable position of the marginal peri-implant mucosa. However, an excessively palatal platform position compels a restoration with irregular contours, which can frustrate proper oral hygiene and professional maintenance. Angled screw access channels allow screw retention without excessive palatal positioning of the platform, avoiding the possibility of cement-related peri-implant disease.

Keywords: crowns, dental cements, dental implants, esthetics, peri-implantitis, treatment outcome

Introduction

Observational studies suggest retained cement following delivery of implant-supported crowns may strikingly increase risk of peri-implant mucositis and peri-implantitis.[1,2] In one study, 81% of implants diagnosed with either peri-implant mucositis or peri-implantitis were found to have retained cement.[1] Moreover, practitioners cannot readily remove residual cement, and attempts to remove retained cement may damage implant components.[3] Various methods to assure complete cement removal at crown insertion have been devised,[4,5] but screw retention eliminates the problem entirely.

For maxillary anterior implants, orienting the long axis of the implant such that the implant platform is 2 mm palatal of the faciocervical contour of the crown has been advocated.[6] Indeed, placing the implant platform slightly toward the palate is clinically advantageous in several ways (Table 1). In addition to hiding the screw access on the crown, palatally positioning the implant platform increases the facial bone thickness adjacent to the implant. Facial bone thickness ≥ 2 mm has been associated with stability of peri-implant bone and mucosa.[7,8] In immediate implant situations, implant platform position toward the palate increases the distance between the implant surface and the facial wall of the extraction socket. This horizontal defect distance (HDD) has been shown to positively correlate with the vertical dimension

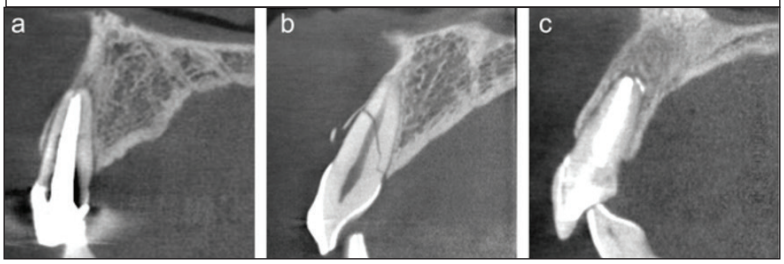
of facial bone after ≈10 years of function.[9] Additionally, palatally positioning immediate implants in the esthetic zone allows practitioners to utilize palatal bone for primary stability when favorable anatomy is present. Finally, palatal/lingual position of teeth or implants has been associated with a wide zone of attached gingiva/mucosa and absence of recession.[10,11]

Table 1. Advantages of positioning maxillary anterior implant platforms toward the palate.

General advantages
Increases facial peri-implant bone thickness
Allows concealment of screw access in crown
Advantages for immediate implants
Avoids trauma to facial socket wall during osteotomy preparation and implant placement
Allows use of palatal bone to increase primary stability
Increases gap between implant surface and facial socket wall[9]
Promotes favorable position of marginal peri-implant mucosa and avoids recession[10,11]

We propose a classification system for palatal bone at maxillary anterior extraction sockets (Figure 1). Favorable palatal bone allows the implant surgeon maximum flexibility in faciopalatal platform position. In an unfavorable palatal bone situation, the palatal bone is monocortical, with appearance similar to the facial cortex. The implant surgeon relies, in these cases, exclusively on apical bone for primary stability and has little flexibility with regard to implant angulation and platform position.

Figure1. Proposed palatal bone classification: a) Favorable palatal bone (maximum flexibility in immediate implant angulation and platform position); b) Intermediate palatal bone (some flexibility); and c) unfavorable palatal bone (primary stability depends principally on apical bone and implant position is largely dictated by extraction socket anatomy).



Case Management

A generally healthy 22-year-old male soldier with history of blunt trauma to tooth #9 presented to Tingay Dental Clinic, Fort Gordon, GA, September 2017. Tooth #9 had previously received root canal therapy and had been reduced to the gingival margin to accommodate an interim removable prosthesis. At baseline (Figures 2 and 3), the patient exhibited areas of visible plaque accumulation generally, with a 50% Modified O'Leary Plaque Index,[12] generalized marginal erythema, edema, and bleeding on probing. Probing depths ranged from 1 mm to 4 mm generally, with local areas of pseudopocketing. We discussed treatment options in detail, and the patient elected extraction of tooth #9 with immediate implant placement and immediate provisionalization. After thorough oral hygiene instructions, initial phase therapy, and re-evaluation, we proceded with the surgical phase.

Following administration of local anesthesia, we removed the excess gingiva covering tooth #9, completed gingivectomy at teeth #6 through #11, and extracted tooth #9 with minimal trauma. The patient received a ø4 x 13 mm implant at the tooth #9 position. We applied a freeze-dried bone allograft (FDBA) in the gap defect between the implant and the facial socket wall and firmly adapted additional allograft particles to the facial peri-implant mucosa using a periosteal elevator (Figure 4). A highly polished provisional implant-supported crown

Figure 2. Clinical appearance of the maxillary anterior after oral hygiene instructions and initial phase therapy.

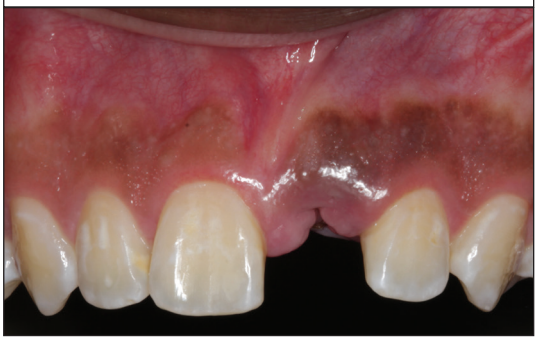


Figure 3. Baseline cone-beam computed tomography image with virtual dental implant a) sagittal view and b) coronal view.

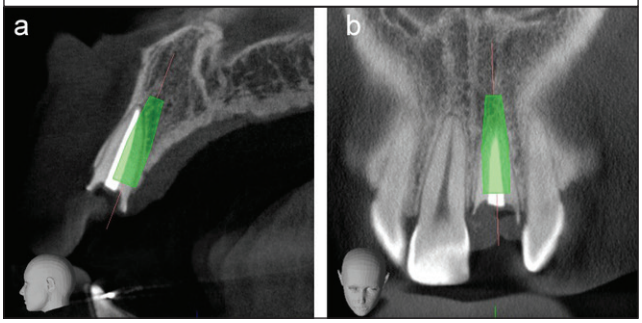


Figure 4. Freeze-dried bone allograft (FDBA) was placed between the implant and the facial socket wall, and a periosteal elevator was used to form FDBA particles against the facial peri-implant mucosa in preparation for immediate provisionalization.

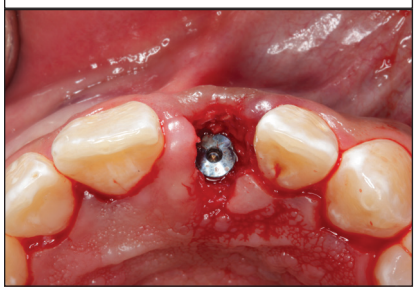


Figure 5. Provisional restoration three months following implant placement.

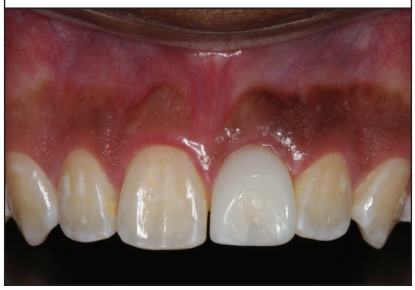
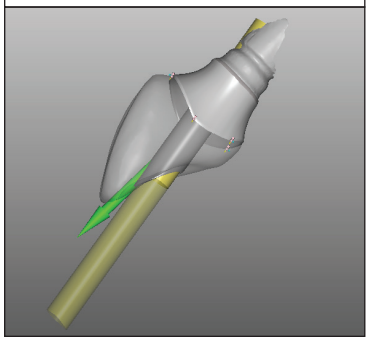


Figure 6. Virtual abutment and crown. The screw access channel deviates from the long axis of the implant (green arrow) by approximately 12 degrees. Because of this deviation, screw retention is possible without compromising esthetics or clensibility. Maximum deviation with the system utilized is 25 degrees.



sealed the socket. The screw access channel in the provisional crown, which was visible on the facial surface, received a composite resin.

The patient reported minimal postoperative discomfort limited to the day of surgery. Healing proceeded uneventfully, and we noted favorable alveolar ridge and peri-implant mucosal contours at postoperative month three (Figure 5). At every follow-up appointment, we reinforced oral hygiene instructions. A specialized abutment permitted an angled screw access channel in the definitive crown. The patient presented for final impression four months following implant placement, and we delivered the definitive screw-retained restoration postoperative month five (Figures 6 through 8).

Discussion

Previous authors have reported use of angled screw access channels in abutments and implant-supported crowns to correct angulation of "labially tilted" dental implants.[13,14] One case report focused on a specific abutment used to redirect the screw access channel in an implant-supported crown in a maxillary central incisor position.[13] A different abutment system corrected excessive implant angulation in a three-case series involving both anterior and posterior implants.[14] In the present case, we avoided cement in favor of screw retention, yet the screw access channel in the implant-supported crown remained palatal of the incisal edge. We could have achieved the same provisions using a straight screw access channel if the platform position was further palatal. However, implant platforms positioned excessively toward the palate necessitate irregular crown and abutment contours. These irregular contours may frustrate proper oral hygiene and possibly predispose the site to peri-implant disease. For the reasons described in this report, angled screw access channels may offer substantive clinical benefit in some maxillary anterior cases even when the fixture position and angulation are nearly ideal with respect to established recommendations.[6]

Conclusion

This case report expounds upon clinical advantages of angled screw access channels for maxillary anterior implant-supported restorations, demonstrates use of a specific abutment system for this purpose, and suggests a classification for palatal bone at maxillary anterior extraction sockets.

Figure 7. Definitive implant supported crown. Although the provisional crown had a screw acces channel that involved the incisal edge, the screw access channel in the final restoration was positioned toward the palate.

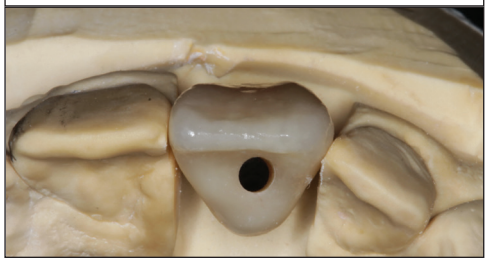
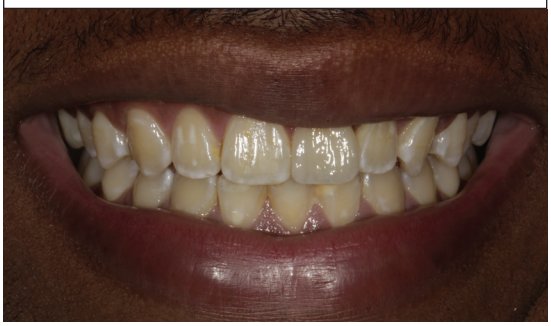


Figure 8. Final implant-supported restoration, #9 position.



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Association between the History of Traumatic Brain Injury and Rates of Dental Treatment, Endodontic Therapy, and Caries Risk: A Records-Based Study

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COL(ret) Stephanie Sidow, DDS
LTC Matthew Phillips, DMD

Abstract

Introduction: Traumatic Brain Injury (TBI) is a prevalent health issue in the US and even more prevalent amongst members of the armed forces. The purpose of this project was to evaluate the association between history of TBI and rates of dental treatment performed, endodontic therapy, and high caries risk.

Methods: This was a retrospective medical and dental records study. The first 100 of a chosen dental hygienist's patients in 2016 who were seen for dental prophylaxis appointments were chosen as subjects. Armed Forces Health Longitudinal Technology Application (AHLTA) and Corporate Dental System (CDS) records were used to gather information on these subjects including rank, age, gender, duty status, tobacco use, history of TBI, total number of dental procedures, total Dental Weighted Value (DWV), number of endodontic procedures, endodontic DWV, high caries risk categorization, total days dental fitness class 1, and total days dental fitness class 3. From these subjects, a "TBI group" and a "Non-TBI group" were formed. T-Test analyses were performed to compare these groups to each other in categories of total number of dental procedures, total DWV, total days dental fitness class 1, and total days class 3. Relative risks ratio analysis was used to compare these groups in terms of high caries risk categorization.

Results: Eight out of 100 subjects had a history of TBI. All TBI events were mild. Six subjects had 1 event, 1 had 2 events, and 1 had 4 events. The TBI group had a statistically higher mean number of dental procedures (P=0.00000025) and mean total DWV (P=0.0000062) compared to the non-TBI group. No subjects from the TBI group had an endodontic procedure. The TBI group had lower mean days in dental fitness class 1 and more mean days in dental fitness class 3, but the results were not statistically significant. The TBI group had lower high caries risk categorization rates than the non-TBI group, but the results were not statistically significant.

Conclusions: Patients with a history of TBI had a significantly higher number of dental procedures performed and DWV generated compared to patients without a history of TBI.

Introduction

TBI is a prevalent health issue in the US. In 2010, the Centers for Disease Control and Prevention (CDC) estimated that TBIs accounted for approximately 2.5 million emergency department (ED) visits, hospitalizations, and deaths in the US, either as an isolated injury or in combination with other injuries.[1] TBI was defined by a consensus panel of experts "as an alteration in brain function or other evidence of brain pathology, caused by an external force."[2] The functional consequences of TBI range from transient, reversible alterations in brain function to profound disability or death.[3]

TBI is even more common for the members of the armed forces. According to the 2013 CDC, National Institute of Health (NIH), Department of Defense (DoD), and Veteran's Affairs (VA) Leadership Panel; from 2000 through 2011, 4.2% of the 5,603,720 who served in the Army, Air Force, Navy, and Marine Corps were diagnosed with a

TBI.[3] According to a Defense and Veterans Brain Injury Center (DVBIC) analysis of surveillance data released by the DoD, TBI cases peaked at 33,149 US military personnel diagnosed in 2011 alone.[4]

Table 1. Patient demographics.

			Gender		Current Duty Status		Military Rank				
	Subjects	Mean Age (years)	% Male	% Female	% Active Duty	% National Guard	% E1-E4	% E5+	% WO	% O1-O2	% O3+
Total	100	30.17	77	23	98	2	35	51	7	4	3
Non-TBI group	92	29.43	77.2	22.8	97.8	2.2	37	47.8	7.6	4.3	3.3
TBI group	8	38.63	75	25	100	0	12.5	87.5	0	0	0

** Traumatic brain injury--TBI*

TBI may be associated with increased need for dental treatment, endodontic therapy, and caries risk for two reasons. First, TBI has been shown to be associated with maxillo-facial injuries. In studies which included all facial trauma cases, the rates of concomitant brain injury ranged from 14% to as high as 41.4%,[5,6] and these numbers are even higher when involving facial fracture.[7,8] As these two injuries are so commonly associated, clinicians should also suspect maxillo-facial injuries when a known TBI has occurred.[6] Maxillo-facial injuries may also involve damage to teeth. This damage often requires various restorative dental procedures that may lead to root canal (endodontic) therapy if the pulp of the tooth is also damaged. Second, TBI has been linked to a decline in general health, and this would likely include a patient's oral health. TBI has been associated to varying degrees with many health conditions. Two symptoms commonly associated with TBI of all severity levels are post-traumatic stress disorder and chronic headaches.[9-13] Other common TBI symptoms include dizziness, balance problems, irritability, memory problems, and, in severe cases, motor impairment including paresis, ataxia, and postural instability.[10,14]

The association between TBI and oral health remains largely unexplored. A 2017 systematic review of acquired brain injury and its association with oral health status showed that oral health had been noted as poor in acquired injury patients and that the quality of life related to oral health improved when oral hygiene interventions were provided.[15] This systematic review did not mention TBI specifically, but it stated that research in this area had largely been related to stroke.

The purpose of this study was to evaluate the association between a history of traumatic brain injury and rates of dental treatment performed, endodontic therapy, and high caries risk utilizing data regarding DWV, caries risk, procedure totals, and the days in specific dental fitness categories. DWV is a numerical value given to all dental procedures which is meant to correlate with the estimated cost if performed in a civilian dental office. Class 1 dental fitness category patients are those with a current dental examination who do not require dental treatment or reevaluation. Class 3 dental fitness category patients require urgent or emergent dental treatment.[16] According to the US Army Health Readiness Center of Excellence, based on 5-year averages from 2013-2017, class 3 patients are 8 times more likely to experience a dental emergency than class 1.[17] Caries risk categorization is a tool that determines a patient's caries risk based on numerous factors, including hygiene, diet, and dental history.[18]

Table 2. Patient tobacco use.

	Tobacco Use	Of Those Who Use Tobacco, % Who Use:					
	%Yes	Less Than ½ Pack/Day	½ Pack/Day	Less Than 1 Pack/Day	1 Pack/Day	More Than 1 Pack/Day	Smokeless
Total	23	69.6	17.4	4.3	4.3	0	4.3
Non-TBI group	20.7	68.4	21	5.3	0	0	5.3
TBI group	50	75	0	0	25	0	0

** Traumatic brain injury--TBI*

Materials & Methods

SUBJECT SELECTION: This was a retrospective medical and dental records study approved by the Dwight D. Eisenhower Army Medical Center Institutional Review Board. Subjects were selected using the systematic sampling approach known as the "100 Consecutive" method. To minimize bias, a hygienist was chosen because he or she would typically treat most patients at regular intervals regardless of number and types of other dental procedures performed. In this case, a dental hygienist was chosen who had worked at an Army dental treatment facility at Fort Gordon, GA for many years. The first 100 of her patients presenting for dental prophylaxis appointments who met inclusion criteria beginning January 1st, 2016 were chosen as subjects. Subjects were excluded if

1) Medical/dental records for years 2016-2017 were incomplete (retirement, recent enlistment, etc.);

2) History of polytrauma, defined as an objective and subjective categorization based on AHLTA codes and/or treatment notes that indicated an injury to the upper extremity that may physically limit oral hygiene.

DATA GATHERING: AHLTA and CDS were utilized to gather data on selected subjects in the areas of demographic information, military data, and basic health data. Specifically, for each subject, data was gathered in the following categories: last name, first name, last 4 numbers of social security number, rank, age, gender,

and duty status. Data regarding patient tobacco use was gathered from AHLTA.

AHLTA was utilized to gather data on selected subjects in the areas of traumatic brain injury and polytrauma. Specifically, for each subject, data was gathered in the following categories: history of polytrauma, history of traumatic brain injury, number of occurrences, and most recent TBI, all categorized by severity. Specifically the following AHLTA codes related to TBI were searched:

- z87.820: Personal history of TBI;
- DOD0101: Personal history of TBI, highest level of severity unknown;
- DOD0102: Personal history of TBI, highest level of severity mild;
- DOD0103: Personal history of TBI, highest level of severity moderate;
- DOD0104: Personal history of TBI, highest level of severity severe;
- S06.0x0: Concussion without loss of consciousness;
- S06.0x0a: Concussion without loss of consciousness, initial encounter;
- S06.0x1: Concussion with loss of consciousness of 30 minutes or less;
- S06.0x9: Concussion with loss of consciousness of unspecified duration;
- S06.0x09a: Concussion with loss of consciousness, initial encounter.

CDS was utilized to gather data on selected subjects in various dental categories. Specifically, for each subject, data was gathered in the following categories: history of maxillofacial surgery, number of endodontic procedures, DWV from endodontic procedures, total number of dental procedures, DWV from all dental procedures, high caries risk categorization, total days in dental classification category 3, and total days in dental classification category 1.

CDS codes were searched to gather data relating to the patient's history of maxillofacial surgery. A search for D7000-D7999 series codes was performed. Based on the specific codes and associated written notes, the research team determined if the patient had a history of maxillo-facial surgery from trauma within 3 months before or after TBI diagnosis. CDS was also utilized to gather data regarding the total quantity and DWV of endodontic procedures. A search for D3000-D3999 codes was performed. All codes in this series were included.

Table 3. Non-TBI group vs TBI group: total dental procedures/total DWV (2016-2017).

	Non-TBI	TBI
Mean Total Procedures	23.65	58.38
Mean DWV	25.97	80.61

** Traumatic brain injury--TBI; Dental weighted value--DWV*

Results

From the first 159 patients seen for dental prophylaxis appointments by the chosen dental hygienist starting January 1st, 2016, 100 subjects met the inclusion criteria. The other 59 patients were excluded due to having incomplete medical and/or dental records for the calendar years 2016 and 2017. No patients were excluded due to history of polytrauma. Among included subjects, 8/100 (8%) had a history of at least one TBI event prior to 2016. All TBI events were categorized as mild, and 6/8 of those subjects showed just one TBI event. One subject had a history of 2 TBI events, and one subject had a history of 4 TBI events. None of the 8 TBI subjects had a history of maxillofacial surgery within 3 months before or after TBI diagnosis.

PATIENT DEMOGRAPHIC & BASIC HEALTH: T-test analysis showed that the TBI group had a significantly higher mean age than the Non-TBI group (P=0.00041) (Table 1). T-test analysis showed that while the TBI group showed a higher percentage of tobacco users than the Non-TBI group, these results were not significant (P=0.059) (Table 2).

TBI & DENTAL HISTORY: T-test analysis showed that the TBI group had statistically higher mean number of dental procedures (P=0.00000025) (Table 3) (Figure 1) and mean total DWV (P=0.0000062) (Table 3) (Figure 2) compared to the non-TBI group. The mean number of endodontic procedures for the non-TBI group was 0.21, and mean DWV was 1.25. No endodontic procedures or endodontic DWV were found in the TBI group. a. Non-TBI group: 24/92 (26.1%) categorized as

Figure 1. Mean total procedures.

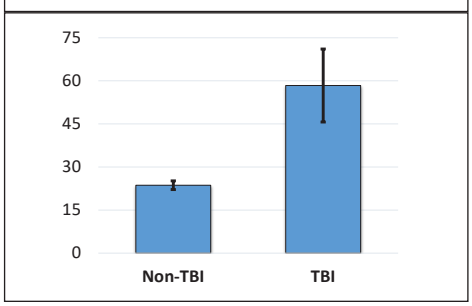
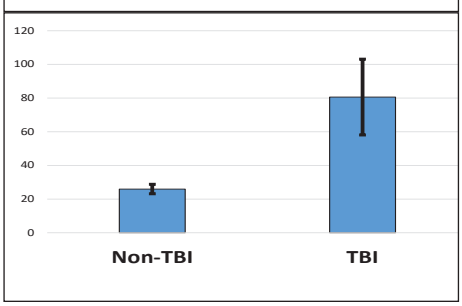


Figure 2. Mean dental weighted value.



high caries risk; b. TBI group: 1/8 (12.5%) categorized as high caries risk. Relative risks ratio statistical analysis performed, and this analysis showed the relative risk to be 0.48, which was not statistically significant (P: 0.44). The TBI group showed less mean days classification 1 and more mean days classification 3, but T-test analysis showed that neither of these were statistically significant (days class 1 P: 0.24, days class 3 P: 0.73) (Table 4) (Figure 3 & Figure 4).

Table 4. Non-TBI group vs TBI group: Mean Days Dental Class 1/ Mean Days Dental Class 3.

	Non-TBI	TBI
Mean Days Dental Class 1	407.3	293.4
Mean Days Dental Class 3	20.7	28.75

** Traumatic brain injury--TBI*

Discussion

The goal of this research was to explore the possible association between history of TBI and overall oral health as quantified by various dental record markers. A positive association was shown between history of TBI and the mean number of dental procedures and DWV. No other categories demonstrated such an association.

This research was limited in several ways. First, the number of subjects was only 100, and because of this, the TBI group amounted to only 8 subjects. As mentioned earlier, from 2000 through 2011, 4.2% of service members were diagnosed with a TBI. The 8% result we observed in our population is likely this high because of the TBI clinic located at Fort Gordon, GA. Nonetheless, only having 8 subjects in the TBI group resulted in limited power. Second, confounding factors exist which cannot be ignored. For example, the TBI group was significantly older and had higher tobacco use rates than the non-TBI group. It is not only possible, but likely that these factors also influenced their oral health.

This was one of the first times that research looked into the association between the history of TBI and oral health. In one study, TBI patients who were given oral hygiene instruction after TBI had better plaque scores than TBI patients with no oral hygiene instruction.[19] This seems likely to be true of any two groups, regardless of TBI diagnosis. In 2012, the University of Washington Dental Education in the Care of Persons with Disabilities (DECOD) Program released an Oral Health Fact Sheet for Dental Professionals about Traumatic Brain Injury.[20] This fact sheet described the possible oral manifestations of TBI as the following:

a. Oral/dental trauma from TBI or self-injurious behaviors;

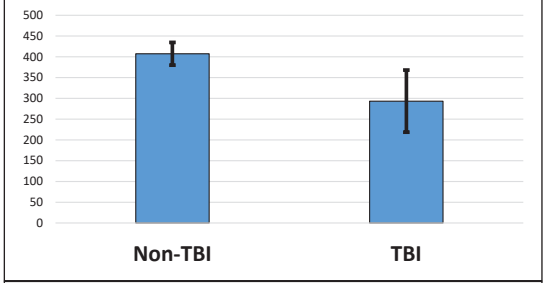
b. Bruxism;

c. GERD (Gastro-Esophageal Reflux Disease) in intubated patients;

d. Inadequate oral hygiene due to cognitive impairments, spasticity, and ataxia.

Research on service members represented a unique opportunity for evaluating associations between TBI and oral health because the population has a higher-than-average TBI population, and their oral health is routinely monitored, addressed, and recorded. Our findings showed that the dental needs of the TBI population were different and greater than the Non-TBI population and would therefore benefit from being treated differently clinically. Routinely, service members are seen annually for dental exams and cleanings. We recommend patients with a history of TBI receive a dental exam and cleaning every 6 months. While on the surface more costly, this will proactively monitor for dental conditions which could have potentially greater long-term costs in terms of the DWV and number of procedures. This preventive measure could dramatically improve service members' oral health and quality of life and may also improve dental readiness. It is our hope that future research further explores the potential association between history of TBI and oral health and what it may mean, not only for service members, but also anyone who has suffered a TBI event.

Figure 3. Mean Days Dental Class 1.



** Traumatic brain injury--TBI*

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Prosthodontic and Endodontic Considerations for Treatment of Military Working Dogs

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Abstract

Military Working Dogs (MWD) are highly trained in substance detection and various phases of controlled aggression to protect military assets and personnel. Dental health is essential to maintain their performance and mission readiness. MWD's dentition is often fractured or worn due to the physically demanding nature of their job. When non-surgical endodontic therapy or full coverage crowns are deemed necessary, good communication between veterinary and dental teams is necessary to provide quality and timely treatment. These two case reports describe important prosthodontic and endodontic procedural steps and treatment considerations for providing care to MWDs.

Keywords: prosthodontics; endodontics; veterinary dentistry; root canal; military working dog

Introduction

Military working dogs (MWD) are highly trained in substance detection and various phases of controlled aggression to protect military assets and personnel. Dental health is essential to maintain their performance and mission readiness. Untreated dental disease, such as periodontal disease, endodontic lesions, or active infections can lead to tooth loss and systemic illnesses. Severe dental disease or tooth structure loss that affects a MWD's ability to function or perform critical tasks can lead to early retirement from active service.[1]

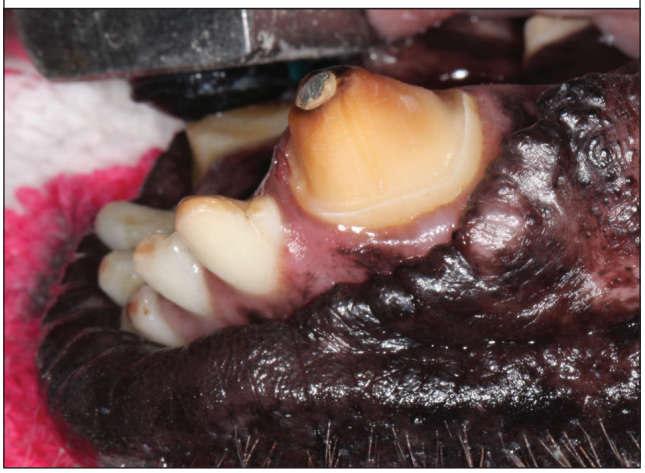
Due to the physical demands of their job, MWDs often suffer from moderate to severe tooth wear or fractures exposing the pulp. Bacteria can enter through this opening causing pain, periapical abscess, and lead to more severe systemic infections. Canines are the most frequently fractured teeth, and every effort is made to save them as their long roots make extraction difficult.[1] Dentists and veterinarians must maintain a good working relationship in order to provide quality and timely treatment for MWDs. Advanced veterinary dental support is often provided by local dental health activities, with sedation/general anesthesia, local anesthetic blocks, and monitoring provided by Veterinary Corps Officers.[2] These two case reports describe prosthodontic and endodontic considerations for treating MWDs.

Case #1: Prosthodontic Considerations

A 6 year old German Shepherd and certified patrol MWD from the 8th Security Forces Squadron at Kunsan Air Base, Republic of Korea (ROK), presented to the US Army Garrison (USAG) Humphreys Veterinary Treatment Facility (VTF) for routine dental examination. Upon intra-oral examination and using the modified Triadan veterinary tooth numbering system, patient had existing non-surgical root canal treatment on #103: maxillary right third incisor, #104: maxillary right canine, #204: maxillary left canine, #304: mandibular left canine, and #404: mandibular right canine.[3] All five teeth had moderate to severe tooth structure loss, secondary to abrasion and attrition, with dentine exposure greater than a third of the tooth surface. Veterinary team contacted dental providers at USAG Humphreys to further evaluate for full coverage indirect restorations. Together, both teams determined it would be beneficial to proceed with full coverage crowns on all five teeth to prevent further tooth structure loss and catastrophic fracture. Indirect dental restorations are generally not indicated in MWDs unless there is severe dental attrition or fracture, as tooth preparations can further weaken the underlying tooth structure.[4] When full coverage restorations are indicated, they should be made with low profile to prevent a fulcrum effect that may lead to fracture of the remaining tooth structure and subsequent

need for extraction.[4] The goal of indirect restorations for MWDs is not necessarily to restore its original anatomy, but to prevent further tooth structure loss or fracture that can limit duty performance.

Figure 1. Tooth preparation with resistance features.

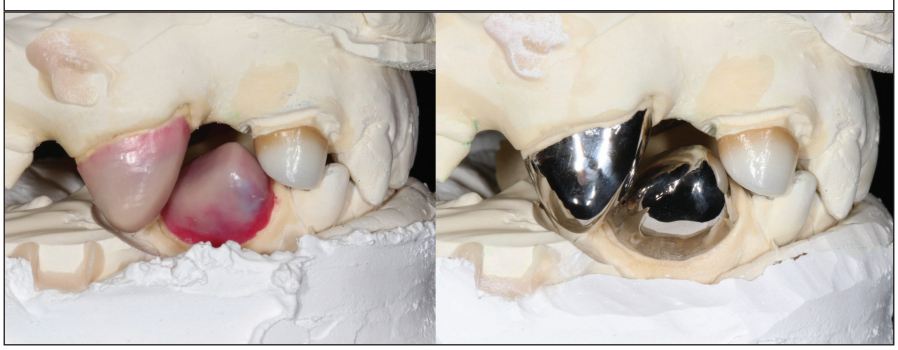


Procedures were completed in two appointments under general anesthesia. The treatment team consisted of the MWD's handler, veterinarian, prosthodontist, animal care specialist, and a dental assistant. An air-driven, high speed hand piece on a portable dental unit was used to prepare teeth for full coverage restorations. Retention of complete crowns on human teeth relies on teeth preparations with ideal total occlusal convergence, occlusal-cervical dimension, finish line, and auxiliary features.[5] In addition, dog teeth have a very thin layer of enamel, and its canines are more tapered on the mesial-distal walls. Every effort was made to preserve supragingival enamel margins, and minimize taper in the cervical half in order to maximize retention and resistance forms. Adding auxiliary grooves to the preparations improved resistance form as well (Figure 1).[6,7] Maxillary and mandibular master impressions were made using regular set light-bodied polyvinylsiloxane (PVS) on teeth preparations, and regular set medium-bodied monophase PVS loaded in large plastic stock trays. Tray borders were modified and extended as needed using red utility wax. Jaw relation record was made using superfast set PVS bite registration material. Providers only have a short amount of time to hand manipulate maxillary and mandibular jaws in occlusion after removal of the intubation tube.

Impressions were transported to Carius Dental Clinic Laboratory, and working casts and dies were poured in Type IV die stone. Casts were articulated on a simple hinge articulator since a dog's main jaw movement is in the vertical direction.[8] All metal restorations were fabricated through traditional wax up, and casted using Type IV gold alloy, while the maxillary incisor was made using computer aided design (CAD) and milled in high strength zirconia (Figure 2). Gold restorations were polished to a high shine. The zirconia restoration was subsequently sintered, polished, stained, and glazed. Intaglio surfaces were particle abraded with 50-microns aluminum oxide to enhance micromechanical retention. Type IV gold alloy was chosen in this case for its adequate hardness, tensile strength, and availability. Titanium alloy and cobalt-chromium are other crown materials with higher strengths used in veterinary dentistry, as they can be more durable against harder chewing surfaces such as metal cages.[9] Zirconia was chosen for its high flexural strength, and its ability to bond to resin cement with primers containing phosphoric acid ester monomers such as 10-methacryloyloxydecyl dihydrogen phosphate (10-MDP) to help improve retention on shorter tooth preparations.

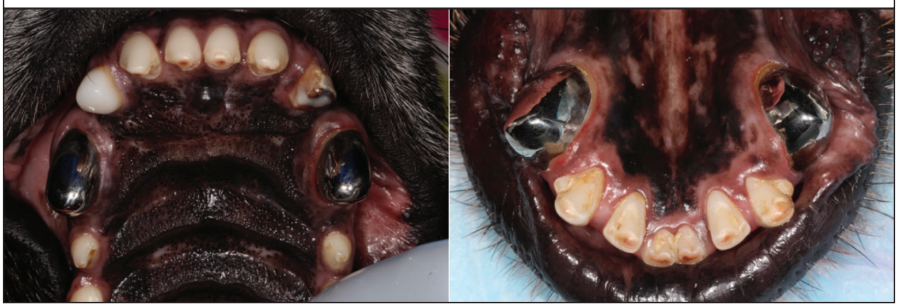
At the delivery appointment, indirect restorations were tried for an evaluation fit and marginal seal. Intaglio surfaces of restorations were cleaned with universal cleaning paste, rinsed, air dried, and scrubbed with universal primer, then set aside for solvent evaporation in preparation for bonding. The universal primer used in this case contains methacrylate phosphoric acid ester, which forms strong covalent bonds to metal/zirconia oxides, and disulfide methacrylate that can bond to gold (Au).[10,11] A 4x4 gauze was used to isolate the bonding area. Since the patient was intubated with no salivary flow, rubber dam isolation for bonding was deemed unnecessary. Tooth preparations were cleaned with flour of pumice. Enamel margins were etched using 37% phosphoric acid, rinsed, and dried with oil

Figure 2. Teeth waxed then cast into gold crowns.



free air. Sixth generation two-step, self-etch adhesive was applied on preparations according to manufacturer's instructions. Dual cure resin cement was used to bond final crowns in place, consistent with veterinary dental literature to enhance retention and longevity of restorations (Figure 3).[12,13] Dentin bonding using the 6th generation adhesive has been shown to be very effective clinically.[14] Immediate dentin sealing at the time of preparation is another method that can improve bond strength; although, there is no feasible method to provisionalize teeth in MWDs.[15] It is important to note that it was not possible to verify occlusion until after the intubation tube was removed. No adjustment was necessary for this case. In addition to dental care, surgical treatment to remove cystic pyogranulomatous tissue was done simultaneously at both appointments by veterinarians. A few weeks following this procedure, it was reported the patient was functioning well and had returned to full duty.

Figure 3. Final gold and zirconia crowns post-cementation.



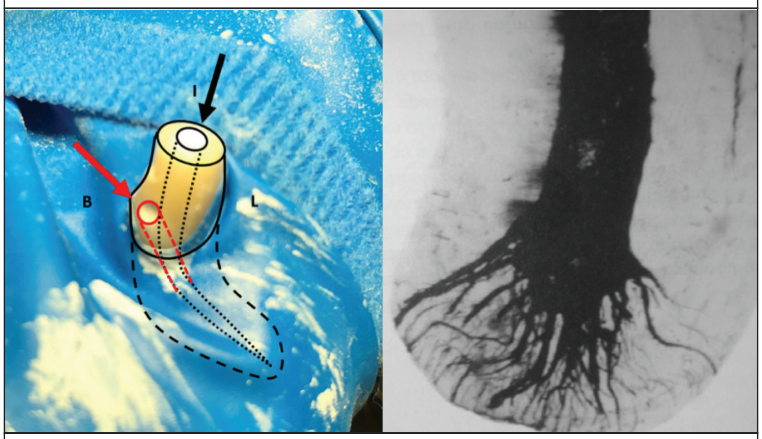
Case #2: Endodontic Considerations

A MWD from Camp Humphreys, Republic of Korea, had a fractured tooth, #104—maxillary right canine, identified during routine dental prophylaxis (Figure 4), which is how most dental issues are identified. According to the *Handbook of Veterinary Care and Management of the MWD*, "Dental fractures are frequently noted in military working dogs. Due to their large size and rostral positioning, the canine teeth are the most frequently affected. Common causes of fracture include aggression training, kennel vices (pan or fence chewing), and overzealous reward retrieval."[4] It was not clear how this MWD fractured the tooth. The MWD did not exhibit signs of pain such as bite avoidance or reluctance to eat, but there was visible heme from the maxillary right canine.

Figure 4.Military working dog presentation prior to non-surgical root canal therapy; local anesthetic block.

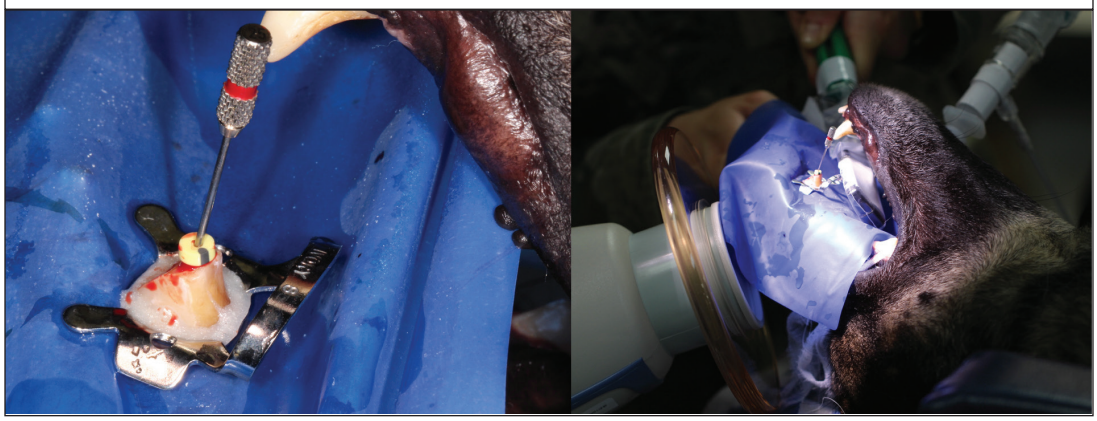
Due to the level of fracture, the root canal treatment could be completed at the level of the canal orifice. On a longer canine tooth, which may be up to 65mm,[16] it may be necessary to create an additional access opening at the buccal cervical surface (Figure 5A), to achieve a more straight-line access to the apex and debride the length of this long, curved canal space. Isolation of the canine was established by etching and placing flowable composite on the buccal and palatal of the tooth to create a "resin shelf" to restrict incisal movement of the clamp due to the tooth's conical shape. After the rubber dam placement, a light

Figure 5.(Left) Example of a buccal-cervical access. (Right) Multiple apical foramina of dog canine. .



* B: buccal; I: incisal; L: lingual

Figure 6. Working length file placement and radiograph.

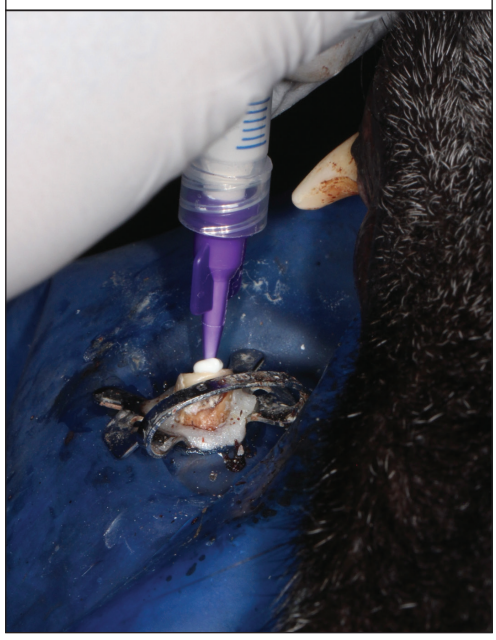


cured gingival barrier was delivered around the tooth to seal any openings.

Working length was determined by placing a size 15, 60mm Hedstrom File into the canal until apical advancement ceased. Electronic apex locators were not used due to the apical anatomy of canine dentition. The apex of a dog tooth consists of multiple apical ramifications; the main canal branches into many smaller canals impeding the advancement of a file out of the apex (Figure 5B).[17] With the Hedstrom file in place, an animal care specialist took a radiograph using the handheld x-ray system with sensor attached to a laptop, similar to equipment found in dental field units (Figure 6).

After working length determination, debridement of the pulp tissue continued with sequentially larger Hedstrom files, and 6% sodium hypochlorite irrigation. Reciprocating files created for canine root canal were not available at this time, but may be useful to decrease preparation time and permit debridement of the entire canal from a single point of entry. In this situation, veterinarian dental resources were limited. Typically, Gutta Percha (GP) is used in human root canal obturation; whereas, in dogs the canals are generally obturated with a mix of thin zinc oxide-eugenol cement, intermediate restorative material delivered through an angiocatheter. In this case, the canal was dried with paper points and obturated with a bioceramic sealer used in combination with GP (Figure 7). Bioceramic sealer was selected in this case due to its fluid nature, biocompatibility, and availability. Treatment continued with preparation for a full coverage restoration due to the severity of tooth fracture. Although a crown was delivered in this case, closure of the access with an amalgam is often the only restoration needed to complete dental treatment following root canal therapy.

Figure 7. Bioceramic sealer placement.



Conclusion

Many key prosthodontic and endodontic principles that ensure success on human teeth also apply to veterinary dentistry. These two case reports described dental treatment sequences and materials used to prolong the service of MWDs. It also highlighted some similarities and differences in dental treatment protocols for humans and canines. It is essential to maintain good collaborative relationships between dental and veterinary services, and understand each other's capabilities to provide timely treatment, enhance force health protection, and maintain MWD mission readiness.

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Development of Military Teledentistry

MAJ Brian Kirkwood, DDS MS

Abstract

Introduction: Virtual health technologies came to the forefront during the COVID-19 Pandemic out of necessity to continue patient care and reduce risk of transmission. The US military began to explore the use of teledentistry in the mid-90s with the technology available at the time. The dental profession is slow at adopting the use of virtual health technologies as a capability to triage, screen, and monitor. Dentist to dentist consults routinely occur in both a civilian and military dental practice via email and phone consults. The idea of teledentistry for the future battlefield requires using existing technology such as advanced digital imaging, cloud technology, and video conferencing to shift towards a real-time virtual encounter. Real-time encounters create opportunities to evaluate a patient at a remote location when a dentist is not physically present. Advance development of virtual health technologies to include teledentistry expands the potential utilization of tele-triage, tele-screening, tele-consult, and tele-monitoring. These capabilities will be useful on the future battlefield during multi-domain operations as part of the Operational Virtual Health (OVH) capability. The application of OVH enables military forces to minimize morbidity and mortality on the battlefield to include prevention of unnecessary medical evacuation.

Methods: Comprehensive literature search was conducted in PubMed for published teledentistry research using military-related and battlefield use of teledentistry keywords.

Results: Two articles were identified that satisfied all inclusion and exclusion criteria.

Conclusion: A review of relevant literature demonstrated a severe paucity of primary sources, highlighting an underdeveloped component of the virtual health capability required to expand access of dental services throughout the military operating environment.

Introduction

When news surfaced near the end of 2019 of a novel virus spreading throughout Wuhan, China, the global impact was still unknown. The novel coronavirus, SARS-CoV-2, became known as COVID-19 and resulted in a pandemic which affected countless lives and seized the global economy.[1] The effect of the pandemic demonstrated the significant need of telehealth technologies.[2] Telehealth is an emerging technology in the healthcare industry that involves a synchronous or asynchronous virtual interaction with a healthcare professional between a distant and originating site. Telehealth encompasses many disciplines throughout the spectrum of healthcare, notably neurology consults for stroke and traumatic brain injury, but also palliative care, dermatology, and psychiatry.[3-7] Multiple definitions and terminology exist that describe the use of technology to provide a link between patient and a healthcare provider, or between multiple healthcare providers across some distance or time.[8] The component of telehealth dedicated to dental-related services is teledentistry. A clear definition for teledentistry in context to military operations has yet to be established. For the purpose of this article, military teledentistry will be defined as utilization of available technologies to advance dental services to operating environments with limited resources enabling remote patient management across the spectrum of multi-domain operations.

When the World Health Organization declared the COVID-19 pandemic on 11 March 2020,[9] many uncertainties arose to include the realization that reliance on the existing healthcare network has inherent vulnerabilities.[10] During a national emergency, a team may be assembled by local, state, and federal governments consisting of members of the civilian sector, the National Guard, and federal agencies. When called upon the Department of Defense (DoD) can act as part of Defense in Support of Civil Authorities (DSCA).[11,12] Operational Virtual Health (OVH) augments deployed military medical assets to minimize the requirement for medical evacuation while reducing morbidity and mortality across all

echelons of care.[13] In addition to improving combat casualty care, there exists a great potential to deploy these technologies during a national emergency and increase access to healthcare as part of DSCA operations. The pandemic almost immediately shut down dental clinics worldwide due to the mechanism of transmission of COVID-19 via aerosolized particles.[1] The immediate halt in dental treatment left patients limited to emergency care only, placed healthcare providers at an increased risk, and highlighted the need to explore technologies that could improve access to care.[1]

During the early stages of the pandemic, telemedicine became widely used throughout the military health system (MHS) and the civilian healthcare networks due to pre-established telehealth capabilities. The profession of dentistry on the other hand was caught off guard. In 2015, the American Dental Association recognized the need for teledentistry; however, minimal progress occurred within the profession of dentistry in terms of legislation, incorporation into dental practices, and dental practice guidelines.[14,15] There are a few teledentistry companies operating on a limited network utilizing intraoral cameras, cellphone cameras, and video conferencing. The US Army is cited by many teledentistry articles as the first to develop teledentistry more than 20 years ago with the Tri-Service teledentistry project called Total Dental Access.[8,16,17] Even though these efforts occurred in the mid-90s, no formal teledentistry program exists within MHS. Teledentistry in the MHS has the potential to leverage existing technologies used for telemedicine encounters.

The MHS provides healthcare to include dentistry across many domains, at military instillations and as part of combat operations around the globe. OVH is the deployable component of the military's telehealth capability. A Tele-health-in-a-bag (THIAB) includes equipment specifically designed for military operations.[18] The equipment utilizes the DoD's cyber-networks to expand access to care and support the healthcare needs of the warfighter in austere environments. Telehealth technologies enable tele-triage, tele-screening, telemonitoring, tele-consultation, and a limited capability to tele-diagnose. Dental professionals can consider teledentistry as a technological tool to manage patient care. Teledentistry is not meant to replace a dental home; however, it provides another avenue to manage a patient when limitations exist that prevent face-to-face encounters. Teledentistry and telehealth utilize similar terminology. When a virtual encounter is initiated it is either an asynchronous (store and forward) or synchronous (live-stream) encounter.[14] The originating site is the site that typically initiates the virtual encounter where the remote site is the location where the consulting healthcare provider is located. Development of the teledentistry component within the MHS will expand the capabilities of OVH, provide a training platform within Defense Health Agency (DHA) facilities for military dentists to gain experience in conducting virtual dental encounters, and serve as a potential resource during DSCA operations.

The military operating environment can rapidly change, become hostile, experience extreme environmental conditions, and be isolated with limited access. Multiple components of this unique military operating environment can parallel those in the civilian sector such as environmental conditions or isolated with limited access. During a national emergency, the civilian sector operating environment can change rapidly whether it is a result of a national disaster or due to a pandemic. To date, there are no literature reviews focused specifically on the development of teledentistry as part of a military operating environment. The purpose of this review is to determine if there is adequate research related to the use of teledentistry within the military or during military-type operations that will aid in the development of teledentistry as part of the OVH capability.

Methods

LITERATURE SEARCH: The primary search of published literature in PubMed identified any article that contained the keywords teledentistry, tele-dentistry, teledental, tele-dental, tele + dentistry, or dental and virtual + dentistry, or dental within the entire reference. The primary search was performed 31 August 2020 with the references stored in a searchable database for further analysis. Duplicate articles were removed prior to screening the articles. The articles identified through the primary search where then queried for any articles that contained keywords relating to a potential battlefield use, triage, consultation, consult, consulting, screen, screening, monitor, monitoring, diagnose, or diagnosis The screened articles were queried for eligible articles containing military-related key words: military, Department of Defense, Army, Air Force, Navy, Marines, soldier, airman, sailor, or marine. Eligible articles' full content were read to determine if the article satisfied inclusion and exclusion criteria for quantitative analysis. Online searches were also carried out in search of additional articles (grey literature) that would be eligible but were not identified through the PubMed database.

ELIGIBILITY CRITERIA: There were no restrictions on the publication dates, given they were published prior to the primary PubMed search. Included articles must contain one of the keywords within the reference and

be related to military use. Articles were excluded if they were non-original publications (reviews, editorial, letters, comments and books chapters), the article was in a language other than English, the article did not describe research methodology, and the focus of the article is not on the use of technology to evaluate, treat, educate, or gain access to care from a distant site for dental-related services.

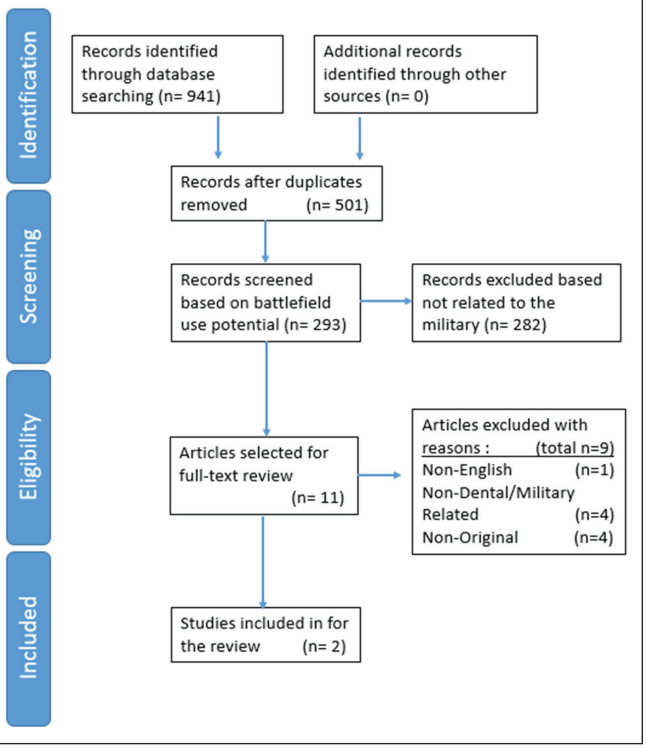
Results

The primary search resulted in 941 published articles identified within the PubMed database with no additional articles identified through grey literature searches. Once duplicates were removed from the primary identification database search results left 501 identified articles. The identified articles pertaining to teledentistry were screened for articles that may be beneficial for battlefield use. This resulted in 293 potential articles with 117 of the articles containing keywords directly relating to the topic of teledentistry; however, 282 of the articles were excluded as they did not contain military-related keywords (Figure 1). Eleven articles were considered eligible for a full text review as each article contained both primary and secondary search keywords. The full text evaluation is to determine if the publication satisfies the inclusion and exclusion criteria. Full text review resulted in two articles meeting all the criteria (Table 1). The two articles that met all the criteria were published over 20 years ago, both articles describes teledentistry projects within the US military. Less than 0.5% of the articles published in PubMed that mention some form of teledentistry within the article directly addresses the use of teledentistry by the military.

Discussion

A defining aspect of this review is the scope resulted in only two articles in the past 25 years, both from the late 1990's, that met all inclusion and exclusion criteria. At first glance, the review may be considered too narrow in focus and, therefore, excludes multiple relevant published literature. The original intent was to highlight original studies focused on the use of teledentistry in the military. The realization teledentistry is primarily an informal tool within the MHS for over 20 years is evident by the lack of formal processes addressing teledentistry encounters. Attempts were made to formalize the use of a dental email consultation system for deployed army dentists around 2008,[19] but the widespread use was not nearly as successful as army medical email consultation system. The most likely reason is the overall smaller size of military dentistry versus military medicine. At the beginning of the pandemic,

Figure 1. Flow diagram depicting the process to identify, screen, and determine the published articles included in the study.



The Defense Health Agency issued teledentistry guidance and included the use of Common Dental Terminology (CDT) procedure codes, D9995 (teledentistry—synchronous; real-time encounter) and D9996 (teledentistry—asynchronous; information stored and forwarded). The scope of practice related to teledentistry is loosely defined with no military-related, evidence-based research that supports development of the dental component of OVH. The reliance on studies conducted outside of the military operating environment will be the basis for providing the foundational knowledge in the development of the teledentistry within the MHS. An evidence-based practice of teledentistry will require the use of existing studies related to all arms of telehealth. Operational telemedicine within the military along with supporting studies date back 15 years, when the US military implemented an electronic mail telemedicine system.[20]

The two articles that meet all criteria to be included in this review were conducted prior to several technological advancements, to include the existence of smartphones, advanced digital imaging, cloud technology, and video conferencing. The Total Dental Access (TDA) project within the DoD focused on patient care, continuing education, and dentist-laboratory communications. The primary conclusion of the TDA project highlights a return on investment within one year of

Table 1. Published articles eligible for full content review to evaluate which will be included in the study.

Article	Included/Excluded	Justification
Baur et al. 1998.[21]	Included	All Criteria Met
Boukhris et al. 2020.[30]	Excluded	Non-Original / Non-Dental (COVID-19)
Chang et al. 2003.[31]	Excluded	Non-Original (Teledentistry)
Chigurupati et al. 2020.[10]	Excluded	Non-Original (Teledentistry)
Duka et al. 2009.[32]	Excluded	Non-English (Military Teledentistry)
Gomez et al. 1996.[33]	Excluded	Non-Dental (Military-Related)
Maddry et al. 2014.[20]	Excluded	Non-Dental (Military)
Marimoutou et al. 2017.[34]	Excluded	Non-Dental (Military-Related)
Person et al. 2003.[35]	Excluded	Non-Dental (Military-Related)
Rocca et al. 1999.[17]	Included	All Criteria Met
Vandre et al. 1999.[36]	Excluded	Non-Original (Military Teledentistry)

deployment of the technology available at the time.[17] This article paved the way for initial uses of teledentistry. Currently in military dental clinics, there is improved dentist-laboratory communications through an online portal as part of the Tri-Service Corporate Dental Systems (CDS) web-based application. Military dentists are offered opportunities to complete continuing education virtually on various digital platforms. In regards to patient care, dentist-to-dentists tele-mentoring and tele-consultation as an asynchronous encounter do occur as an informal process and is unit dependent. The TDA project was successful at advancing military dentistry into the 21st century. A new effort similar to the TDA project is needed to advance virtual health technology relevant to military dentistry to a level that will be necessary during multi-domain operations.

Following the TDA project, army dental and medical research units went one step further with a clinical study that utilized telemedicine technology to project dental expertise worldwide for orthognathic examination. The study demonstrated with the aid of technology a relatively accurate orthognathic examination can be performed remotely.[21] As pointed out earlier, this study was performed prior to major technological leaps. The article highlighted clinicians have to be confident in technology for widespread implementation to be successful. The authors pointed out telemedicine is not meant to replace a comprehensive examination; rather it is a tool to aid in case management. Since these points still hold true more than two decades later, they are relevant justifications to revitalize and expand virtual health technology research. A requirement for successful implementation of teledentistry is the availability of supporting clinical research. US military operations in the 1980's to the late 1990's were based on the Airland Battle Doctrine, which focused on a large scale conventional war. Large-scale military operations will result in an increased amount of casualties where the aid of advance health technologies will be beneficial. The efforts by the DoD in the 1990's to develop telemedicine and associated technologies were based on large-scale combat operations. Since the early 2000's, medical research and capability gaps revolved around military doctrine focused on counter-insurgency operations where there was the benefit of air superiority enabling ease of air evacuation. The shift in military operating doctrine towards multi-domain operations revisits concepts from the Airland Battle Doctrine that include large-scale military operations. The resulting change in the landscape of the future battlefield creates a challenge that development of virtual health technologies, to include teledentistry, can overcome capability gaps to optimize combat casualty care.

Defining and establishing a scope of practice for the use of teledentistry is important to gain support by dental professionals to incorporate such technologies into current clinical practice. Military dentistry requires all military personnel to be examined in-person by a credentialed dentist at least annually to determine the service member's Dental Readiness Classification (DRC).[22-24] DRC is influenced by many aspects of dental services throughout the military. The DRC communicates to unit commanders a service member's operational readiness from a dental perspective. The lack of evidence-based literature to support the use of teledentistry technologies as a tool in assessing DRC during tele-triage, tele-screening, and tele-monitoring patient encounters can potentially limit the military application of teledentistry. Military-focused teledentistry research could help promote widespread use of teledentistry across the entire spectrum of the military operating environment. Research conducted by academic or by other non-military research institutions related to teledentistry are highly unlikely to consider the impact teledentistry will have on the military unique metric, DRC. The guiding regulations that establish clinical practice guidelines within military dentistry are supported by peer-reviewed publications. For military dentistry to adapt with the future operating environment, teledentistry research related to the

unique requirements of the military need to be addressed. Multiple opportunities exist throughout the MHS to study avenues teledentistry can improve or expand existing clinical processes. The various military post-graduate dental residency programs can be leveraged to conduct multiple small scale studies to build upon providing foundational research to develop the military's teledentistry capability.

Recent teledentistry research demonstrates the COVID-19 pandemic altered dental professionals' opinions on the use of teledentistry and its future potential.[25] There are an increasing number of publications discussing the use of tele-consultation across a broad spectrum of dental specialties, to include periodontics, oral surgery, orthodontics, and oral pathology.[1,26-28] Direct-to-consumer use of teledentistry is expanding around the world out of necessity due to the pandemic for tele-triage and to tele-monitor patients following urgent procedures.[1] Studies related to tele-triage, teleconsulting, and tele-monitoring are beneficial to develop teledentistry capabilities within the MHS. In addition, other important factors to note are patients report positive experiences using teledentistry,[29] and early teledentistry training for dentists positively increases its utilization.[15]

Incorporating teledentistry as another tool will need to overcome some challenges, to include establishing the scope of practice for a virtual encounter so military dentists can confidently report or assess DRC following a tele-triage encounter or a tele-monitoring encounter. If research is not directed to overcome this challenge then military dentistry will not be adequately positioned for the future battlefield during multi-domain operations. The direct-to-consumer concept, as it relates to the military operating environment, is the ability to advance teledentistry capability to Role 1 echelon of care, commonly known as battalion aid stations. The use of teledentistry in this way will have an operational impact on the battlefield by reducing unnecessary casualty evacuations and advancing dental services forward on the battlefield. However, if evidence is not available to support safe implementation, accurate assessment of DRC, and tele-diagnosis then widespread use of teledentistry will be restrictive. Senior military leadership may be hesitant on adapting policies to enable broad spectrum use of teledentistry on military personnel without adequate supporting research.

Conclusion

The dental component of OVH as a military capability will have limited advancement until the establishment of a scope of practice for teledentistry. Until then informal teledentistry encounters will continue to be utilized in a similar manner for consultations and mentoring via the use of email, telephones, and digital imagery. Formally developing teledentistry capabilities sets the foundation to create decision support tools and other virtual health technologies to use on the future battlefield. Development of military teledentistry by extension advances all components of the OVH capability. Military teledentistry has potential to be on the leading edge of virtual health technology, and this review of relevant literature demonstrated a severe paucity of primary sources, highlighting an orphaned field related to critical readiness.

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Overlay Analysis of Cone-Beam Computed Tomography Volumes Acquired before and after Horizontal Alveolar Ridge Augmentation

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Abstract

Objective: The objective of this study was to illustrate the efficacy of a novel imaging analysis technology to capture horizontal and vertical dimensional changes following horizontal alveolar ridge augmentation (HRA).

Methods: Cone-beam computed tomography (CBCT) volumes from 65 HRA sites in 57 patients were available for evaluation, employing a three-dimensional analysis software to overlay preoperative and post-augmentation CBCT volumes. Horizontal and vertical alveolar ridge dimensional (HRD/VRD) changes were recorded considering a panel of patient-, site-, and procedure-related explanatory variables.

Results: VRD changes ranged from -2.9 to 3.0 mm, more than half anterior sites losing alveolar ridge height. Mean HRD increase at the 3- and 5-mm levels apical to the alveolar crest amounted to 2.3±1.6 and 2.4±1.3 mm, respectively, membrane fixation and non-resorbable membrane use associated with significantly greater gains.

Conclusions: To date, studies reporting dimensional changes following HRA predominantly rely on serial in situ orofacial caliper recordings omitting vertical alterations. The protocol employed in this study allows simultaneous HRD and VRD evaluations and assures baseline and post-augmentation recordings are made at the same alveolar ridge position. Compared with in situ recording, CBCT overlay analysis may achieve a more complete characterization of dimensional changes following HRA.

Keywords: alveolar ridge augmentation, allografts, dental implants, polytetrafluoroethylene, cone-beam computed tomography, treatment outcome

Objective

The 2017 World Workshop on Classification of Periodontal and Peri-Implant Diseases and Conditions defines a hard tissue deficiency prior to implant placement to exist when alveolar ridge dimensions do not accommodate a standard dental implant fully anchored in native alveolar bone.[1] Various reports in turn suggest that 40% or more dental implant sites demand alveolar ridge augmentation prior to or concomitantly with implant placement.[2-4] These estimates implicitly assume 1) a prosthetically determined implant position, and 2) provision of a sufficient alveolar bone volume and geometry, human and animal studies having shown favorable tissue stability when peri-implant bone thickness equals or exceeds 2 mm.[5-7]

Implant survival has served as a principal measure of alveolar ridge augmentation success, with virtually all studies reporting comparably high implant survival rates when implants are placed in augmented versus native alveolar bone.[8-19] Also, implant survival rates

Table 1. Studies reporting changes in alveolar ridge dimensions following horizontal ridge augmentation procedures.

Study	Graft/Biomaterials	Patients/ Sites	Measurement Technique	Mean Gain (mm)	Range (mm)
Urban et al. 2011[17]	Resorbable polymer membranes and particulate autogenous bone ± ABBM.	22/25	Intrasurgical initial (at GBR surgery) and final (prior to implant placement) HRD was recorded using calipers at a single point, 2 mm apical to the osseous crest.	5.6	Not reported
Urban et al. 2013[18]	Resorbable collagen membranes with particulated autogenous bone + ABBM. Membranes were fixed with titanium pins.	25/31	HRD 2 mm apical to the crest was recorded using calipers at the time of grafting and again at implant placement.	5.7	2 - 10
Meloni et al. 2017[19]	Resorbable collagen membranes with particulated autogenous bone + ABBM. Membranes were fixed with titanium pins.	18/22	CBCT scans were performed before and seven months after ridge augmentation. DICOM files were imported into analysis software where baseline and final volumes were superimposed. HRD was recorded 2 mm below the bone crest, before and after treatment.	5.0	Not reported
Buser et al. 1996[22]	Block grafts from the chin or ramus with bone chips, ePTFE membranes, membrane fixation screws, graft fixation/tenting screws.	40/66	Intraoperative caliper use to measure HRD to the nearest quarter mm at a point 2 mm apical to the osseous crest. The distance from the measurement site to the adjacent tooth was recorded in order to repeat the measurement upon re-entry.	3.5	1 - 7
von Arx & Buser, 2006[23]	Combination of autogenous block grafts with ABBM and collagen membranes.	42/58	For single-tooth edentulous sites, measurements were made in the middle of the edentulous span. A protocol was utilized to determine measurement locations for multiple adjacent missing teeth and distal extension situations. Measurements recorded 1 mm apical to the osseous crest using calipers to the nearest half mm.	4.6	2 - 7
Beitlitum et al. 2010[24]	Ribose cross-linked collagen membrane and FDBA ± addition of autogenous bone chips in a bi-layered grafting technique.	12/12 (control) 15/15 (bi-layered)	During the GBR procedure, the minimum HRD was measured clinically, and the point of measurement was related to the nearest tooth or implant for repeat measurement at re-entry surgery.	5.0 (control) 3.6 (bi-layered)	Not reported
Geurs et al. 2008[25]	Synthetic membranes and DFDBA / cortical cancellous chips in a thermoplastic biologic carrier.	51/98	The alveolar ridge was measured at a single mesiodistal position along the deficient ridge both at the crest and 4 mm apical to the crest before augmentation and at re-entry.	2.8 (crest) 3.1 (4 mm apical to crest)	2 – 7 (crest) -0.5 - 7 (4 mm apical to crest)
Block et al. 2012[26]	Particulate ABBM with resorbable membranes ± resorbable membrane fixation tacks (procedures completed in the anterior maxilla).	12/12	HRD was measured at three vertical positions from the osseous crest (designated as crestal, midway, and apical ridge thickness) using a CBCT scanner. CBCT volumes were acquired at five time points (pre-operatively, immediately after augmentation, three to six months after augmentation, immediately after implant placement, and after osseointegration).	< 1 (crest) 2.7 (midway) 2.8 (apical)	Not reported

ABBM = anorganic bovine bone mineral; CBCT = cone-beam computed tomography; CI = confidence interval; DICOM = Digital Imaging and Communication in Medicine; ePTFE = expanded polytetrafluoroethylene; FDBA = freeze=dried bone allograft; GBR = guided bone regeneration; HRD = horizontal alveolar ridge dimension

appear similar and high whether ridge augmentation occurs prior to or concomitantly with implant surgery.[20,21] In addition to implant survival, other ridge augmentation outcomes have included implant success,[14] changes in radiographic bone levels,[14,15,19] frequency of implant placement following augmentation,[17-19,22-24] and incidence of postoperative complications.[17-19,22-26]

A limited number of investigations report the magnitude of increase in horizontal alveolar ridge dimensions (HRD) following horizontal alveolar ridge augmentation (HRA) (Table 1).[17-19,22-26] Most of these investigations recorded the orofacial alveolar ridge dimension in conjunction with augmentation surgery and again at re-entry.[17,18,22-25] The purpose of this cohort study was to illustrate the efficacy of a novel analysis technology, overlaying cone-beam computed tomography (CBCT) volumes acquired before and after HRA.

Methods

Ethical Guidelines: The Director of the Army Human Research Protections Office, Falls Church, VA, reviewed this protocol and determined this research to be exempt from regulatory requirements of 32CFR§219 in accordance with paragraph 104(d)(4)(ii). This report complies with Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

Inclusion Criteria: CBCT volumes acquired for patients undergoing HRA procedures at the Army Postgraduate Dental School, Fort Gordon, GA, 1 July 2012 through 10 July 2020, were assessed. All CBCT volumes were acquired using a single scanner in the routine course of treatment planning for dental implant placement and surgical guide fabrication. CBCT field of view (FOV) was ø40 x height 40 mm (isotropic 80-µm voxel), ø60 x height 60 mm (isotropic 125-µm voxel), ø80 x height 80 mm (isotropic 160-µm voxel), or ø100 x height 100 mm (isotropic 250-µm voxel). All scans utilized a 360º arc of rotation, peak tube potential 90 kV, current 5 - 8 mA, and exposure time 10.5 - 30.8 seconds Augmented sites included in the study required diagnostic baseline and follow-up CBCT volumes, and the surgical goal was primarily HRA in preparation for dental implant placement. Sites were excluded if no implant was planned,

Figure 1. Example cone-beam computed tomography overlay (anterior). Wound closure for primary intension healing (A). The #9 site received a dense polytetrafluoroethylene membrane with fixation and a freeze-dried bone allograft. Incisal view of the site five months following ridge augmentation (B). Baseline CBCT volume (C). Overlay of baseline and post-augmentation CBCT volumes with measurements of ΔV, ΔH3, and ΔH5 (D).

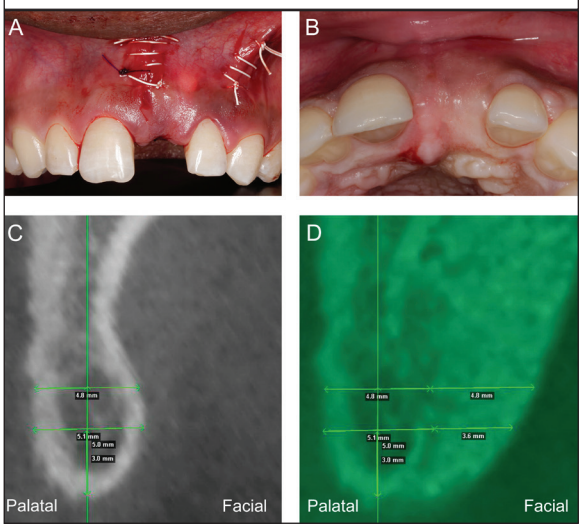
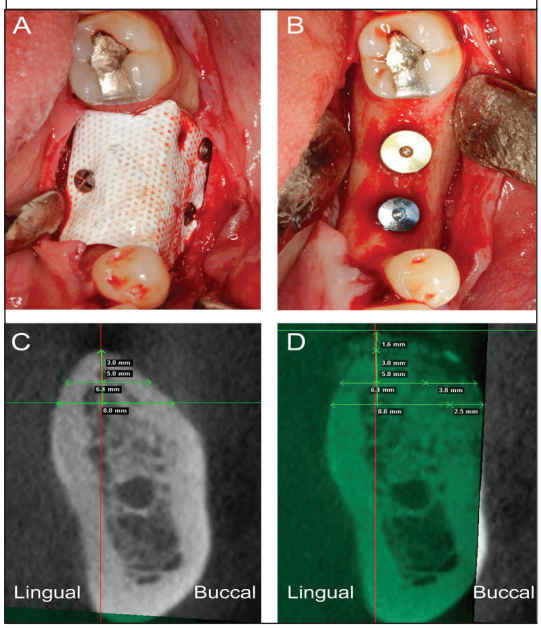


Figure 2. Example cone-beam computed tomography overlay (posterior). Titanium-reinforced dense polytetrafluoroethylene membrane with three fixation screws (A). Site received freeze-dried bone allograft. Appearance of the alveolar ridge at implant surgery (B). Baseline CBCT volume (C). Overlay of baseline and post-augmentation CBCT volumes with measurements of ΔV, ΔH3, and ΔH5 (D).



the augmentation occurred simultaneously with implant placement, the surgical goal was primarily vertical ridge augmentation, the site had received previous alveolar ridge augmentation, or either CBCT volume (baseline or follow-up) was not acquired. Baseline CBCT acquisition greater than 8 weeks prior to the augmentation procedure also excluded sites from this study. Patient records were reviewed to confirm the treatment plan and assess patient-, site-, and procedure-related explanatory variables: gender, age, race/ethnicity, smoking status, dental arch, region (anterior/posterior), graft type, membrane type, membrane fixation, titanium reinforcement in the membrane, tenting screw use, time between baseline and follow-up CBCT scans, and baseline ridge width 3 (BRW3) and 5 (BRW5) mm apical to the alveolar crest, in the mesiodistal center of the augmentation site.

CBCT Volume Overlay: For all cases meeting inclusion criteria, Digital Imaging and Communications in Medicine (DICOM) files were exported from the CBCT scanner system and imported to an analysis software. Baseline and post-augmentation CBCT volumes were superimposed using fixed anatomical landmarks such as the inferior border of the mandible, the subantral floor, the anterior nasal spine, the cementoenamel junction of adjacent teeth, the mental foramen, and other fixed landmarks appearing in both volumes. We assessed the quality of CBCT volume alignment by closely inspecting the anatomical landmarks in the superimposed images. For example, appearance of a "single" mandibular inferior border following the overlay process confirmed excellent alignment (Figures 1 and 2).

CBCT Recordings: Outcome variables assessed included the change in vertical position of the alveolar crest (ΔV) and the change in HRD at 3 and 5 mm apical to the baseline alveolar crest (ΔH3 and ΔH5). All recordings were made in the mesiodistal center of the augmented site. A positive value of ΔV indicated gain in the vertical alveolar ridge dimension (VRD), and a negative value of ΔV denoted VRD reduction. Positive ΔH3 and ΔH5 values indicated increases in HRD, whereas negative values of ΔH3 and ΔH5 indicated HRD reduction. Investigators recorded values for the three outcome variables at each HRA site after confirming proper CBCT volume alignment. The investigator then repeated measurements of ΔV, ΔH3, and ΔH5 to permit intra-examiner reliability assessment. In all analyses, the average of the duplicate recordings was used.

Statistical Analyses: Descriptive statistics were calculated for all qualitative and quantitative variables, reported as means ± standard deviations. The significance level was set at 0.05. Individual multiple linear regression models were established to determine associations between each outcome and the explanatory variables. Each explanatory variable was first examined in a bivariate model on each of the outcomes. Explanatory variables

significant at the 0.2 alpha level in a simple linear model were used to build a multiple linear regression model. Akaike information criterion (AIC) were examined for each possible model, and the model with the lowest AIC was determined to be the best model for each outcome variable.

One-way ANOVA (independent variables having at least three categories) and two-sample t-tests (independent variables having only two categories) were used to assess differences in the three outcomes among the levels of the categorical independent variables. Tukey-Kramer tests were used to assess for multiple comparisons when a one-way ANOVA was statistically significant. A two-sample test of proportions was calculated to determine if the percentage of sites exhibiting reduced VRD was different for anterior versus posterior sites. Intraclass correlation coefficients (ICCs) were calculated to estimate intra-examiner reliability.

Table 2. Study population characteristics.

Patient Level (n = 57)					
Gender male/female	41 (72%)			16 (28%)	
Race/ethnicity	26 (46%) African American	6 (9%) Hispanic	1 (2%) Asian	23 (40%) Caucasian	1 (2%) unknown
Age [years]	mean 39.3 ± 11.0, range 21 - 67				
Smoking status	45 (79%) never smoked	6 (11%) former smokers	6 (11%) smokers	0 (0%) heavy smokers	
Site level (n = 65)					
Gender male/female	47 (72%)			18 (28%)	
Race/ethnicity	32 (49%) African American	6 (9%) Hispanic	1 (2%) Asian	25 (38%) Caucasian	1 (2%) unknown
Age [years]	mean 39.5 ± 10.9, range 21 to 67				
Smoking status	53 (82%) never smokers	6 (9%) former smokers	6 (9%) smokers	0 (0%) heavy smokers	
Site type	21 (32%) anterior		44 (68%) posterior		
Dental arch	22 (34%) maxillary		43 (66%) mandibular		
Graft or biomaterial	5 (8%) autogenous bone	9 (14%) autogenous bone combined with ABBM or FDBA	51 (78%) allogeneic bone derivative (FDBA or solvent-dehydrated bone allograft)		
Barrier membrane	53 (82%) non-resorbable	5 (8%) resorbable collagen	5 (8%) acellular dermal matrix	1 (2%) no barrier membrane	
Membrane reinforcement	18 (28%) titanium reinforced membrane		47 (72%) non-reinforced membrane or no membrane used		
Tenting screw use	14 (22%) sites received tenting screws		51 (78%) sites did not receive tenting screws		
Membrane fixation	58 (89%) sites received membrane fixation		7 (11%) sites did not receive membrane fixation		
Interval between preoperative and follow-up CBCT volumes [months]	mean 6.5 ± 2.2, range 3.0 - 13.0				
Baseline HRD, 3 mm apical to crest [mm]	mean 6.0 ± 1.9, range 0.8 - 11.0				
Baseline HRD, 5 mm apical to crest [mm]	mean 7.2 ± 2.4, range 0.6 - 12.7				
Preoperative CBCT volume FOV	14 (22%) Ø 100 × height 100 mm	21 (32%) Ø 80 × height 80 mm	24 (37%) Ø 60 × height 60 mm	6 (9%) Ø 40 × height 40 mm	
Follow-up CBCT volume FOV	9 (14%) Ø 100 × height 100 mm	19 (29%) Ø 80 × height 80 mm	25 (38%) Ø 60 × height 60 mm	12 (18%) Ø 40 × height 40 mm	

ABBM = anorganic bovine bone mineral; FDBA = freeze-dried bone allograft; CBCT = cone-beam computed tomography; HRD = horizontal alveolar ridge dimension; FOV = field of view.

Results

Study Population: CBCT volumes from 57 patients met inclusion criteria for this study. Eight patients had received two HRA procedures at separate alveolar locations. Thus, CBCT volumes from 65 sites were available for analysis. Eighty-four dental implants were planned; 77 (92%) implants were actually placed following the HRA. Five patients were unavailable to complete implant installation, accounting for five implants planned but not placed. One patient received HRA that resulted in inadequate HRD to support dental implant placement.

ICC scores for ΔV, ΔH3, and ΔH5 were 0.998, 0.997, and 0.996, respectively, indicating high intra-examiner reliability. Table 2 presents characteristics of the study population, and individual patient data is presented in Appendix 1. Briefly, 41 patients (72%) were male, mean patient age 39.3±11.0 years. Forty-five patients (79%) had never smoked. Overall mean values for ΔV, ΔH3, and ΔH5 were 0.1±1.2, 2.3±1.6, and 2.4±1.3 mm, respectively.

Fsctors Influencing Postoperative Alveolar Ridge Dimensions: Multiple linear regression models identified statistically significant factors influencing each dependent variable. The final model for ΔV included dental arch, membrane fixation, and BRW3. Only membrane fixation (β=0.86, p=0.046) and BRW3 (β=0.16, p=0.022) were statistically significant factors affecting ΔV. The final model for ΔH3 included membrane fixation, tenting screw use, time between CBCT images, and BRW5. Only membrane fixation (β=1.36, p=0.42) exhibited a statistically significant association with ΔH3. The final model for ΔH5 included region (anterior vs. posterior) and membrane type (non-resorbable vs. resorbable). Anterior sites (β=0.73, p=0.040) and sites receiving non-resorbable membranes (β=0.61, p=0.024) exhibited

significantly greater ΔH5.

Table 4 presents one-way ANOVA and two-sample t-test results. Posterior sites exhibited significantly greater mean ΔV compared with anterior sites (0.4±1.4 vs. -0.4±1.0 mm, p=0.012). Mandibular sites exhibited statistically greater mean ΔV compared with maxillary sites (0.3±1.2 vs. -0.3±1.0 mm, p=0.028). Membrane fixation, compared with no membrane fixation, was associated with significantly greater mean ΔV (0.2±1.1 vs. -0.7±1.1 mm, p=0.042) and mean ΔH3 (2.5±1.5 vs. 1.1±2.3, mm p=0.038). Sites receiving non-resorbable rather than resorbable membranes also experienced significantly greater mean ΔV (0.2±1.2 vs. -0.6±0.7 mm, p=0.037) and mean ΔH3 (2.5±1.6 mm vs. 1.4±1.5 mm, p=0.034).

Overall, 24 HRA sites (37%) lost VRD, 24 sites (37%) gained VRD, and 17 sites (26%) exhibited no change in the vertical dimension of the alveolar ridge. In a two-sample test of proportions, 11 of 21 anterior sites (52%) and 13 of 31 posterior sites (30%) exhibited decrease in VRD. This difference was not statistically significant (p=0.074).

Table 3. One-way analysis of variance and two-sample t test results.

Variable	Level	ΔV Mean ± SD (mm)	p value	ΔH3 Mean ± SD (mm)	p value	ΔH5 Mean ± SD (mm)	p value
Sex	Female n = 18	-0.2 ± 1.1	0.200	2.0 ± 1.8	0.362	2.3 ± 1.5	0.547
	Male n = 47	0.2 ± 1.2		2.4 ± 1.6		2.5 ± 1.3	
Race/ ethnicity	Asian n = 1	0.0	0.251	2.3	0.889	1.4	0.905
	African American n = 32	0.2 ± 1.1		2.4 ± 1.7		2.3 ± 1.2	
	Caucasian n = 25	0.1 ± 1.3		2.2 ± 1.7		2.5 ± 1.4	
	Hispanic n = 6	-0.8 ± 0.5		2.1 ± 1.8		2.5 ± 2.1	
	Unknown n = 1	1.6		3.8		2.6	
Smoking status	Former smoker n = 6	0.6 ± 0.7	0.515	2.6 ± 1.2	0.880	2.2 ± 1.4	0.928
	Never smoked n = 53	0.0 ± 1.2		2.3 ± 1.6		2.4 ± 1.3	
	Smoker n = 6	0.3 ± 1.3		2.5 ± 2.4		2.5 ± 1.8	
Dental arch	Mandibular n = 43	0.3 ± 1.2	0.028	2.6 ± 1.5	0.106	2.2 ± 1.1	0.281
	Maxillary n = 22	-0.3 ± 1.0		1.9 ± 1.8		2.7 ± 1.7	
Region	Anterior n = 21	-0.4 ± 1.0	0.012	1.9 ± 1.5	0.152	2.8 ± 1.5	0.130
	Posterior n = 44	0.4 ± 1.1		2.5 ± 1.7		2.2 ± 1.2	
Graft or bio-material type	Autogenous bone n = 5	-1.0 ± 1.3	0.059	1.2 ± 2.6	0.241	1.9 ± 1.0	0.310
	Autogenous bone combination n = 9	0.5 ± 1.1		2.7 ± 1.1		2.9 ± 1.1	
	Allogeneic bone derivative n = 51	0.1 ± 1.1		2.4 ± 1.6		2.4 ± 1.4	
Membrane type	Resorbable n = 11	-0.6 ± 0.7	0.037	1.4 ± 1.5	0.034	1.8 ± 1.4	0.092
	Non-resorbable n = 54	0.2 ± 1.2		2.5 ± 1.6		2.5 ± 1.3	
Titanium reinforced membrane	No n = 47	-0.0 ± 1.0	0.090	2.2 ± 1.5	0.388	2.5 ± 1.4	0.411
	Yes n = 18	0.5 ± 1.4		2.6 ± 1.9		2.2 ± 1.0	
Membrane fixation	No n = 7	-0.7 ± 1.1	0.0421	1.1 ± 2.3	0.038	2.1 ± 1.4	0.496
	Yes n = 58	0.2 ± 1.1		2.5 ± 1.5		2.4 ± 1.4	
Tenting screw use	No n = 51	0.0 ± 1.1	0.214	2.2 ± 1.6	0.124	2.3 ± 1.3	0.547
	Yes n = 14	0.5 ± 1.1		2.9 ± 1.5		2.6 ± 1.5	

ΔV = change in vertical dimension of the alveolar ridge relative to the baseline osseous crest; ΔH3 = change in horizontal dimension of the alveolar ridge (3 mm apical to the baseline osseous crest); ΔH5 = change in horizontal dimension of the alveolar ridge (5 mm apical to the baseline osseous crest); SD = standard deviation

Discussion

The present study analyzed HRA at 65 sites utilizing 130 CBCT volumes with the objective to illustrate the efficacy of a novel imaging technology to assess alveolar bone dimensions. Prior investigations reporting HRD changes following ridge augmentation procedures predominantly have relied on serial intraoperative caliper recordings.[17,18,22-25] Unlike the recording methods used in these studies, our overlay protocol assured a consistent alveolar position for baseline and post-augmentation comparison capturing both HRD and VRD changes. Intuitively, postoperative variations in the VRD may bias the estimated HRD gain in studies relying upon caliper recordings.

Clinician scientists commonly distinguish HRA procedures from those aiming at vertical ridge augmentation. However, it appears obvious that any ridge augmentation may impact the alveolar envelope volume and geometry regardless of primary surgical objective. In HRA, clinicians typically seek to increase HRD such that a dental implant may be fully invested and anchored in bone,[1-3] preferably achieving a circumferential bone thickness equal to or exceeding 2 mm.[5-7] Minor alterations in the VRD following HRA may be of limited clinical consequence, particularly at posterior sites. However, loss of VRD is generally undesirable, and as such may compromise esthetics and/or limit effectiveness of personal hygiene practices. Four factors in the present study were associated with mean reduction in VRD—anterior site, maxillary site, lack of membrane fixation, and use of a resorbable barrier membrane. We observed VRD reduction at more than half of anterior HRA sites. Moreover, in the multiple linear regression analysis, baseline alveolar ridge width correlated negatively with VRD, suggesting that, as expected, thin alveolar ridges may be particularly vulnerable to untoward dimensional changes following HRA. Prior studies relying on

serial intraoperative orofacial caliper recordings were incapable of similar assessments.

Considering the relative importance of reported HRA outcomes, the magnitude of HRD increase may rank lower than implant success/survival, long-term peri-implant tissue stability, percent vital bone achieved, and other parameters. In fact, the amount of horizontal augmentation required to produce an ideal alveolar ridge varies from site to site; a modest augmentation does not necessarily imply a less favorable treatment outcome. Nevertheless, seasoned clinician scientists have reported HRD gains following ridge augmentation surgery (Table 1).[17-19,22-26] These reports may serve to guide expectations and suggest limitations considering a range HRA protocols.

In the present study, two factors, membrane fixation and non-resorbable membrane use, were associated with statistically significant increases in HRD at the 3-mm level. These observations are consistent with prior reports,[27,28] although multiple investigators have reported satisfactory HRA outcomes utilizing either resorbable or non-resorbable barrier membranes.[17-19,22-28] Five sites in the present study received acellular dermal matrix (ADM) barriers. Although limited data support use of ADM for alveolar ridge augmentation/preservation,[29-33] in the present study, sites receiving the ADM device tended to exhibit less favorable treatment outcomes. In fact, the only HRA site assessed that could not accommodate implant placement utilized an ADM barrier.

Understanding the degree to which HRA sites maintain short- and long-term dimensional stability is of practical importance to implant surgeons. Continued remodeling of the alveolar ridge in the long-term—following the implant phase—may result in unfavorable esthetics and predispose the site toward biologic complications.[34-37] In the short-term, if ridge dimensions at HRA sites remain relatively stable, practitioners may choose to acquire CBCT volumes early. This approach would facilitate HRA outcome assessment, implant planning, and surgical guide fabrication, while permitting additional maturation prior to the implant phase. In a previous analysis of 84 patients receiving only a single CBCT scan following HRA, we found no correlation linking the interval between surgery and follow-up CBCT with the buccal bone thickness adjacent to virtual dental implants.[27] Similarly, in the present study, the interval between baseline and postoperative CBCT volumes did not correlate with the observed HRD increase. These findings suggest that over a range of healing intervals from about two to nine months, post-augmentation CBCT HRD measurements do not exhibit large dimensional changes. Thus, from a practical perspective, a clinician might choose to image a site early to expedite implant planning, while allowing an additional maturation period before implant surgery.

Conclusion

Viewed in context with prior investigations,[38-40] our findings reiterate the significance of space provision in alveolar ridge augmentation. Consistent with previous reports,[27,28] most sites assessed herein included barrier membrane fixation, and these sites exhibited a statistically greater mean HRD increase compared with sites not using membrane fixation. Additionally, sites that did not receive membrane fixation exhibited a mean reduction in VRD. Especially when utilizing a relatively rigid barrier, such as dense polytetrafluoroethylene, membrane fixation may maintain the space available for augmentation and also increase wound stability. Also consistent with our previous report,[27] no statistically significant difference was detected in mean HRD increase at sites receiving and not receiving tenting screws. Mixed observations appear in the literature regarding this topic. Recently, César Neto and colleagues reported the effect of tenting screws on the orofacial ridge dimension following HRA and found statistically greater mean HRD in the tenting screw group.[41] The authors concluded tenting screws may particularly aid in achieving consistent ridge augmentation at deficient palatal/lingual sites.[41] It is possible that tenting screws are beneficial when the defect configuration is unfavorable for space maintenance but unnecessary at space-providing HRA sites. Tenting screw removal at implant surgery may result in a localized defect in augmented bone, and the additional hardware adds cost and complexity to the procedure. Although controlled clinical research is necessary, practitioners may consider avoiding tenting screw use unless clearly beneficial in specific cases.

Multiple clinicians performed the procedures included in the present study, and various faculty members with individual preferences and treatment philosophies supervised these procedures. The augmentations did not employ a standardized graft material and barrier membrane combination. Furthermore, the patient sample may not necessarily be representative of the broader population. Despite clinical protocol variations and clinician preferences, our indirect assessment method permitted simultaneous HRD and VRD evaluation, while assuring baseline and post-augmentation recordings at the same alveolar ridge position. Compared with direct in situ recording, the described protocol—and methods involving new technologies such as optical scanning—may achieve a more complete characterization of dimensional changes at alveolar ridge augmentation sites.

Appendix 1. Individual patient data.

		Explanatory variables														Outcome variables		
		Patient-related				Site-related				Procedure-related								
Patient	Site	Sex [M, F]	Age [Years]	Race / ethnicity [H, A, AA, C]	Smoking status [NS, FS, S, HS]	Arch [MX, MN]	Region [Ant, Post]	BRW3 [mm]	BRW5 [mm]	Graft type [AB, ABC, BB]	Membrane type [RCM, ADM, dPTFE]	Titanium reinforced membrane [Y/N]	Membrane fixation [Y, N]	Tenting screw use [Y, N]	Time between CBCT scans [Months]	ΔV [mm]	ΔH3 [mm]	ΔH5 [mm]
1	1	F	58	AA	NS	MX	Posterior	6.9	8.5	BB	dPTFE	N	Y	N	4	0.0	4.6	4.2
2	2	M	49	AA	NS	MN	Posterior	8.3	10.7	BB	dPTFE	Y	Y	N	11	1.9	3.1	1.3
3	3	M	46	A	FS	MX	Posterior	10.3	11.5	BB	dPTFE	N	Y	N	4	0.0	2.3	1.4
4	4	F	35	AA	NS	MN	Posterior	8.4	9.5	BB	dPTFE	Y	Y	N	7	1.5	3.3	2.4
5	5	M	38	C	FS	MN	Anterior	4.6	4.7	BB	dPTFE	N	Y	Y	7	1.0	4.1	4.1
6	6	M	25	C	NS	MX	Anterior	3.6	4.3	BB	dPTFE	N	N	N	5	0.0	1.3	2.3
7	7	M	56	AA	NS	MN	Anterior	5.9	8.2	BB	dPTFE	Y	Y	Y	7	0.0	3.6	3.2
	8					MN	Anterior	8.9	10.7	BB	dPTFE	Y	N	Y	7	0.0	1.6	2.1
8	9	F	50	AA	NS	MN	Posterior	7.9	7.8	BB	dPTFE	N	Y	N	4	0.0	3.9	4.2
	10					MN	Posterior	11	11.9	BB	dPTFE	N	Y	N	4	1.2	1.5	0.8
9	11	M	38	AA	NS	MN	Posterior	7.2	7.8	BB	dPTFE	N	Y	Y	6	1.3	4.0	4.4
10	12	F	48	AA	NS	MX	Posterior	6.1	8	BB	dPTFE	N	Y	N	12	0.0	0.6	0.5
11	13	M	46	H	NS	MX	Anterior	4.1	4.3	BB	dPTFE	N	Y	Y	11	-1.6	4.5	6.0
12	14	M	38	AA	NS	MN	Posterior	9.1	12.7	BB	dPTFE	N	Y	N	11	0.0	2.2	1.0
	15					MX	Anterior	5.2	6.3	ABC	dPTFE	N	Y	N	7	1.4	1.9	1.9
13	16	M	32	C	NS	MX	Anterior	4.6	3.8	BB	dPTFE	N	Y	N	6	1.1	3.7	5.4
	17					MX	Anterior	4.9	4.5	BB	dPTFE	N	Y	N	6	-0.9	0.8	3.2
14	18	F	21	C	NS	MX	Anterior	5.7	5.6	BB	RCM	N	N	N	5	-1.5	2.1	3.0
15	19	F	45	C	S	MX	Posterior	5.8	7.1	BB	dPTFE	N	Y	N	4	0.0	4.6	5.2
16	20	M	23	H	S	MX	Anterior	4.9	5.3	BB	RCM	N	N	N	4	-0.6	-0.4	0.9
17	21	M	44	C	S	MN	Posterior	8.9	9.9	BB	dPTFE	N	Y	N	5	0.0	3.7	2.9
18	22	F	46	H	NS	MN	Posterior	5.4	5.5	ABC	dPTFE	N	Y	N	6	-0.5	3.6	4.4
19	23	M	33	C	NS	MN	Posterior	4	5.3	BB	dPTFE	N	Y	Y	4	1.2	3.4	2.0
20	24	M	41	AA	NS	MN	Posterior	8.2	11	BB	dPTFE	N	Y	Y	7	-0.4	3.9	3.1
21	25	M	38	C	FS	MN	Posterior	5.9	8.5	BB	RCM	N	Y	Y	8	0.9	1.2	0.0
22	26	M	56	AA	FS	MN	Posterior	7.4	9	BB	RCM	N	N	N	7	0.0	3.7	3.2
23	27	M	48	AA	NS	MN	Posterior	6	7.9	BB	dPTFE	Y	Y	N	5	0.0	5.5	3.8
24	28	M	22	C	S	MN	Posterior	4	6.2	ABC	dPTFE	Y	Y	N	4	2.5	4.7	3.7
25	29	M	25	AA	NS	MX	Anterior	5.3	4.8	ABC	dPTFE	N	Y	N	7	0.0	3.4	4.8
26	30	M	67	AA	NS	MN	Posterior	5.3	4.3	BB	dPTFE	N	Y	N	5	-1.0	0.0	2.8
27	31	F	30	AA	NS	MN	Posterior	4.7	5.4	AB	dPTFE	Y	N	N	11	-3.0	-3.3	0.5
28	32	M	33	AA	NS	MN	Posterior	5	7.9	BB	dPTFE	Y	Y	Y	5	-0.6	4.6	2.8
	33					MN	Posterior	6.4	8.1	BB	dPTFE	Y	Y	N	9	1.0	2.9	1.5
29	34	M	41	AA	NS	MN	Posterior	7	8	AB	dPTFE	Y	Y	N	7	0.5	3.0	2.6
30	35	M	22	C	NS	MN	Anterior	2.1	4.2	BB	dPTFE	N	Y	N	6	-2.6	2.4	2.8
31	36	M	48	C	NS	MX	Anterior	5	5.3	BB	dPTFE	N	Y	N	8	0.6	1.4	2.5
32	37	M	36	H	NS	MN	Posterior	5.3	6.9	AB	dPTFE	Y	Y	N	5	-1.2	1.2	1.1
33	38	M	45	AA	NS	MN	Anterior	2.7	2.3	BB	dPTFE	N	Y	N	6	0.0	2.1	2.5
34	39	M	50	AA	NS	MN	Posterior	6.7	8.4	BB	dPTFE	N	Y	Y	6	2.9	2.6	1.8
	40					MN	Posterior	5.5	7.1	BB	dPTFE	Y	Y	N	8	2.5	2.8	0.8
35	41	F	28	AA	NS	MN	Posterior	5.6	7.3	BB	dPTFE	Y	Y	N	4	0.0	2.0	2.6
36	42	M	30	Unknown	NS	MN	Posterior	6.4	8.8	BB	dPTFE	Y	Y	Y	6	1.6	3.8	2.6
37	43	M	56	AA	NS	MN	Posterior	7.2	8.6	BB	dPTFE	Y	Y	N	8	0.8	2.8	2.8
	44				NS	MN	Posterior	6.7	7.3	ABC	dPTFE	Y	Y	N	8	-0.9	1.6	2.7
38	45	F	29	C	NS	MN	Posterior	6	8.1	AB	dPTFE	N	Y	N	6	-0.8	2.2	2.8
	46					MN	Posterior	6.3	6.8	ABC	dPTFE	N	Y	N	6	1.0	2.3	2.2
39	47	M	35	H	NS	MN	Posterior	8.8	11	BB	ADM	N	Y	N	5	-0.4	2.3	1.7
40	48	M	36	C	S	MX	Anterior	5.8	6.4	BB	None	N	Y	Y	13	-1.0	-0.8	1.2
41	49	F	57	AA	NS	MX	Anterior	0.8	0.6	BB	ADM	N	Y	N	6	-1.1	1.3	1.7
42	50	M	24	C	NS	MX	Anterior	2.2	2.5	BB	ADM	N	Y	N	6	-1.4	0.4	1.5
43	51	M	35	AA	NS	MX	Posterior	9.3	11.2	AB	dPTFE	N	Y	N	5	-0.4	2.8	2.4
44	52	M	38	C	NS	MX	Posterior	6.5	8	BB	dPTFE	N	Y	N	7	-2.1	-2.4	0.2
45	53	M	28	C	NS	MN	Posterior	6.7	8.2	BB	dPTFE	Y	Y	N	8	1.7	1.5	1.7
46	54	M	33	C	FS	MX	Posterior	9.4	10.9	ABC	dPTFE	N	Y	N	5	1.5	2.9	2.6
47	55	F	49	C	NS	MX	Anterior	3.1	4.2	BB	dPTFE	N	Y	N	4	-1.3	1.0	1.8
48	56	M	35	AA	NS	MN	Posterior	5.2	6	ABC	dPTFE	N	Y	N	5	-0.4	1.2	1.7
49	57	M	25	C	NS	MN	Posterior	6.3	7.4	ABC	dPTFE	N	N	N	9	0.0	2.6	2.6
50	58	F	34	AA	NS	MN	Anterior	4.4	4.3	BB	ADM	N	Y	N	5	-0.7	0.4	0.6
51	59	M	26	C	NS	MX	Anterior	6.3	7.3	BB	ADM	N	Y	N	8	-0.2	4.0	4.8
52	60	M	32	AA	FS	MX	Anterior	6.3	7.5	BB	dPTFE	N	Y	Y	6	0.0	1.5	2.0
53	61	F	53	C	S	MN	Posterior	6	8.1	BB	dPTFE	N	Y	Y	6	1.0	3.1	1.0
54	62	F	43	H	NS	MN	Posterior	5.8	7.1	BB	RCM	N	Y	N	3	-0.3	1.1	1.2
55	63	M	34	C	NS	MN	Posterior	6.3	8.5	BB	dPTFE	N	Y	N	5	1.3	3.0	1.9
56	64	F	54	AA	NS	MN	Posterior	5.3	7	BB	dPTFE	Y	Y	N	9	1.1	2.5	1.3
57	65	M	43	C	NS	MN	Posterior	5.4	6.5	BB	dPTFE	N	Y	N	9	0.6	3.1	2.1
															Mean	0.1	2.3	2.4
															SD	1.2	1.6	1.3
															Minimum	-3.0	-3.3	0.0
															Maximum	2.9	5.5	6.0

F = female; M = male; H = Hispanic; A = Asian; AA = African American; C = Caucasian; NS = never smoked; FS = former smoker (no cigarette within 90 days of procedure); S = current smoker; HS = heavy smoker (> ten cigarettes per day); MX = maxillary arch; MN = mandibular arch; BRW3 = baseline ridge width (3 mm apical to osseous crest); BRW5 = baseline ridge width (5 mm apical to osseous crest); AB = autogenous bone; ABC = autogenous bone combined with freeze-dried bone allograft (OraGRAFT, Lifenet Health, Virginia Beach, Virginia, United States) or anorganic bovine bone mineral (Bio-Oss, Geistlich Pharma, Wolhusen, Switzerland); BB = allogeneic bone biomaterial (OraGRAFT, Lifenet Health or Puros Cortico-cancellous Particulate Allograft, Zimmer Biomet, Warsaw, Indiana, United States); dPTFE = dense polytetrafluoroethylene (Cytoplast, BioHorizons, Birmingham, Alabama, United States); RCM = resorbable collagen membrane (BioGide, Geistlich Pharma or BioMend Extend, Zimmer Biomet); ADM = acellular dermal matrix (Dermis Allograft Tissue Matrix, Zimmer Biomet); Y = yes; N = no; ΔV = change in vertical dimension of the alveolar ridge relative to the baseline osseous crest; ΔH3 = change in horizontal alveolar ridge dimension (3 mm apical to the baseline osseous crest); ΔH5 = change in horizontal alveolar ridge dimension (5 mm apical to the baseline osseous crest)

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Targeted Alveolar Ridge Augmentation for Patient-Centered Dental Implant Site Development

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Abstract

Introduction: Guided bone regeneration (GBR) is the most commonly utilized procedure for augmenting deficient alveolar ridges in support of dental implant placement. In a GBR procedure, barrier membrane dimensions, bone graft volume, and surgical complexity may influence the risk of postsurgical morbidity.

Case presentation: A 25-year-old female in good general health received GBR at two mandibular first molar sites exhibiting horizontal ridge deficiency. High-density polytetrafluoroethylene membranes were intentionally limited in size, and small-volume freeze-dried bone allografts were applied only where clinically beneficial for implant site development. Treatment resulted in clinically favorable ridge augmentation with no appreciable swelling and minimal postoperative discomfort.

Conclusion: At dental implant sites exhibiting modest alveolar ridge deficiency, limiting GBR barrier membrane dimensions and bone graft volumes may enhance patient-centered outcomes while accomplishing clinical goals.

Keywords: allografts; dental implants; minimally invasive surgical procedures; patient outcome assessment; polytetrafluoroethylene; postoperative complications; treatment outcome

Introduction

Guided bone regeneration (GBR) is a well-established technique for augmenting deficient alveolar ridges in support of dental implant placement.[1] Reported complications associated with GBR include wound dehiscence, membrane exposure, infection, nerve and vascular damage, pain, swelling, and patient suffering.[2-5] Severe alveolar bone defects receiving GBR require large membranes, multiple points of membrane fixation, enhanced space maintenance methods (e.g. membrane reinforcement with titanium struts or placement of tenting screws), large graft volumes, and considerable flap advancement to achieve wound closure with primary intention healing.[2-9] Barrier membranes are often extended beyond the site of desired augmentation in order to accommodate membrane fixation and placement of adequate graft or biomaterial volume.[2-9] Although no data support a relationship between nonresorbable barrier membrane dimensions and incidence or severity of complications, smaller membranes intuitively promote a favorable postsurgical course. When dense polytetrafluoroethylene (dPTFE) membranes are used in GBR, blood supply from the bone to the soft tissue covering the membrane is compromised for the duration that the cell-occlusive barrier remains in place.[10] Thin soft tissue covering a dPTFE membrane appears especially prone to atrophy, and excessive flap tension may also contribute to wound dehiscence.[10] In perspective, the exposure rate of dPTFE membranes may be as high as 40%.[11] When practicable, intentionally limiting the area of augmentation may diminish postsurgical morbidity. The present case illustrates a targeted GBR approach minimizing postsurgical pain and swelling and hastening patient return to normal activities.

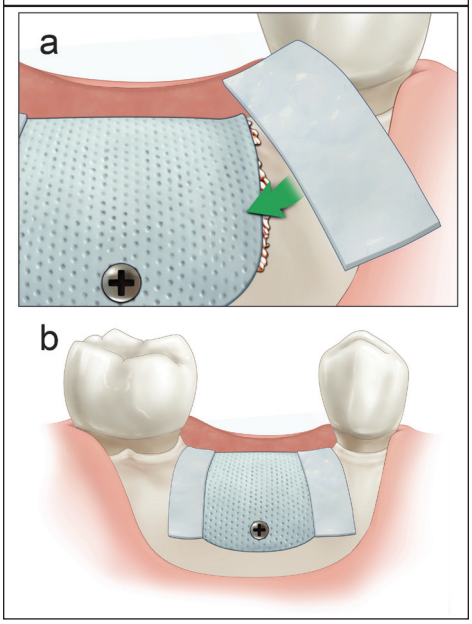
Clinical Presentation

In July 2016, a healthy 25-year-old female patient presented to the Army Periodontics Program, Fort Gordon, GA, missing teeth #19 and #30. Examination revealed horizontal ridge deficiency in #19 and #30 areas.

Case Management

The patient elected GBR in advance of dental implant placement (#19 and 30 positions) after a thorough review of treatment options. Following oral hygiene instructions, initial phase therapy, and re-evaluation, the patient received GBR in the #30 area. The procedure began with a crestal incision in the #30 position after administration of local anesthesia. Horizontal incisions were placed at the base of buccal papillae from tooth #27 to #29, with an oblique/vertical incision from mid-distal of tooth #31 toward the buccal. Buccal and lingual full thickness mucoperiostal flaps allowed access to the alveolar bone, and the surgeon prepared intramarrow penetrations through the buccal cortex using a #2 round bur. The surgeon stabilized a minimally-trimmed 12 x 24 mm dPTFE membrane in the #30 area using a single 1.5 x 3 mm fixation screw applied apical to the alveolar defect, centered mesiodistally in the #30 position (Figure 1). The distance between membrane margins and adjacent teeth measured ≈ 1.5 to 2.0 mm at the alveolar crest. The surgeon placed a 0.5-cc mineralized allogeneic bone derivative and stabilized the free margin of the membrane under the lingual flap. An absorbable collagen wound dressing stabilized allograft particles under the membrane (Figure 1). The surgeon closed the wound using 4/0 expanded PTFE sutures. GBR proceeded at the #19 site using the same protocol in a subsequent appointment (Figures 2 - 4), with the addition of a membrane tenting screw placed in the alveolar bone.

Figure 1. a) Placement of collagen wound dressing to contain and immobilize graft particles and eliminate dead space at the margins of the dense polytetrafluoroethylene (dPTFE) membrane. b) Collagen dressing in place on mesial and distal margins of the membrane.



Clinical Outcome

Following each GBR procedure, the patient noticed no swelling and reported minimal postsurgical discomfort limited to the first two postoperative days. Four months following GBR at the #30 site, a small crestally-located membrane exposure was noted. The surgeon opted to remove both membranes at that time in deference to patient military duties, which precluded close monitoring. The patient consented to cone-beam computed tomography (CBCT) ≈ six months following GBR to facilitate surgical implant guide fabrication (Figure 5). Approximately seven months following the ridge augmentation phase, the patient received 5 x 10 mm implants with 6 x 5 x 4 mm healing abutments at the #19 and #30 positions (Figures 6 - 8). The

Figure 2. Horizontal ridge deficiency, #19 area. A 1.5 x 8 mm tenting screw was placed to facilitate space maintenance for alveolar ridge augmentation.

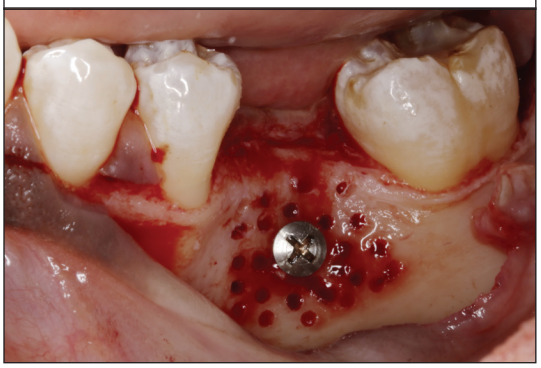


Figure 3. A dense polytetrafluoroethylene (dPTFE) membrane was secured in the #19 area using a single membrane fixation screw (not shown), and a tenting screw was placed at the site of the deficient alveolar ridge.

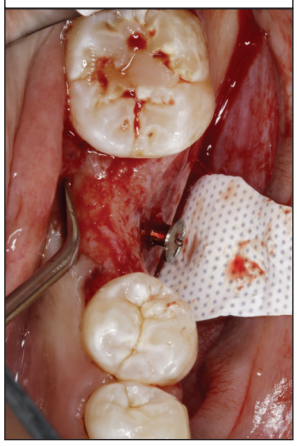


Figure 4. Freeze-dried bone allograft applied at #19 site.

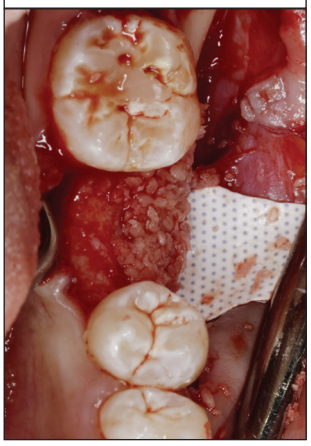


Figure 5. Cone-beam computed tomography images ≈ six months following GBR. Favorable alveolar ridge dimensions were noted at both sites: a) axial view; b) coronal view.

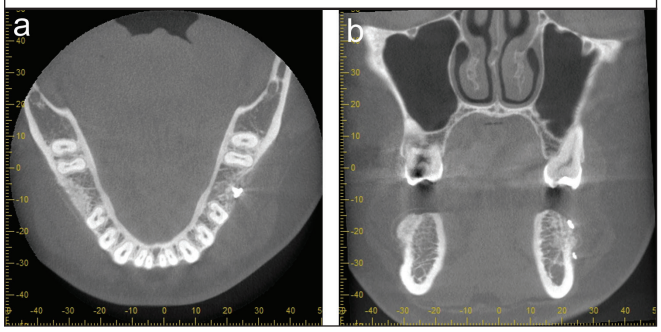
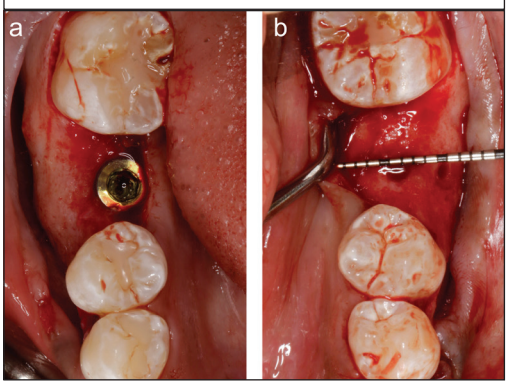


Figure 6. Re-entry surgery at ≈ seven months following GBR. Both #30 (a) and #19 (b) sites exhibited favorable ridge dimensions for dental implant placement. Clinical quality of the augmented sites was excellent.



surgeon augmented peri-implant mucosa at each site concomitantly with implant placement using acellular dermal matrix.

Discussion

Limiting GBR barrier membrane size and graft/biomaterial volume may offer direct and indirect advantages to patients and clinicians. The targeted GBR approach presented in this report required minimal membrane trimming, one fixation screw per site, and no superfluous placement of allograft. Thus, the technique curtailed both material costs and surgical time required. Shorter surgery duration has been associated with fewer complications and decreased pain.[12] Additionally, the quality of the alveolar ridges established with this technique was clinically favorable. Visually, the regenerate surfaces appeared similar to adjacent resident buccal cortex. Individual allograft particles were not readily apparent. CBCT evaluation prior to implant placement revealed homogenous high-density bone-like tissue buccal to the native cortex in the augmented areas. The estimated gains in horizontal ridge dimension were 3.5 mm and 4.1 mm at the #19 and #30 positions, respectively (measured on the CBCT image 2 mm apical to the crest in the mesiodistal centers of planned implant positions). During implant osteotomy preparation, both sites exhibited dense bone. No fibrous tissue was clinically apparent, and the bone did not exhibit flaking during osteotomy preparation. Based on prior histologic evaluations of human dental implant sites augmented with allografts and other biomaterials, the grafted area was most likely comprised of new vital bone, residual allograft particles, and connective tissue.[13-17] Following implant placement, both fixtures exhibited at least 2 mm bone thickness circumferentially, an important factor in long-term stability of the peri-implant tissue.[18-20]

The reported technique utilized conventional site access and is not considered a minimally invasive procedure. However, the method is in some respects a midpoint, between minimally invasive and conventional techniques. The procedure seeks to augment bone where necessary, while purposefully limiting the impact on surrounding tissue and accelerating recovery for the patient. The technique does require re-entry to retrieve the membrane and fixation/tenting screws. Re-entry could be avoided using a resorbable barrier and subsequently a flapless implant surgery. If flap reflection is intended at implant placement, selection of a resorbable versus nonresorbable barrier appears inconsequential. In the presented case, a targeted GBR approach resulted in favorable bone quality and volume at implant surgery, and the patient reported a positive overall experience.

Figure 7. Periapical radiographs at implant surgery: a) #30 site and b) #19 site.

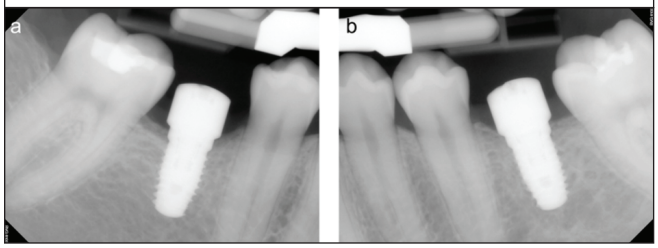
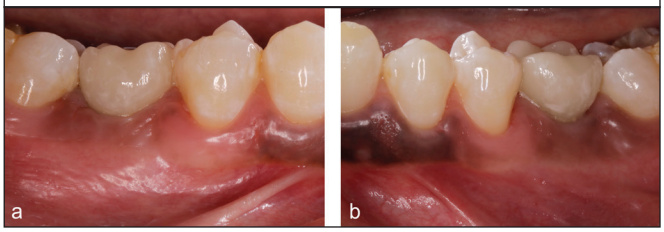


Figure 8. Definitive implant-supported crowns: a) #30 implant and b) #19 implant.



Investigation into the influence of nonresorbable GBR barrier membrane size on clinical and patient-centered outcomes is warranted. Certainly, smaller alveolar ridge defects are easier for clinicians to manage. Whether or not intentionally minimizing membrane size affords any meaningful benefit when controlling for defect severity appears unstudied.

Conclusion

Intentionally limiting GBR barrier membrane size may have contributed to a favorable postoperative course for the patient. The targeted GBR approach simplified and shortened the procedure and minimized material cost. The alveolar ridge defects in this case were small and could have been managed via a wide range of alveolar ridge augmentation options. Extensive defects require larger procedures involving advanced materials and techniques, and typically more protracted recovery periods. However, the principle of judiciously selecting membrane dimensions appears applicable generally when utilizing dPTFE barrier membranes.

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Enhanced Submentoplasty as an Adjunct to Orthognathic Surgery for the Improvement of the Neck-Throat Point

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Abstract

Orthognathic surgery has been used to enhance the function of the maxillomandibular complex with numerous positive effects on facial esthetics, as it can profoundly alter the skeletal architecture of the face. Numerous adjunctive surgical techniques are used to enhance the overall cosmetic results of orthognathic surgery to include the following: genioplasty, midface augmentation, rhinoplasty, fillers, and liposuction. Mandibular advancement, submental liposuction and genioplasty are all techniques that help to define the neck throat point (NTP), minimize submental sagging, and enhance throat length (TL) in order to establish a more harmonious facial profile. However, these procedures may still be insufficient to define the NTP in the low hyoid, retrognathic patient. This report presents the case of an adult male, with a non-existent NTP and retrognathia, who underwent corrective orthognathic surgery with the novel enhanced submentoplasty and a suture assisted resuspension of the platysma in order to establish the NTP, increase TL, minimize submental sagging, and enhance mandibular border definition.

Keywords: orthognathic surgery; facial cosmetic surgery; face lift

Introduction

Orthognathic surgery has been used to enhance the function of the maxillomandibular complex with numerous positive effects on facial esthetics, as it can profoundly alter the skeletal architecture of the face and ultimately influence the soft tissue drape.[1] Numerous adjunctive surgical techniques have been discussed in literature to enhance the overall cosmetic results of orthognathic surgery to include the following: genioplasty, midface augmentation, rhinoplasty, fillers implants, and liposuction.[2,3]

The following report presents the case of an adult male, with a non-existent neck throat point (NTP) and retrognathia, who underwent corrective orthognathic surgery with the enhanced submentoplasty and a suture assisted suspension of the platysma in order to establish the NTP, increase throat length (TL), minimize submental sagging, and enhance mandibular border definition.

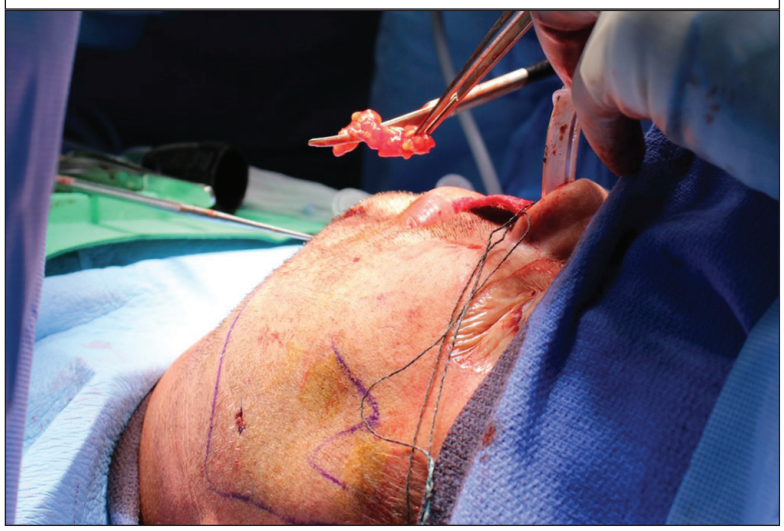
Case

History & Physical, Treatment Planning & Consent: A 35 year-old male presented to the Department of Oral and Maxillofacial Surgery at a large US Army military post stating, "I do not like my smile, and my chin is little." After extensive discussion with him, he voiced he was also unhappy with his open bite and lack of chin projection and definition. His past medical history was

unremarkable except for a spinal fusion surgery of the C5-C6 vertebrae completed in 2013.

During an initial comprehensive clinical evaluation and orthodontic consultation he was diagnosed with mandibular anterior-posterior (AP) hypoplasia, maxillary AP hypoplasia, apertognathia, maxillary absolute transverse discrepancy, mandibular asymmetry, moderate maxillary and mandibular crowding, and a non-existent NTP. After compiling his problem list, a treatment plan was developed that included a two prong approach: first to undergo a surgically assisted rapid palatal expansion that was completed in December 2014 to coordinate his maxillary and mandibular arches; second, an orthognathic surgery of the upper and lower jaws would be undertaken.

Figure 1. Lipectomy.



In August 2016, the patient returned to the oral surgery clinic for his final orthognathic work-up, presenting with apertognathia, chin point off to the right, and an ill-defined neck throat point. A final orthognathic treatment solution was planned using virtual surgical planning. The plan included a bilateral sagittal split osteotomy (BSSO) of the mandible to correct the mandibular cant and the midline discrepancy. A maxillary Lefort I osteotomy with 5 mm anterior advancement and posterior differential impaction would align the jaws and close the apertognathia. The horizontal mandibular osteotomy (HMO) would help balance out the newly improved facial profile by giving him a stronger chin. After reviewing the pre-surgical treatment plan it was noted the patient would still have an ill-defined neck throat point of approximately 180 degrees. The patient was informed of these findings and the surgical team offered him enhanced submentoplasty in order to establish his neck throat point, define his mandibular border, and de-bulk excess adipose tissue in the submental region.

Surgical Procedure: Thirty minutes prior to incision, the patient was pre-medicated with dexamethasone 8 mg and an intravenous infusion of ampicillin/sulbactam 3 g; both were re-administered at the six-hour interval. Following induction, the patient was nasally intubated under general anesthesia and remained so for the duration of the case with a mean arterial pressure goal of approximately 60 mm Hg.

The 3-jaw orthognathic surgery was completed primarily via a mandible first approach BSSO with a 3.5 mm advancement and transbuccal bicortical screw placement. Attention was then directed to the Lefort I osteotomy that was completed via transoral osteotomy and rigid fixation with multiple plates and screws. Final movements of the maxilla included 4.5 mm advancement and a posterior differential impaction. The HMO was then completed via the intraoral route, and the chin was advanced approximately 5 mm and fixated with a standard five screw-hole advancement plate. After completing the orthognathic surgery, his occlusion was verified and the patient's NTP was assessed. As anticipated, the NTP remained ill-defined.

The patient was again re-prepped with povidone-iodine and sterile drapes reapplied. A sterile marking pen was used to design the proposed surgical incisions. Tumescent fluid, consisting of 50 ml 2% lidocaine mixed with 1 ml epinephrine 1:1000 in 1 L of normal saline, was then injected in the subcutaneous plane with a 22-gauge spinal needle to aid in surgical hemostasis and define the surgical plane. Local anesthesia was initiated along the pre-designed surgical incisions with 2% lidocaine with 1:100,000 epinephrine. A 2.5 cm midline submental incision was made within a resting skin tension line 1 cm posterior to soft tissue pogonion.

After incision, 2 mm liposuction cannulas were inserted in the supra-platysmal plane and used to pre-dissect the surgical plane. To avoid trauma to vessels and nerves of the neck, the liposuction cannulas should stay within the anterior border of the sternocleidomastoid muscles, the inferior border of the mandible, and the superior border of the thyroid cartilage.[4] These cannulas were passed repeatedly in order to facilitate easier dissection with facelift scissors. After utilizing the facelift scissors and establishing the submental lipocutaneous flap, the

Figure 2. Dissection in sub-cutaneous plane.

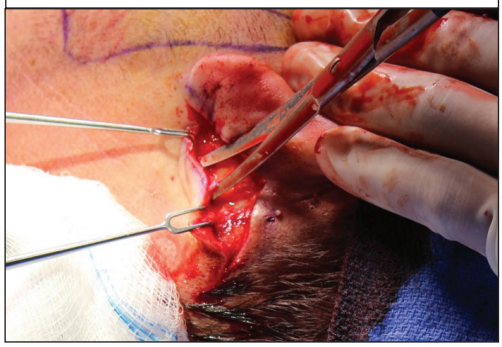
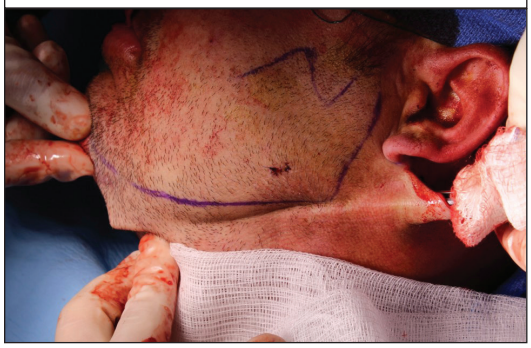


Figure 3. Dissection continued to midline.



platysma was visualized and direct lipectomy of significant submental fat deposition was completed (Figure 1). A 3 mm liposuction cannula connected to suction was used to remove additional adipose deposits on the supra-platysmal side of the dissection.

A lighted retractor facilitated visualization within the submental lipocutaneous flap. Meticulous hemostasis was achieved using bayonet bipolar forceps. The midline platysma was then inspected for dehiscences, which were identified and subsequently closed with 4-0 simple interrupted sutures to avoid functional banding. Attention was then directed to the posterior auricular incision, which were made via a retroauricular approach with a posterior extension to the hairline. Facelift scissors were used to develop a subcutaneous soft tissue pocket (Figure 2). Two mm liposuction cannulas (Figure 3) were passed inferiorly and anteriorly to connect the posterior auricular soft tissue pocket to the pre-established submental soft tissue pocket. Facelift scissors were then used to create a tunnel, to allow for the passage of the suspension sutures.

In order to define the NTP, a double throw of 2-0 suture was placed in the platysma at the desired position of the NTP 2 cm lateral to the midline. This suture was then passed though the contralateral soft tissue tunnel and sutured to the mastoid fascia (Figure 4a, 4b). After placing this suspension suture bilaterally they were simultaneously tightened to define the NTP, enhance CL and provide a balanced harmonious lower face profile.

The skin incisions were closed with 4-0 deep sutures and 6-0 running sutures to re-approximate the skin. The final NTP was significantly improved over orthognathic surgery alone (Figure 5). Bacitracin was placed over the wounds, and a compression dressing was used to prevent post-operative seroma/hematoma formation. The patient was allowed to emerge from general anesthesia in the operating room.

Post-Op Follow-Up & Clinical Results: Per the residency standard protocol, the patient was admitted to the medical center overnight. He reported some minimal post-operative discomfort, bilateral cranial nerve V2 and V3 paresthesia and minimal nausea. His nausea was successfully treated with antiemetics. The patient was maintained in a supportive, elastic compression head wrap and was asked to wear it continuously for one week post-operatively. The patient was discharged from the hospital on post-operative day two, with a standard post-operative orthognathic medication regimen of amoxicillin/clavulanate tablets, ondansetron tablets, oxymetazoline nasal spray, pseudoephedrine tablets, ibuprofen, docusate sodium, and oxycodone and acetaminophen tablets.

Figure 4. Left: Suspension sutures to midline. Right: Suspension suture from midline to mastoid fascia.

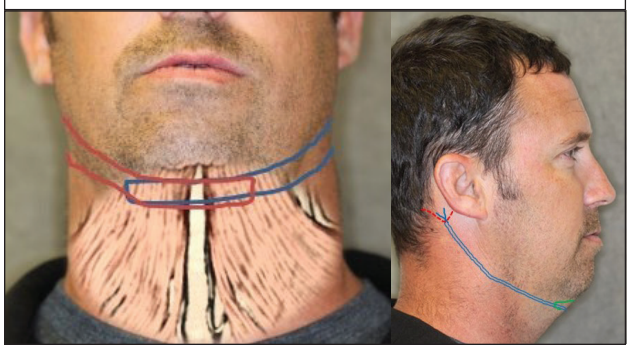


Figure 5. Left: Orthognathic surgery alone. Right: Orthognathic surgery plus enhanced submentoplasty.

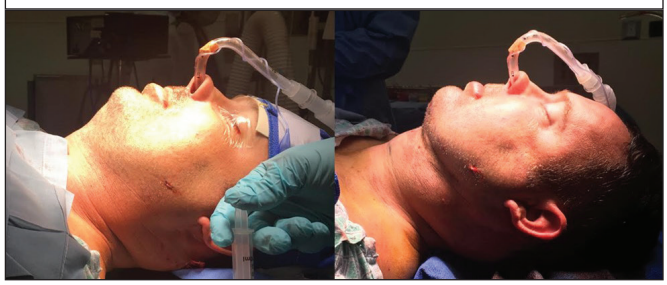
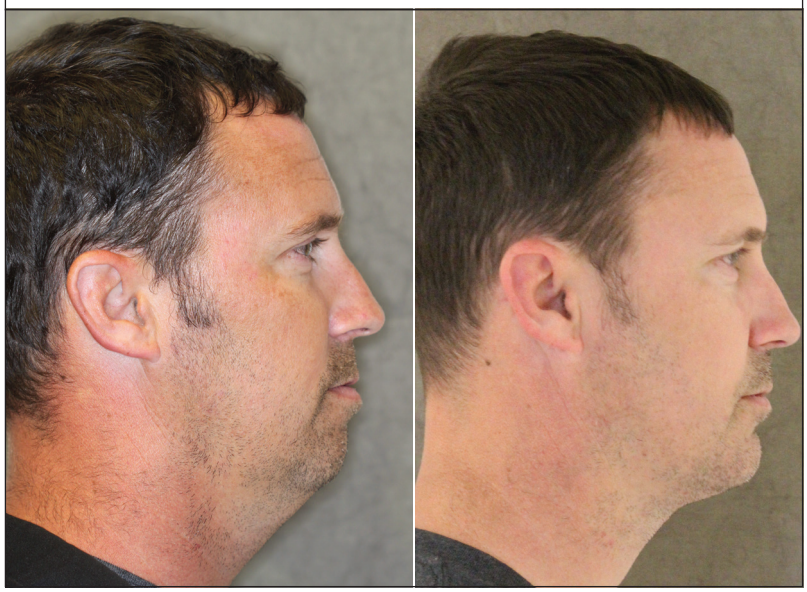


Figure 6. Patient profile before (left) and after (right) procedure.



Follow up appointments were scheduled at one week, two weeks, four weeks, two months, three months, and five months. The patient stated in his initial follow-up appointments he had some minimal neck discomfort with tightness on rotation that resolved by his one-month follow-up. Additionally, at his first week follow-up, a seroma had formed behind the left posterior auricular incision that resolved spontaneously by his next follow-up. His pain was adequately controlled with nonsteroidal anti-inflammatory drugs by post-operative week two. He was highly satisfied with his cosmetic outcome stating that he, close friends, and family all noted a significant improvement in his profile (Figure 6). At the five month follow-up, he still had bilateral ipsilateral mandibular (cranial nerve V3) paresthesia that was improving. The patient was highly satisfied with his cosmetic outcome and would likely undergo the surgical procedures again.

Discussion

Enhanced submentoplasty in conjunction with orthognathic surgery is an excellent adjunct to define the neck throat point. It is a technique that can be successfully applied when mandibular advancement and genioplasty are insufficient or not warranted to enhance a patient's NTP, cervicomental angle, and throat length. Initially employed as a suture suspension platsymaplasty by Giampapa et al, the technique is usually completed without the additional skeletal architecture changes of orthognathic surgery. While numerous refinements of the sutures suspension platysmplasty have been described in the literature, it has yet to be paired with orthognathic surgery.[4]

Orthognathic surgery, specifically mandibular advancement, is usually sufficient to aid in the correction of minimal neck deformities by establishing a more harmonious facial profile and NTP. Occasionally we encounter patients, many with low hyoids, for whom a mandibular advancement seems to unsuccessfully address their facial profile. These patients have typically been offered HMO and submental liposuction in order to address their cosmetic concerns about their neck and chin. Their satisfaction with post-operative occlusion and facial profile remain high but they are less than satisfied with their neck definition. This led us to employ the enhanced submentoplasty technique more frequently in order to obtain higher overall patient satisfaction. The procedure itself, while daunting to those who do not regularly do extensive soft tissue dissections, is relatively straightforward and employs many of the techniques already ubiquitously adopted by orthognathic and cosmetic surgeons.

Enhanced submentoplasty is presented as a technique to improve overall patient satisfaction in the patient undergoing orthognathic surgery. The procedure can be safely completed in conjunction with orthognathic surgery. By combining the surgeries, we are able to successfully address the specific treatment goals and cosmetic concerns of patients, whose diagnosis may not be amenable to orthognathic surgery, HMO, submental liposuction, or platysmaplasty alone.

Numerous descriptors of the submandibular and submental region, in profile, have been employed in orthognathic, orthodontic, and plastic surgery journals. In our practice, treatment plans are developed in a systematic approach including pre-operative radiographs, photographs, and models. We reference the NTP qualitatively as excessive, minimal, absent, or normal and use Dedo Classification of Facial Profiles.[5] Orthodontic literature describes the harmonized throat length (NTP to Pogonion) 58.2+/-5.9 in females and 61.3+/-7.4 in males.[6] Alternatively, the NTP has been quantitatively described as the cervicomental angle (CM) that is defined as the horizontal plane of the submental region and the vertical plane of the neck.[7] Generally, a CM between 90-100 degrees is associated with a youthful neck. A reasonable treatment objective would result in a CM within normal

limits of 105-120 degrees, depending on the pretreatment CM, Dedo classification, and treatment objectives.[8]

Conclusion

Mandibular advancement, submental liposuction and genioplasty are all techniques which help to define the (NTP), minimize submental sagging and enhance throat length in order to establish a more harmonious facial profile.[9] Orthognathic surgery has a wonderful track record of establishing excellent bony architecture for appropriate soft tissue drape, but may still require additional soft tissue augmentation as a viable option to correct certain neck deformities. Orthognathic surgery may still be insufficient to define the NTP in the low hyoid, retrognathic patient.[10] Soft tissue techniques, specifically the suture suspension platysmaplasty as first described by Giampapa et al in 1993, can increase the level of access to the submental region, provide the soft tissue augmentation to define the NTP, and lengthen throat length, which may still be absent after orthognathic surgery.

Author's Note

Patient's authorization and release consent form for clinical and radiographic photographs was acquired and archived with the authors. This case report is HIPAA-compliant with protection of individually identifiable health information.

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Practical Steps toward Prosthodontic Rehabilitation of Free Fibula Flaps: Sequential Techniques of Two Cases

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MAJ Devin Whalstrom
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Abstract

The free fibula flap has become a relatively common reconstruction modality for composite defects of the maxillo-mandibular skeleton. After establishment of vascular and osseous integration, the next functional goal would include prosthetic rehabilitation. There are specific biological and bio-mechanical parameters required to optimize the success of prosthodontic rehabilitation. These requirements translate to a specific set of surgical modifications to the composite free flap. These case illustrations will outline the sequence of events from a well-established free fibula flap to implant supported hybrid denture. This case review will emphasize anatomical variation of the fibular bone, soft tissue profile, and spatial orientation in light of prosthodontic goals.

Background

The osteomyocutaneous fibula free flap (FFF) has become a ubiquitous reconstructive option for ablative defects of the mandible. Although the biological environment and underlying indication in which this type of microvascular free flap varies, ideally the final and most comprehensive reconstruction will include dental rehabilitation. Uniquely, with the robust tissue composite characteristic of the FFF, there are specific modifications that need to be included in order to harmonize the tissue replacement benefits of the flap with biological prerequisites for implant supported dental prosthetics. These illustrative case reports will outline a chronological progression for preparing the FFF for long-term implant supported prosthetic viability.

As a hard tissue platform for the integration of endosseous dental implants, the fibula bone has several unique structural characteristics that distinguish it from the native mandible. Cortical to cancellous bone ratio in the fibula is consistently higher than a native mandible. This allows for assured primary stability with the use of generally applied implant osteotomy sequences.[1] Engagement of the endosseous implant at both alveolar and inferior border cortices is feasible and often times accomplished to further enhance primary stability.[2,3] Cross sectional orientation of the fibula is uniquely triangular at certain locations and exact fixation position can dictate implant platform trajectory. Since in most cases the axial implant position is primarily dependent on existing surrounding bone, it would be prudent to include the final prosthetic vision in the initial calculus that guides the location and orientation of the fibular reconstruction. When evaluating bone volume loss in comparison to other free flaps used to reconstruct the mandible, the FFF demonstrates the least amount of bone volume loss per computed tomography (CT) imaging analysis.[4] Most currently, there have been several multi-disciplinary work flow algorithm recommendations that begin with the "end in mind" and eventually streamline and consolidate what was once a very fragmented treatment sequence.[5,6] The aim of this case series is to highlight the phase of treatment in which an already consolidated FFF is prepared for implant supported fixed or removable prosthetic.

Figure 1. Soft tissue profile of the free fibula flap (FFF).

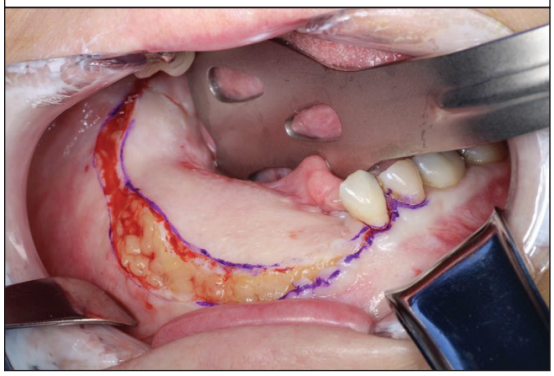
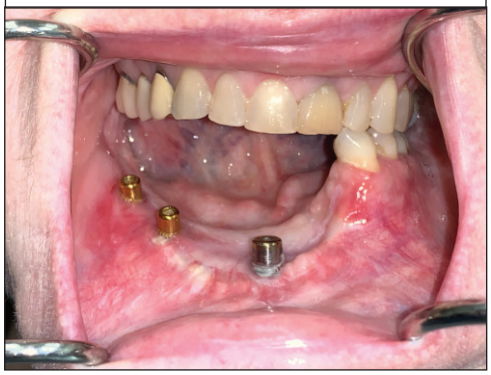


Figure 2. Inter-occlusal dimension.



Case Presentation

Case #1: A 56 year old female with a well-integrated two segment composite FFF, secondary to ablation of an extensive chronic sclerosing osteomyelitis of the mandible, has a flap that exhibits a robust cutaneous margin with a remarkable subcutaneous adipose tissue (Figure 1). The myocutaneous portion of the flap is lifted to expose the fibula bone with subsequent placement of endosseous dental implants in alignment with the bony housing. An exaggerated inter-occlusal clearance is common in situations in which the native mandible is not atrophic, and the fibula free flap is adapted at the inferior border of the idealized mandible (Figure 2). Subcutaneous debulking at the time of implant placement will result in noticeable squamous metaplasia. This is noted clinically with a regression of overall dermal surface area secondary to a remarkable mucosalization of the skin flap. The initial transitional denture was retained with locators and subsequently transitioned with placement of angle correcting multi-unit abutments. The desired orientation of the multi-unit abutments was determined extracorporeal on a fully mounted articulator. Once the desired location was determined, the spatial orientation of the multi-unit abutments was transferred to the patient using a splinting acrylic carrier (Figure 3). The patient was subsequently fitted with an implant supported fixed denture as the final prosthesis (Figure 4).

Case #2: A 60 year old male was presented with a well integrated three segment composite FFF secondary to ablation of stage III medication related osteonecrosis of the jaw. Uniquely, this is a case in which the first free flap attempt partially failed with loss of the middle and left fibula segments with viable retention of the right fibula segment. The revision surgery which incorporated the contralateral fibula is noted in the middle and left body segments. Comparatively, it is important to note the bucco-lingual width discrepancies of the neo-alveolus (fibula bone) when comparing the right verses the middle and left fibula segments (Figure 5). Further reinforcing the value of idealizing the orientation of the fibula during the treatment planning process was in an effort to maximize the neo-alveolus platform width. Vestibuloplasty is accomplished in a standard fashion, leaving behind a very thin layer of periosteum, minimizing any residual muscle fibers (Figure 6), following a direct transition to placement of angle correcting multi-unit abutment based on pre-determined final prosthetic orientation. The material was adapted and retained using a pre-formed clear acrylic stent. The acrylic stent was buffered with a soft reline and retained by light curing

Figure 3. Extracorporeal orientation of multi-unit abutments.

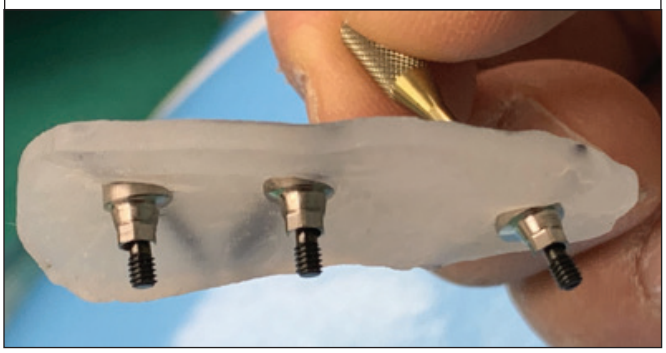


Figure 4. Finalized hemi-arch prosthetic rehabilitation.

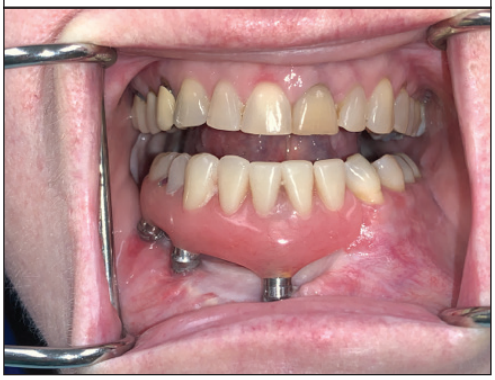


Figure 5. Exposed fibula with varied alveolar width.

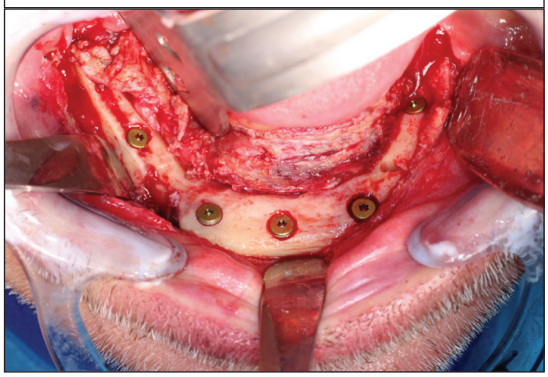
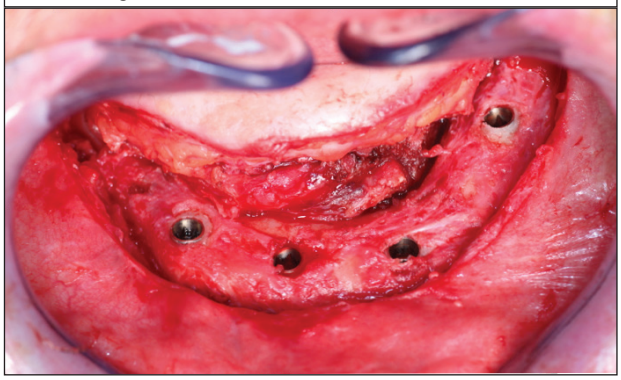


Figure 6. Revised free fibula flap (FFF) with idealized width of alveolar ridge.



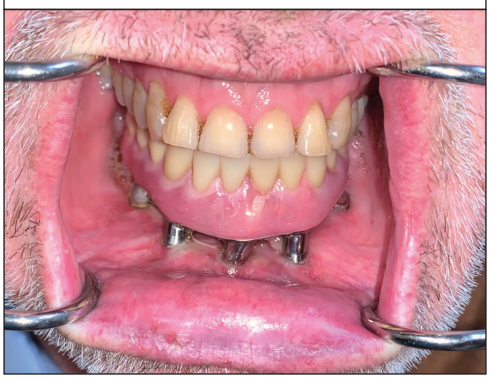
flowable acrylic to bond the splint onto the transfer copings. After three weeks of healing, the prosthetic screws stabilizing the acrylic stent were removed and the splint was discarded. Long term clinical inspection demonstrates generalized soft tissue profile reduction around the dental implants with reconfiguration of vestibular sulcus creating space amenable for hygienic measures (Figure 7).

Discussion

As a hard tissue replacement option, a well executed FFF has shown to have a predictably high osseous integration rate. Undoubtedly, without bony fusion at the native mandibular bone interface or in-between fibular segments, endosseous implants can still osseointegrate without continuity of the basal mandible. Leading to the awareness that the first diagnostic step in evaluating the readiness of a "well healed" FFF is image confirmation of union at the junctional approximations of bony segments.[7,8] A general survey of the literature will support the notion that osseointegration of dental implants placed in the fibula are above 90 percent, and usually maintain that level for the 1-year and 5-year time spectrum.[9]

The spatial orientation of the fibula "neo-mandible" should be considered in light of the ideal alveolar table contour that is desired for implant retained/supported "hybrid" prosthetics.[10] The platform usually is preferably flat with minimal rounding of the buccal and labial osseous line angles. The second case illustrates this variability by including fibular segment from two different harvest sites. By preemptively considering the prosthodontics goals on the second revision surgery, the contralateral fibula was harvested with a priority to orient the bone in an effort to have the widest portion of the cross sectional "triangle" at the alveolar crest. This position accommodates the requirement of having circumferential bone around the implant as well as a flat alveolar table that allows for idealized counters of the intaglio surface of the prosthetic, further accommodating a hygienic peri-prosthetic environment.

Figure 7. Finalized full arch prosthetic rehabilitation.



The first sequential phase towards dental implants would include placement of dental implants and selective removal of the sub-dermal adipose tissue. The incision access usually only releases up to 180 degrees of the circumference of the skin flap. It has been the authors' routine observation that aggressive debulking of the adipose tissue without excision of the dermal layer leads to a peripheral transition of the dermis into mucosal epithelial tissue. This process does not clinically manifest as marginal wound dehiscence with secondary epithelialization, but instead intact skin margins over the course of 2-3 months display a certain form of squamous metaplasia. This repeated observation is theorized to manifest because of the diminution of capillary nutrient supply to the adnexal structure of the epidermal layer. This further leads to hypo-metabolic atrophy of adnexal tissue with the surrounding remnant extracellular matrix to serve as a stable scaffold for the migration, incorporation, and integration of peripheral epithelial based pluripotent stem cells.

Vestibuloplasty following placement of dental implants to the oral cavity is a common procedure. The procedure attempts to define the soft tissue contours of the alveolar ridge with the goal of establishing firmly adhered, preferable keratinized peri-implant tissue, to create a hygienic environment for the prosthetic. Additionally, any residual

tissue from the flap can be transposed to reinforce the establishment of a labial or lingual sulcus. A standard supraperiosteal dissection is used to create a marginal zone of thin and preferably adhered peri-implant tissue. There are numerous options for interposition onlay material, to include healing by secondary intention, autograft, allograft, and xenograft.

In this case series, a decellularized porcine derived urinary bladder matrix (UBM) was used. Porcine UBM has been reported with much success in other surgical disciplines for application in acute and chronic wounds, burn wounds, and other surgical reconstructions.[11] Previous oral & maxillofacial case reports using porcine UBM have been limited. One reported case used the UBM to salvage a FFF skin paddle.[12] The other case used UBM as a temporomandibula joint (TMJ) meniscus reconstruction.[13]

These products are different from other available dermal matrix products, in that they have an intact lamina propria and epithelial basement membrane. Additionally, they are not crosslinked, theoretically allowing for more effective cellularization and vascularization in the wound bed compared with cross-linked products.[14,15] The porcine UBM is available in 1, 2, 3, or 6 layers, and also as a powder that can be flexibly applied to multiple body surfaces. The authors favor the 2- or 3-cell layer matrix due to the general handling characteristic that allows for ease of passage and retention of positional sutures, non-deformation upon wetting, and contact stability upon placement onto the wound bed. The multilaminate variety of the porcine UBM allows for variation in mechanical strength and can be tailored towards the biological requirement of the recipient site.[16]

An additional regenerative potential of porcine UBM is that upon harvest and decellularization of the urinary bladder matrix the urothelial basement membrane structure is left intact. The presence of this smooth, dense structure is thought to be advantageous in prevention of adhesion formation at the site of implantation.[17] Ultimately, most if not all, interposition materials serve as cellular induction templates within a scaffold matrix, the desired outcome being deposition of new site appropriate host-derived tissue and early angiogenesis. The early angiogenesis is a beneficial feature that will potentially offset the risk of bacterial induced catabolic inflammation. Additionally, the unanswered clinical question is whether applying products like UBM strategically in the midst of keratinized tissue might promote the recruitment of keratinized like epithelium. Taking into account the host-derived influx of migratory cells, perhaps slight surgical modification, might lead to more "resilient" tissue being available around the dental implants.

A standard format to retain the interpositional tissue graft will include some type of surgical splint. A more appropriate name would be "tissue conformers," as they can be designed with extensions that can modify the surrounding vestibular apparatus and peri-oral musculature.[18] The first case demonstrated a method for fixation when the provisional prosthetic or prosthetic armamentarium is not available. Simply drilling standard fixation screws through an acrylic splint would be feasible to obtain retention by osseous screw engagement. The more contemporary method would involve using the provisional restoration or a similar construct to engage multiunit abutments secured to the transfer copings, which then retains the tissue conformer. This method is much more retentive, obviates any issues with fixations screw loosening, anesthetic for removal, and moves the patient further along towards dental rehabilitation by employing shared prosthetic parts. Additionally, it allows for quick clinical assessment and replacement of tissue conformer if further modification is required.

Conclusion

After confirmation of a well integrated fibula free graft, a small series of surgical modifications can optimize long term dental rehabilitation. Preemptively, if possible, spatial orientation of the fibula should aim towards the ideal prosthetically favorable alveolar crest platform. Soft tissue debulking can be done concurrently with dental implant placement with resulting diminution of dermal tissue surface area. Porcine derived matric (UBM) is a consistent wound modifying, interpositional material that has good physical and biological advantages. Tissue conformers made with utilization of prosthodontics materials can maximize ease, retention, and consolidation of effort. Overall, considering simple biological criteria and utilization of fundamental "pre-prosthetic" surgical techniques, a well healed FFF can predictably be augmented to create a platform that supports a successful dental rehabilitation.

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Time- and Species-Dependent Bacterial Adhesion to Titanium over Short Exposure Periods: An In Vitro Study

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Abstract

A considerable percentage of dental implant patients experience biofilm-mediated peri-implant disease following transmucosal abutment application. Bacterial adhesion is an early step in biofilm development. Our purpose was to assess adhesion of specific bacterial species to titanium over short exposure periods. Eight bacterial species were selected for this analysis: *Streptococcus oralis*, *Streptococcus mitis*, *Gemella haemolysans*, *Streptococcus gordonii*, *Streptococcus sanguinis*, *Neisseria flavescens*, *Streptococcus salivarius*, and *Pseudomonas aeruginosa*. We cultured each species with appropriate media and exposed titanium foil discs to the bacteria for 60, 15, 5, 1, or 0.25 minutes. Optical density at 600-nm wavelength (OD600) was assessed for the baseline inoculum and each species/exposure combination. The proportion of bacteria adherent to titanium was determined for each experimental condition. Striking titanium adhesion was noted for all evaluated species even when exposure time was limited to 15 seconds. Strategies to limit bacterial adhesion at dental implant surfaces may offer potential for improved treatment outcomes and preservation of peri-implant health.

Keywords: bacterial adhesion; biocompatible materials; biofilms; dental implants; titanium; dental plaque

Introduction

Titanium is a biocompatible material supportive of direct bone contact at the light microscope level.[1] When titanium implants are used to replace missing teeth, exposure of titanium surfaces to bacteria is exceedingly common and possibly inevitable. The supracrestal tissues investing an implant and transmucosal abutment include a connective tissue adhesion and an epithelial attachment, analogous to the supracrestal attached tissues around teeth.[2-4] During establishment of this interface between the soft tissue and the implant/abutment, a limited amount of bone resorption can be anticipated.[4] Indeed, at sites treated with bone level implants, the first bone-implant contact typically occurs approximately 1.5 mm apical to the implant platform.[2,3] Peri-implant bone loss can be accompanied by mucosal recession.[4-6] Abutment and implant surfaces that lie coronal to the epithelial attachment are subject to pellicle formation and bacterial adhesion. Thus, supramucosal and submucosal biofilm formation on titanium abutment and implant surfaces represents a practical reality of implant dentistry, leading to significant disease burden for implant patients worldwide. In perspective, the patient-level prevalences of peri-implant mucositis and peri-implantitis may be as high as 65% and 15%, respectively.[5-9] Clearly, dental implants are susceptible to biofilm-mediated inflammatory lesions. Risk indicators such as ineffective oral hygiene, history of periodontitis, inconsistent professional maintenance, smoking, and history of radiation therapy may place patients at higher risk for these biologic complications.[5,6]

In addition to bacterial exposure to titanium surfaces during normal function or development of an inflammatory lesion, another opportunity for bacterial access to titanium occurs at the very introduction of the metal to the oral cavity—at implant surgery. Intraoperative bacterial contamination of implant surfaces has been suggested as a cause of early implant failure[10,11] and as a justification for perioperative antibiotic use.[12-17] Adhesion is a critical step in bacterial interaction with titanium, preceding biofilm formation and clinical infection.[18-21] The purpose of the present study is to assess bacterial adhesion to titanium surfaces over short periods of exposure.

Table 1. Growth conditions for the bacterial species assessed.

Genus and species	Reference Number	Rotation (rpm)	Media	Time to Maximum OD_{600} (hours)
Streptococcus oralis	ATCC #6249	0	BHIB + 1% IsoVitaleX	18 to 24
Streptococcus mitus	NCIMB #13770	0		18 to 24
Streptococcus gordonii	ATCC #51656	0	MHB + 5g/L yeast extract + 2.5 g/L NaCl + 2.5 g/L Na_2HPO_4 + 1% IsoVitaleX	18 to 24
Pseudomonas aeroginosa	ATCC #10145	0		18 to 24
Streptococcus sanguinis	ATCC #10556	250		18 to 24
Streptococcus salivarius	ATCC #13419	250		18 to 24
Neisseria flavescens	ATCC #13120	250		24 to 36
Gemella haemolysans	ATCC #10379	250	TSB + 5g/L yeast extract + 1% IsoVitaleX + 1% Tween-80	24 to 36

rpm = revolutions per minute, OD600 = optical density at 600 nm, BHIB = brain heart infusion broth, MHB = Mueller-Hinton broth, TSB = tryptic soy broth

Materials & Methods

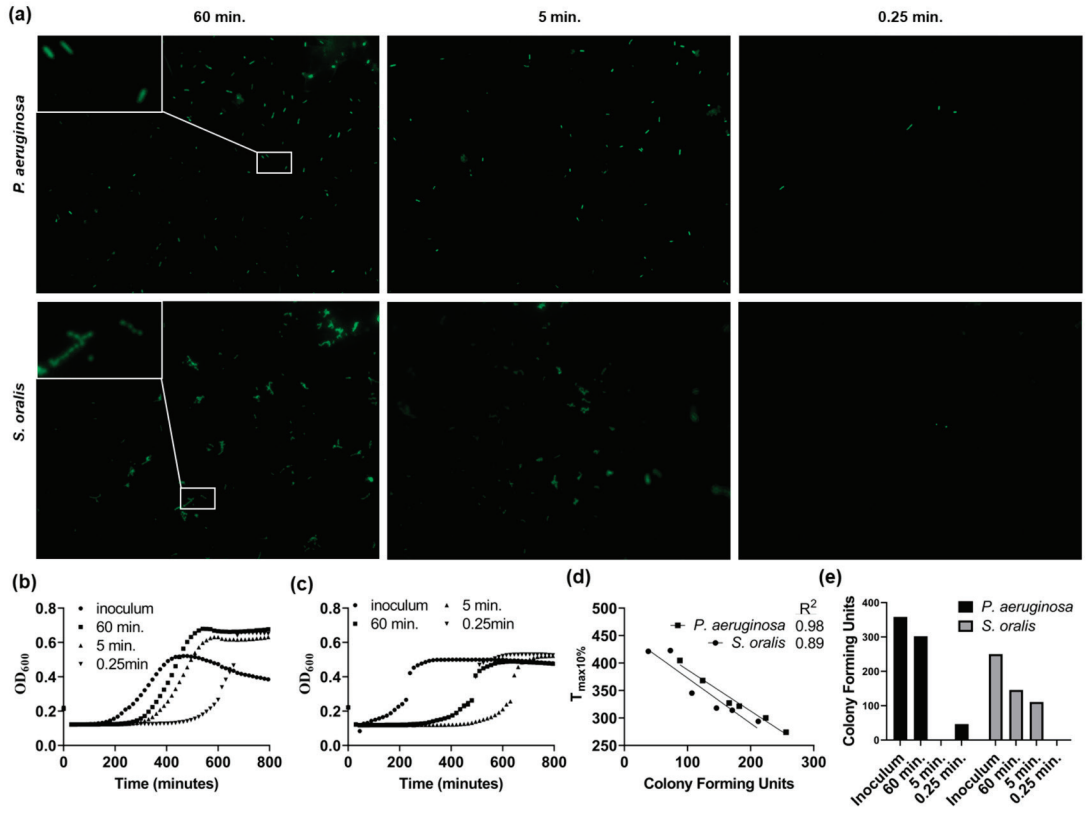
Bacteria & Growth Conditions: Eight bacterial species were selected for analysis in this study: *Streptococcus oralis*, *Streptococcus mitis*, *Streptococcus sanguinis*, *Streptococcus gordonii*, *Streptococcus salivarius*, *Neisseria flavescens*, *Gemella haemolysans*, and *Pseudomonas aeruginosa*. All organisms were cultured on brain heart infusion agar. For broth cultures of *G. haemolysans*, we used tryptic soy broth with 5 g/L yeast extract, 1% enrichment medium, and 1% polysorbate-80. We used brain heart infusion broth (BHIB) with 1% enrichment medium for broth cultures of *S. oralis*, *S. mitis*, *S. sanguinis* and Mueller-Hinton broth with 5 g/L yeast extract, 2.5 g/L sodium chloride, 2.5 g/L disodium phosphate, and 1% enrichment medium for broth cultures of *S. gordonii*, *S. salivarius*, *N. flravescens*, and *P. aeruginosa*. *G. haemolysans*, *S. sanguinis*, *S. Salivarius*, and *N. flavescens* were rotated at 250 rpm during growth, while other organisms remained unmoved. We formulated artificial saliva in the manner of McKnight-Hanes and Whitford, without the addition of sorbitol.*22* Dilution media was composed of 20% BHIB in phosphate buffered saline (PBS) with the pH adjusted to 7.2. Bacterial growth conditions are summarized in Table 1.

Titanium Adhesion Assay: Bacteria were grown to near mid-log from glycerol stock for four to six hours. Growth culture was gradually diluted into artificial saliva, by making three, three-fold dilutions—first into dilution media, then into half dilution media and half artificial saliva, and finally into artificial saliva. We added 500-µl volumes of the 5-3 diluted cultures to 7-mm diameter, 0.025 mm thick 99.6% titanium foil discs (7440-32-6) in 24-well plates. An additional 500-µl volume remained under experimental conditions as the baseline inoculum. The exposure times of the titanium foil discs to the tested bacterial species varied. Each plate was incubated at 37° C and gently rocked for 60, 15, or 5 minutes or incubated at room temperature for 1 minute or 15 seconds. Then, the culture was gently removed from the well. Each well was washed with 2 ml, then 1 ml, and finally 1 ml using dilution media. Discs and 10 µl of the baseline inoculum were gently transferred to 1 ml of appropriate growth media and incubated for 2 hours (5% CO2, 37° C). We transferred a 200-µl volume from each growth culture to a 96-well plate and further incubated the samples for 30 minutes. The plate was then sealed with transparent film for spectrophotometric analysis, with a microplate reader set at 37° C for at least 16 hours, recording optical density at 600-nm wavelength (OD600) every 20 minutes. We repeated each bacterial adhesion experiment four to eight times, including OD600 assessment of the inoculum.

To relate growth curves with colony counts, 12 three-fold serial dilutions were established for each bacterial species. A 10-µl aliquot was plated on a 150-mm agar plate containing appropriate media and grown overnight in a 37° C incubator. An additional 10-µl aliquot was added to 150 µl of appropriate media in a 96-well plate. The plate was analyzed in the microplate reader at 37° C for at least 16 hours, recording OD600 every 20 minutes. We read colony counts on the agar plates after 24 to 48 hours.

Bacterial Staining: We performed bacterial staining

Figure 1. Adherence of *Pseudomonas aeruginosa* and *Streptococcus oralis* to titanium. Acridine-orange-stained bacteria adherent to titanium discs at three time points: 60, 5, and 0.25 min (a). *P. aeruginosa* rods and *S. oralis* cocci in chains are displayed in the insets. Inoculum and adherent bacterial growth curves [optical density at 600 nm (OD600) versus time] of *S. oralis* (b) and *P. aeruginosa* (c). Time at 10% of maximum optical density (Tmax10%) versus colony forming units (CFUs) identified on agar plates (d). Estimation of *P. aeruginosa* and *S. oralis* colony forming units adherent to titanium at 60, 5, and 0.25 min (e).



according to the technique of Ladd and coworkers.[23] After washing non-adherent bacteria from the discs, we fixed discs with 1 ml of 0.1 M sodium cacodylate, 0.5% glutaraldehyde for 60 minutes. Then, discs were washed twice with 2 ml of PBS, stained for 2 minutes with 1 ml of acridine orange (#158550), 5 mg/ml in 1% glacial acetic acid, and again washed. We counterstained the discs with 1 ml of malachite green (#HT80216) for 10 minutes. Discs were then washed, dried, and viewed at 488 nm by 400X magnification.

Growth Curve & Statistical Analyses: The OD600 readings, reported as mean ± SEM, were curve-fitted using a sigmoidal four parameter logistic regression. Maximum and minimum optical densities were used to calculate the OD600 value at 10% of the maximum. We then interpolated the time (Tmax10%) at which the growth became exponential. We plotted Tmax10% versus colony count and used linear regression to relate data from titanium binding growth curves to live bacteria counts. The percentage of bacteria adherent to titanium discs was calculated by dividing the Tmax10% of the titanium-adherent by Tmax10% of the inoculum.

Table 2. Overall mean percent adherent by species, including all time points.

Species	Number of measurements (%)	Repetions	Mean percent adherent (SD)
Streptococcus oralis	20 (10.6)	4	52.8 (7.0)
Streptococcus mitis	20 (10.6)	4	69.3 (6.6)
Streptococcus salivarius	35 (18.5)	8	50.8 (5.8)
Streptococcus gordonii	20 (10.6)	4	49.6 (5.7)
Streptococcus sanguinis	27 (14.3)	6	57.9 (7.6)
Gemella haemolysans	20 (10.6)	4	58.7 (4.4)
Neisseria flavescens	27 (14.3)	6	58.5 (7.1)
Pseudomonas aeruginosa	20 (10.6)	4	68.8 (6.0)

Significance level set at 0.05 for all statistical analyses. Descriptive

statistics were calculated for all qualitative (bacterial species) and quantitative variables (percent adherent bacteria). The outcome variable assessed in this study was percent adherent bacteria, and the two independent variables were species and time. To compare percent adherent values for different species and exposure times, we used a mixed-model repeated measures analysis of variance (ANOVA). The model included fixed effects of time and species as well as an interaction between time and species. Percent adherent was determined for each species at five time points (0.25, 1, 5, 15, and 60 minutes) with four to eight repetitions. The mixed-model repeated measures ANOVA includes adjusted one-way ANOVAs for each independent variable (time and species). Post-hoc pairwise comparisons between groups for the one-way ANOVA models were performed using Tukey-Kramer's multiple comparison procedure. Adjusted least square means and standard errors were reported to adjust for dependent measure data.

Table 3. Mean percent adherent values by species and exposure time.

	Mean (SD) Percent Adherent Bacteria				
Species	0.25 min	1 min	5 min	15 min	60 min
Streptococcus oralis	50.6 (5.2)	47.8 (4.5)	51.7 (6.0)	56.1 (8.9)	57.8 (7.7)
Streptococcus mitis	64.8 (6.6)	66.4 (5.8)	68.8 (5.0)	72.9 (6.4)	73.8 (7.2)
Streptococcus salivarius	44.2 (4.4)	48.8 (3.0)	47.3 (2.1)	56.2 (4.5)	54.9 (3.9)
Streptococcus gordonii	46.5 (5.0)	48.4 (4.4)	50.0 (6.7)	50.2 (3.6)	53.0 (8.5)
Streptococcus sanguinis	52.9 (6.3)	54.7 (7.8)	57.4 (5.1)	57.7 (6.7)	65.2 (7.2)
Gemella haemolysans	55.3 (4.4)	57.9 (3.5)	56.8 (3.1)	61.0 (4.2)	62.7 (3.5)
Neisseria flavescens	54.8 (4.0)	54.0 (1.4)	57.1 (4.6)	59.2 (8.3)	67.4 (7.3)
Pseudomonas aeruginosa	63.8 (3.7)	68.3 (7.2)	70.3 (4.9)	69.2 (8.8)	72.3 (2.9)
All	53.6 (8.2)	55.5 (8.8)	56.4 (8.8)	59.7 (8.8)	62.7 (9.1)

Results

Bacterial growth curves were plotted, and Tmax10% was determined for each inoculum and species-time condition. Tmax10% was converted to colony count as described, and the ratio of Tmax10% (titanium-adherent) to Tmax10% (inoculum) was calculated to assess the percentage of bacteria adherent to the titanium discs. Figure 1 presents photomicrographs of adherent bacteria, growth curves, and colony forming unit (CFU) estimates for two representative species, *P. aeruginosa* and *S. oralis*.

Descriptive Statistics: Descriptive statistics for each species are presented in Table 2. Considering all time points, every species assessed demonstrated an overall mean percent adherent value of at least 50%.

Table 3 provides the mean percent adherent values over time. When considering individual time points, *S. salivarius* exhibited the lowest recorded percentage of bacteria adherent to titanium (44% adherent at the 0.25-minute exposure time). *S. mitis* and *P. aeruginosa* consistently demonstrated the highest percent adherent values at all time points.

Table 4. Results of Tukey-Kramer tests for multiple comparisons on adjusted least squares means, by species .

Species	Percent Adherent Least Squares Mean (Standard error)	Comparison	Difference	Adjusted p-value for comparison
S. Oralis (N=20)	52.8 (1.9)	*P. aeruginosa*	-16.0	<0.0001
		G. haemolysans	-5.9	0.3593
		S. sanguinis	-4.6	0.5768
		N. flavescens	-5.8	0.2952
		S. mitis	-16.6	<0.0001
		S. salivarius	2.5	0.9567
		S. gordonii	3.2	0.9299
P. aeruginosa (N=20)	68.8 (1.9)	*G. haemolysans*	10.1	0.0131
		S. sanguinis	11.4	0.0012
		N. flavescens	10.2	0.0047
		S. mitis	-0.6	1.0000
		S. salivarius	18.5	<0.0001
		S. gordonii	19.2	<0.0001
G. haemolysans (N=20)	58.7 (1.9)	*S. sanguinis*	1.4	0.9992
		N. flavescens	0.2	1.0000
		S. mitis	-10.6	0.0077
		S. salivarius	8.5	0.0195
		S. gordonii	9.1	0.0325
S. sanguinis (N=27)	57.4 (7.6)	*N. flavescens*	-1.2	0.9994
		S. mitis	-12.0	0.0007
		S. salivarius	7.1	0.0039
		S. gordonii	7.8	0.0595
N. flavescens (N=27)	58.5 (7.1)	*S. mitis*	-10.8	0.0026
		S. salivarius	8.3	0.0081
		S. gordonii	8.9	0.0186
S. mitis (N=20)	69.3 (1.9)	*S. salivarius*	19.1	<0.0001
		S. gordonii	19.7	<0.0001
S. salivarius (N=35)	50.3 (1.4)	*S. gordonii*	0.6	1.0000
S. gordonii (N=20)	49.6 (1.9)			

Inferential Statistics: Results of the repeated measures ANOVA with compound symmetry model structure showed the interaction term, time*species, was not significant (p=0.6556). However, both main effects—exposure time (p<0.0001) and species (p<0.0001)—significantly influenced the percentage of bacteria adherent to titanium. These findings indicate percent adherent values were significantly impacted by both exposure time and species. However, the differences found between species were not dependent on the time point measured.

Table 5. Results of Tukey-Kramer tests for multiple comparisons on adjusted least squares means, by exposure time.

Exposure Time (minutes)	Percent Adherent Least Squares Mean (Standard error)	Comparison	Difference	Adjusted p-value for comparison
0.25 (N=37)	54.1 (0.9)	1 minute	-1.7	0.5368
		5 minutes	-3.3	0.0227
		15 minutes	-6.3	<0.0001
		60 minutes	-9.3	<0.0001
1 (N=34)	55.8 (1.0)	5 minutes	-1.6	0.5942
		15 minutes	-4.6	0.0006
		60 minutes	-7.6	<0.0001
5 (N=39)	57.4 (0.9)	15 minutes	-3.0	0.0518
		60 minutes	-6.0	<0.0001
15 (N=40)	60.3 (0.9)	60 minutes	-3.1	0.0384
60 (N=39)	63.4 (0.9)			

Table 4 provides the results of the Tukey-Kramer tests for multiple comparisons of species (each species compared with all other species). Mixed methods were used to account for the dependent data. Statistically significant differences in percent adherent least squares means were noted for as follows:

- *S. oralis* compared with *S. mitis* (p<0.0001) and *P. aeruginosa* (p<0.0001);
- *S. sanguinis* compared with *S. mitis* (p=0.0007) and *S. salivarius* (p=0.0039);
- *S. mitis* compared with *S. salivarius* (p<0.0001) and *S. gordonii* (p<0.0001);
- *G. haemolysans* compared with *S. mitis* (p=0.0077), *S. salivarius* (p=0.0195), and *S. gordonii* (p=0.0325);
- *P. aeruginosa* compared with *G. haemolysans* (p=0.0131), S. sanguinis (p=0.0012), *N. flavescens* (p=0.0012), *S. salivarius* (p<0.0001), and *S. gordonii* (p<0.0001).

Table 5 provides the results of the Tukey-Kramer tests for multiple exposure time comparisons (each time point compared with all other time points). Statistically significant differences in percent adherent least squares means were noted for as follows:

- Exposure time of 0.25 minutes compared with 5 (p=0.0227), 15 (p<0.0001), and 60 (p<0.0001) minutes;
- Exposure time of 1 minute compared with 15 (p=0.0006) and 60 (p<0.0001) minutes;
- Exposure time of 5 minutes compared with 60 (p<0.0001) minutes;
- Exposure time of 15 minutes compared with 60 (p=0.0384) minutes.

Statistically significant differences in mean percent adherent bacteria were noted for some species when different exposure times were compared (Figure 2). These statistically significant differences were noted for as follows:

- *S. salivarius* (60 minutes compared with 1 minute and 0.25 minutes; 15 minutes compared with 1 minute and 0.25 minutes);
- *N. flavescens* (60 minutes compared with 0.25 minutes);
- *S. sanguinis* (60 minutes compared with 1 minute and 0.25 minutes).

Discussion

For this investigation, we selected oral bacterial species likely represented during dental implant surgery in healthy patients. In the early stages of dental biofilm development, facultative and aerobic bacteria of the genera *Streptococcus* and *Neisseria* are known to predominate.[24] In a study utilizing molecular techniques to assess bacterial profiles of nine intraoral sites in each of five healthy individuals, species common to all sites included the genera *Gemella*, *Granulicatella*, and *Streptococcus*.[25] In one individual, *S. mitis* accounted for 79% of all clones identified.[25] In addition to these health-associated genera, we assessed titanium adhesion of *P. aeruginosa* for comparison with prior research.[21]

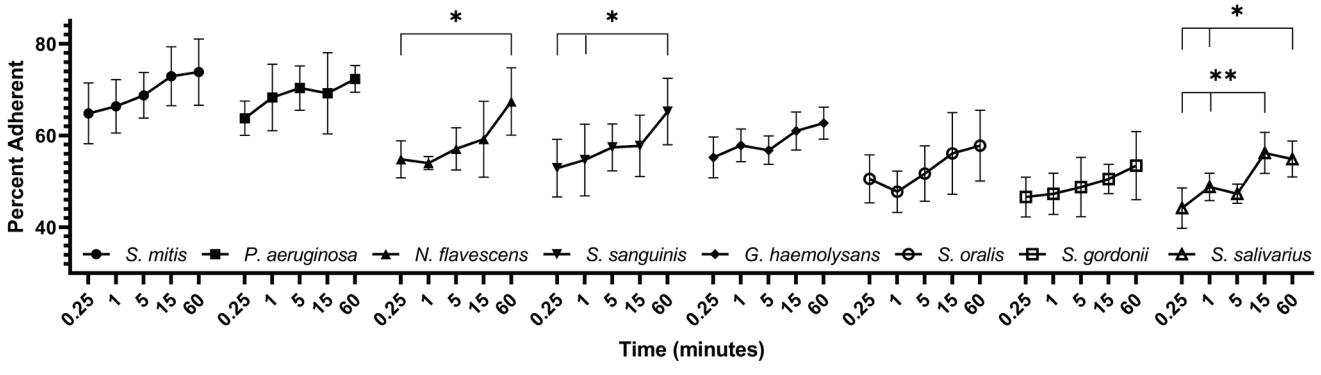
Bacterial adhesion is a process involving both physicochemical and molecular interactions.[26] Generally, nonspecific interactions mediate adhesion to abiotic substances, whereas specific ligand-receptor interactions predominate in bacterial adhesion to biological

surfaces.[27-29] *S. oris*, *S. mitis*, and *S. gordonii* are early colonizers that possess specific cell surface adherence proteins (adherins) which bind protein, glycoprotein, or polysaccharide elements of the acquired pellicle on various oral surfaces.[30] Adhesins also mediate specific intrageneric and intergeneric coaggregation interactions.[30] As the biofilm matures, cell surface adhesins on secondary colonizers bind receptors on early colonizers such as *Streptococcus* and *Actinomyces* species.[31]

In this study, we assessed bacterial adhesion to a single substrate and did not vary the surface characteristics of the titanium foil. However, surface chemistry, surface topography, and presence of adsorbed macromolecules appear to influence adherence of both bacterial and host cells.[32-37] At titanium interfaces, any change to the surface oxide thickness or composition, surface free energy, or surface topography will affect multiple parameters and influence cellular responses.[35] A systematic review focused on effects of material characteristics and surface topography on biofilm development concluded that surface roughness above the Roughness Average (Ra) threshold of 0.2 µm favors biofilm accumulation, as most bacteria are larger in size.[34] Material properties that promote osseointegration—such as Ra of 1 to 1.5 µm and ability to absorb calcium, phosphate, and serum proteins—may also favor bacterial adhesion.[34-36] We did not evaluate the Ra of the titanium foil used in this study, and the manufacturer could not provide a detailed analysis of the surface characteristics. In perspective, "machined" dental implant surfaces typically exhibit Ra values less than one micron; whereas, commercially available implant surfaces, roughened through sand-blasting, acid etching, or other processes, commonly exhibit Ra values of approximately one to two microns.[34-37] Intuitively, the titanium foil substrate utilized in this study and machined dental implants may perform comparably with regard to bacterial adhesion and biofilm accumulation. Relative to the substrate utilized in this study, roughened dental implant surfaces undoubtedly perform differently. Interestingly, the relatively smooth titanium surfaces utilized in the present investigation permitted striking bacterial adhesion even when exposure was limited to 15 seconds. At this lowest studied exposure time, the mean percentages of bacteria adherent to titanium ranged from 44% (*S. Salivarius*, 0.25-minute exposure) to 74% (*S. mitis*, 60-minute exposure), considering all experimental conditions.

Under the described parameters, bacterial adhesion correlated with exposure time. Although clinicians must use caution when drawing conclusions from in vitro observations, this finding, if confirmed, could have practical implications for implant surgery. The professional experience of the surgeon has been shown to influence treatment planning, clinical judgement, operating time, and dental implant survival.[38-40] Decreased intraoperative implant contamination may represent one factor accounting for such observations. Experienced practitioners, compared with those in training, may maintain greater control over the surgical field, place implants with superior efficiency, and reduce or eliminate contamination of implant surfaces during insertion. We acknowledge the high survival and success rates achieved with implant therapy, despite inevitable intraoperative contact between titanium surfaces and contaminated oral biofluids.[41] Osseointegration has increasingly become a predictable process, owing in part to favorable manipulation of host cell responses through modifications to implant surfaces.[35] Intraoperative contamination of implant surfaces represents only one of many procedure-, site-, and patient-related factors impacting treatment outcomes. For most patients, implant exposure to bacteria during surgery is insufficient to

Figure 2. Percentage of bacteria adherent to titanium by species and exposure time (mean ± standard error). Statistical significance at the 0.05 level relative to the 60-minute* and 15-minute** exposure times.



effect osseointegration failure. Conversely, long-term exposure of abutment and implant surfaces to biofilms leads to biological complications—predominantly peri-implantitis and peri-implant mucositis—for a relatively high proportion of implant patients.[4-6]

Increase in antibiotic resistance is a concerning observation common to multiple oral bacterial species,[42-44] and evidence that routine antibiotic use substantially enhances implant treatment outcomes remains questionable.[12-17] Unfortunately, the results of the present study fail to demonstrate that bacterial adhesion to titanium does not occur over short exposure periods. While our observations do not support routine prophylactic antibiotic prescription for implant surgery, neither do our results counter the rationale for this controversial practice.

An emerging concept in implant dentistry is the idea that the quality of the early implant-mucosal interface may influence crestal peri-implant bone levels and long-term peri-implant health.[4,45] Synergistic effects of oral biofilms with cyclic mechanical loading of implants may result in corrosion, deposition of metal ions in surrounding tissues, chronic inflammation, and breakdown of the protective biologic seal at the implant-mucosal interface.[45-47] It is possible, in the absence of biofilm-mediated inflammation, formation of a high-quality connective tissue adhesion and epithelial attachment at the transmucosal implant interface may serve as a key for preserving peri-implant bone levels and osseointegration. Further characterization of bacterial adhesion to dental implant/abutment surfaces appears warranted. Scrutiny of implant collar design characteristics may be justified. Moreover, considering the increasing rates of antibiotic resistance among oral bacteria, targeting mechanisms of bacterial adhesion may represent a promising anti-infective strategy.[48]

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2021

Joseph L. Bernier Dental Research 1st Place Winner

Post-Cure Polymerization and Depth-of-Cure Behaviors of Dental Bulk-Fill Resin-Based Composites

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Abstract

Introduction: Polymerization for modern dental resin-based composites (RBCs) not only occurs immediately upon light exposure but also continues for another 24 hours, well beyond after light is terminated. However, many questions still remain about the role of polymerization kinetics in optimizing the physical properties of a new RBC type—the bulk-fill.

Objective: The aim is to study the post-cure polymerization kinetics of bulk-fill RBCs and to compare their degree of polymeric conversion (DC) and depth-of-cure (DoC) with an incremental-fill, conventional RBC.

Methods: Five representative bulk-fill RBCs [Surefil SDR+Stress Decreasing Resin Flow Plus (SDRFP), Tetric EvoCeram Bulk Fill (TECB), Filtek 1 Bulk Fill (F1B), Venus Bulk Fill (VB), and Sonicfill (SF3)] and one conventional RBC [Filtek Supreme Ultra (FSU)] were investigated. The upper surface per RBC specimen was exposed to a light curing unit (Paradigm, 3M-ESPE, irradiance=1221 ± 5 mW/cm^2) for 20 seconds. The DC per RBC brand were measured at the bottom surface (specimen Ø=4 mm, thickness=3 mm and 5 mm) as a function of post-curing times using a Fourier transform infrared attenuated total reflection spectrometer. Real-time data recording for post-cure DC began immediately upon light exposure and continued at steady intervals, up to15 min, then again after 24 hours. The DoC of all six RBC brands (n=6 / group) were measured according to ISO-4049. Data were analyzed with nonlinear regression and analysis of variances (ANOVA)/Tukey (α=0.05).

Results: Mean DC for the six RBCs with 5 mm curing height after 24 hours were: TECB=79.5%, VB=75.7%, SDRFP=69.2%, SF3=65.8%, F1B=51.8%, and FSU=44.0%. Bulk-fill RBCs showed higher DC efficiency than the conventional RBC for both the 3 mm and 5 mm curing heights. Significant differences in DoC were found amongst the six RBC brands: VB=5.1 mm, SDRFP=4.6 mm, F1B=3.8 mm, TECB=3.5 mm, FSU=3.0 mm, and SF3=2.7 mm.

Conclusion: DCs were more affected by specimen thickness, through which the curing light was attenuated, than RBC types. Clinician should be aware not all bulk-fill RBCs have a DoC greater than or equal to 4 mm. Also, a bulk-fill RBC that has a high DC after a post-cure time of 24 hours may not have a high DoC, which is typically measured relatively soon after light exposure.

Introduction

According to the Centers for Disease Control and Prevention, dental caries remains to be the most common chronic disease in the US.[1] If left untreated, dental caries can cause pain and infections, which consequently can impact the quality of life and compromise daily operations. In the last decade, the American Dental

Table 1. The five bulk-fill and one conventional RBC brands investigated.

Product		Manufacturer	Type	Filler Chemistry	Matrix Chemistry	Manufacturer Claim Depth of Cure	Curing Wavelength	Shade
Surefil SDR+	SDRFP	Dentsply Sirona, United States	Nanohybrid	SiO_2, Ba-Al-F-B-Si Glass, Sr-Al-Fl-Si Glass YbF_3	UDMA, TEGDMA	4 mm	440-480 nm	Universal
Tetric EvoCeram Bulk Fill	TECB	Ivoclar Vivadent, Liechtenstien	Nanohybrid	SiO_2, Ba-Al-B-Si Glass, YbF_3	Bis-EMA, Bis-GMA, UDMA	4 mm	400-500 nm	A2
Filtek 1 Bulk Fill	F1B	3M ESPE, United States	Nanofill	SiO_2, Zirconia, YbF_3	AFM, DDDMA, UDMA	5 mm	400-500 nm	A2
Venus Bulk Fill	VB	Heraeus Kulzer Gmbh, Japan	Nanohybrid	SiO_2, Ba-Al-F-Si Glass, YbF_3	UDMA, EBADMA	4 mm	N/A	Universal
Sonicfill 3	SF3	Kerr, United States	Hybrid	SiO_2, Ba Glass	Bis-EMA, Bis-GMA, TEGDMA	5 mm	400-520 nm	A2
Filtek Supreme Ultra	FSU	3M ESPE, United States	Nanofill	SiO_2, Zirconia, YbF_3	Bis-EMA, TEGDMA, UDMA	2 mm	400-500 nm	A2

Abbreviations: N/A = Not avaliable; SiO_2 = Silicon Dioxide; Ba-Al-F-B-Si = Barium-Aluminum-Fluoride, borosilicate; Sr-Al-F-Si = Silanated strontium alumino-fluoro-silicate; YbF_3 = ytterbium fluoride; UDMA = Urethane dimethacrylate; TEGDMA = Triethylene gycol dimethacrylate; Bis-EMA = Bisphenol A-ethoxylated dimethacrylate; Bis-GMA = Bisphenol A-gylcidyl methacrylate; AFM = Addition fragmentation monomers; DDDMA = Dodecanediol dimethacrylate; EBADMA = ethoxylated bisphenol-A-dimethacrylate

Association reported dental pains accounted for 2.1 million emergency visits in the US in 2010, which resulted in an upsurge of 1 million visits since the year, 2000.[2]

Although US armed forces are meeting mission requirements while maintaining a high level of readiness, dental emergencies (DE) have always had a negative repercussion on military operations and can present significant morbidity during armed conflicts. DE for deployed US service members have been well-documented.[3,4,5] A recent study found the mean incident rate of DE was 118, 2 per 1,000 personnel per year in theater of operations.[6] As such, the sequela of an untreated DE inflicts not just morbidity but also interrupts daily function, operational tempo, and readiness posture—as well as missing window-of-opportunities, not to mention financial loss. During Operation Iraqi Freedom, these emergencies cost the US Army well over $1.8M per month or an equivalent of $21.4M and $21.9M for years 2009 and 2010 respectively.[7] Caries, broken/lost/defective restoration, and tooth fracture accounted for the majority of DE in a deployed setting.[8,9,10,6] In a similar fashion, these problems are equally prevalent in civilian dental emergency practices as well.

Whether in a military or civilian backdrop, the stakes are high, and crucial pieces of information about how to enhance the oral health and resilience of the care recipients or warfighters—especially why dental composite restorative materials have often failed clinically—are still absent. As a result, the quest for new restorative materials has played an important role in advancing dentistry.

Current dental research efforts focus on innovating new organic and inorganic formulation of resin-based composites (RBCs), such that their clinical performance can resist polymerization stress and curing contraction, while their esthetics and thermo-elastic properties can match those of natural teeth. This effort is directly driven by the demands to ameliorate the shortcomings of today's RBCs. Past clinical data have indicated there are several limitations associated with placing direct RBC restorations. One, their proper execution requires a technique-delicate or -sensitive approach, which relies on good isolation and appropriate armamentariums, such as having a sectional matrix system and a light curing unit with adequate radiant energy. Two, besides having a good working knowledge of dental materials, clinicians often must draw on their clinical experiences to overcome the adhesive issues between RBCs and enamel-dentin substrates and to prevent against insufficient depth-of-cure, contraction, and polymerization stress during light curing. Lastly, placement of direct restorations using RBC materials is time consuming. This is because the technicalities to accomplish marginal adaptation, proximal contacts, and occlusion can be complicated. In addition, clinicians also must rely on their artistic skills to finish a RBC restoration that restores anatomical form, function, and esthetics.

Recently, a new class of direct restorative material—bulk-fill resin-based composite (RBC)—has been introduced. Unlike the conventional RBC, a bulk-fill RBC is designed to reduce the number of incremental layers that would otherwise be required when placing an RBC into a tooth prep/cavity.[11] Anecdotal reports from practitioners suggest that multiple-layering technique using a range of translucent and opaque shades is slow and laborious to perform. Furthermore, filling a cavity prep in bulk seems to result in fewer voids or porosities within a restoration.[12] Driven from the drawbacks of the conventional RBCs, manufacturers' philosophy behind the development of bulk-fill RBCs was to simplify and ease the placement of RBCs, whereby making this process relatively more efficient. Manufacturers have also claimed these bulk-fill RBCs with their new polymeric chemistry and photo-sensitivity to curing lights are formulated to contest against inadequate depth-of-cure and volumetric contraction after polymerization. Therefore, the question regarding whether these bulk-fill RBCs can truly provide adequate cure in deep preparations remains. Also, the underlying polymerization kinetics and their roles in optimizing the final physical properties of

bulk-fill RBC need further exploration. Hence, the aim of this study is to evaluate the post-cure polymerization kinetics of bulk-fill RBCs and to compare their degree of polymeric conversion (DC) and depth-of-cure (DoC) with an incremental-fill, conventional RBC. The null hypothesis was as follows: there was no difference in DC and DoC between bulk-fill and conventional RBCs.

Methods & Materials

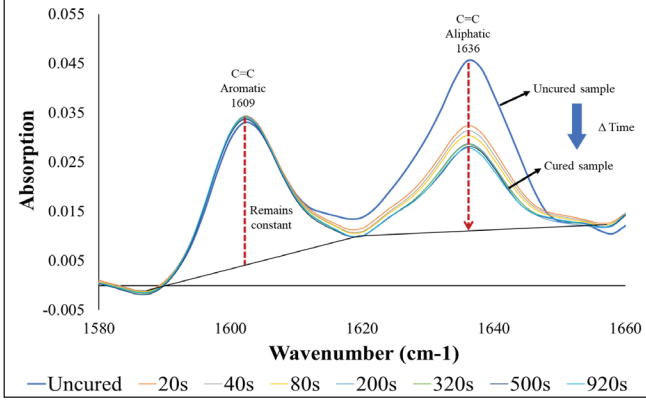
Degree of Conversion (DC): Five bulk-fill and one conventional RBC brands were investigated (Table 1). A Fourier transform infrared attenuated total reflection (FTIR-ATR) spectrometer was used to measure the DC per RBC brand at the bottom surface (specimen thickness=either 3 or 5 mm, Ø=4 mm) as a function of post-cure times. RBC was placed following manufacturer's instructions inside a polyvinylsiloxane (PVS) mold (height=either 3 or 5 mm, Ø=4 mm) with direct contact to the ATR crystal. Care was taken to exclude any air bubbles.

A Mylar strip was placed over the sample, followed by a microscope glass slide, which was placed on top of the Mylar. A force gauge was used to press the sample against the ATR crystal. At this point, the baseline uncured spectrum was collected. Next, the microscope glass slide was removed. Then, the exit aperture of the curing light unit (LCU) was positioned concentrically onto the mold opening and directly against the Mylar strip surface. To validate the manufacturer claimed irradiance, an integrating sphere (sphere diameter=15 cm and entry port=19 mm), coupled to a calibrated spectrophotometer was used to measure the LCU irradiances.

Each specimen was light cured for 20 seconds (sec) with 1221 ± 5 mW/cm^2. Real-time recording of the infrared spectrum (IR) (2500 – 600 cm^{-1}) began immediately upon curing and continued at 20 sec, 1 minute (min), 3 min, 5 min, 8 min, and 15 min. Then, the specimens were removed from the spectrometer and kept in a dark room at room temperature. After 24 hours of dark curing, three FTIR spectra were collected. Also, at each of the collecting intervals, three scans (8 cm^{-1} resolution per scan) were averaged to produce an IR spectrum.

Accordingly, the degree of polymeric conversion (DC) is often defined as the amount to which monomeric carbon-carbon double bonds are converted to carbon-carbon single bonds.[13] A high DC usually correlates with an increase in strength and hardness of a restoration as well as its dimensional, chemical, and color stability, thereby improving the longevity of the restoration.[14] The DC [%] was determined by the following equation:

Figure 1. Representative fourier transform infrared attenuated total reflection (FTIR-ATR) spectra of (SDRFP) resin-based composites (RBCs) are shown. Immediately after light exposure, RBC polymerization begins, which this is indicated by the reduction of aliphatic peaks in absorption intensity at 1637 cm-1 as a function of time (i.e., Δ Time = 20s, 40s, 80s, 200s, 320s, 500s, and 920s), whereas the aromatic peaks at 1608 cm^{-1} remain relatively unchanged or constant. After baseline correction, this study used the absorbance of aromatic double bonds as an internal reference.



$$DC\,[\%] = 100\left[1 - \frac{\left(\frac{A_{1636}}{A_{1609}}\right)_{polymer}}{\left(\frac{A_{1636}}{A_{1609}}\right)_{monomer}}\right]$$

where A_{1636} and A_{1609} represented the heights of the IR absorption intensities at 1636 cm^{-1} (C=C of the aliphatic bond stretch) and 1609 cm^{-1} (C-C of the aromatic bond stretch) respectively and where

$$\left[\left(\frac{A_{1636}}{A_{1609}}\right)_{polymer} \Big/ \left(\frac{A_{1636}}{A_{1609}}\right)_{monomer}\right]$$

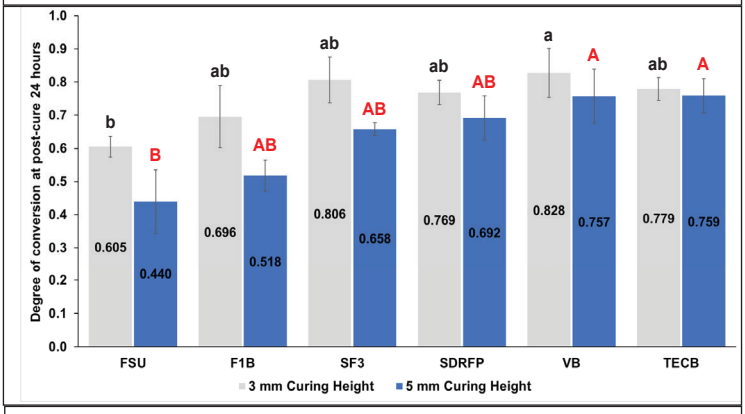
represented the absorption-peak ratio of the aliphatic to aromatic stretch of the polymer normalized by the absorption-peak ratio of aliphatic to aromatic stretch of the monomer (Figure 1).

Volumetric Contraction: The volumetric contraction per RBC sample were determined using the Archimedes principle. First, an un-polymerized mass per RBC brand was weighed in air ($M_{dry\ uncured}$, [mg]) and then weighed submerged ($M_{wet\ uncured}$, [mg]) in distilled water using a density scale. Next, the volume of the un-polymerized RBC sample ($V_{uncured}$, [cm^3]) was calculated from the following equations:

$$V_{uncured} = \frac{M_{dry\ uncured}}{\rho_{uncured}},$$

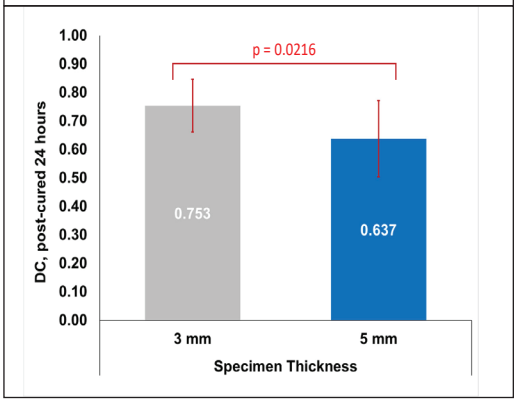
$$\text{where } \rho_{uncured} = \frac{M_{dry\ uncured}}{M_{dry\ uncured} - M_{wet\ uncured}}\,\rho_{water}$$

Figure 2. Degrees of conversion of various bulk-fill resin-based composites are plotted, after 24 hours of dark cure, via 20 s exposure to 2031 ± 5 mW/cm2 irradiances. The cylindrical height of each resin-composite sample for which curing light traversed was either 3 mm or 5 mm thick. The cylindrical diameter was kept constant at 4 mm. The same case letters across columns are not significantly different than each other (p > 0.05).



** FSU: Filtek Supreme Ultra; F1B: Filtek 1 Bulk Fill; SF3: Sonicfill; SDRFP: Stress Decreasing Resin Flow Plus; VB: Venus Bulk Fill; TECB: Tetric EvoCeram Bulk Fill.*

Figure 3. Effect of the sample's thickness on resin-based composites' (RBC) degree of conversion.



Here, $\rho_{uncured}$ [g/cm^3] and ρ_{water} [g/cm^3] were the densities of un-polymerized RBC and water at 25.6ºC, respectively. Afterwards, this un-polymerized mass per RBC brand was light cured for 20 sec using the same Paradigm LCU. From there, this polymerized mass per RBC brand was weighed in air ($M_{dry\ cured}$, [mg]) and then weighed submerged ($M_{wet\ cured}$, [mg]) in distilled water using the same density scale. Next, the volume of the polymerized RBC sample (V_{cured}, [cm^3]) was calculated from the following equations:

$$V_{cured} = \frac{M_{dry\ cured}}{\rho_{cured}},$$

$$\text{where } \rho_{cured} = \frac{M_{dry\ cured}}{M_{dry\ cured} - M_{wet\ cured}} \rho_{water}$$

Here, ρ_{cured} [g/cm^3] was the density of polymerized RBC. Finally, the volumetric shrinkage or contraction [%] was determined from the following equation:

$$\text{contraction [\%]} = \frac{V_{uncured} - V_{cured}}{V_{uncured}} * 100$$

Depth-of-Cure (DoC): DoC was measured according to the ISO-4049.[15] Samples (n=3) were made for each RBC using stainless steel (SS) molds. All SS molds were 4 mm in diameter but varied in height. The determination for which mold height to be used was based on each RBC manufacturer's claimed DoC and on the formula, mold height=2 * (manufacturer's claim DoC) + 2, as specified by the ISO-4049.[15] Once a proper mold was selected and placed on top of a Mylar strip, below which a glass slab was place, it was filled with the test RBC, and prepared in accordance with the manufacturer's instructions. Care was taken to exclude any air bubbles. Next, another Mylar strip was placed over the sample, followed by another glass microscope slide. After finger pressure was used to displace excess materials, the top microscope slide was removed. Then, the exit aperture of the LCU light tip was positioned concentrically to the mold opening and directly against the Mylar surface. Immediately after curing for 20 sec, the sample was removed from the mold. Any remaining soft uncured RBC was manually scraped away using a plastic spatula. The maximum height of the remaining hard RBC was measured three times with a digital caliper (± 0.1 mm). The three measurements were averaged and divided by two to yield DoC. Based on the aforementioned ISO-4049 method, the DoC was measured in triplicate (n=3) for each RBC brand.

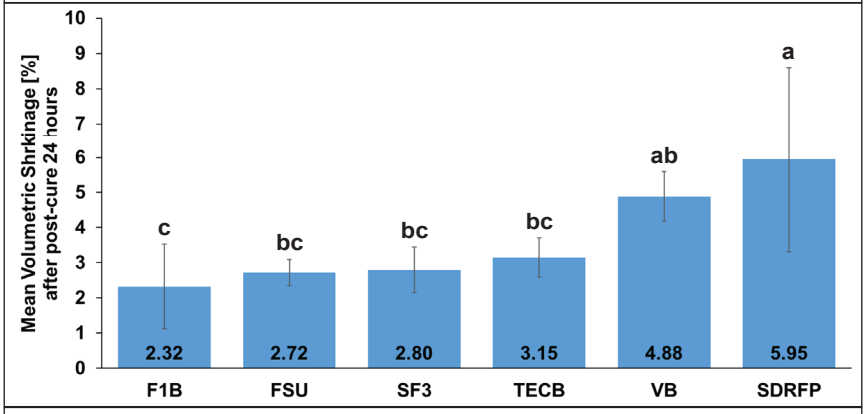
Statistics & Data Analysis: Data were first tested for homogeneity of variances using the Levene's test and Mauchly's test of sphericity, which were not violated. Then, data were analyzed with nonlinear regression, analysis of variances (ANOVA), repeated-measures ANOVA, and Tukey post hoc test ($\alpha = 0.05$), using statistical software.

Results

Degree of Conversion (DC): After 24 hours of dark cure, the DC of the five bulk-fill RBCs were compared with the DC of a conventional RBC brand (Figure 2). When curing through a 5 mm specimen height, only two bulk-fill RBCs, Venus Bulk Fill (VB) (0.759=75.9%) and Tetric EvoCeram Bulk Fill (TECB) (0.757=75.7%), showed significantly higher DC at their bottom surfaces (p=0.0123) than the DC of the conventional RBC, Filtek Supreme Ultra (FSU) (0.440=44%). In contrast, when curing through a thinner specimen height of 3 mm instead of 5 mm, only one bulk-fill RBC, VB (0.828= 2.8%), were significantly higher than the DC of the conventional RBC, FSU (0.605=60.5%). Furthermore, regardless

whether the RBC is a bulk-fill or a conventional type, the DC at the bottom surfaces for the 3 mm height specimens are significantly greater than those specimens with a 5 mm specimen height. This influence of the sample's thickness on RBC DC is best illustrated in Figure 3.

Figure 4. Volumetric shrinkage percentages of various bulk-fill resin-based composites are plotted, after 24 hours of dark cure, via 20 seconds' exposure to 2031 ± 5 mW/cm^2 irradiances. The same case letters across columns are not significantly different than each other ($p > 0.05$).



** F1B: Filtek 1 Bulk Fill; FSU: Filtek Supreme Ultra; SF3: Sonicfill; TECB: Tetric EvoCeram Bulk Fill; VB: Venus Bulk Fill; SDRFP: Stress Decreasing Resin Flow Plus.*

Volumetric Contraction: Amongst the five bulk-fill and one conventional RBCs, SDRFP, a flowable bulk-fill, exhibited the highest volumetric contraction (5.95%); whereas, F1B has the lowest volumetric shrinkage (2.32%) (Figure 4). Although VB may have the second highest volumetric shrinkage amongst the six RBCs tested, volumetric shrinkage of VB is statistically not significant than those of TECB, Sonicfill (SF3), and FSU. Although past data have indicated volumetric shrinkage is associated with polymerization, based on the data of this study, no direct relationship is observed between volumetric shrinkage and degree of conversion, whereby a RBC that exhibited a high DC did not present a high volumetric shrinkage.

Depth-of-Cure (DoC): Of the six RBCs tested, the DoC (5.06 mm) of VB is significantly higher than the other five RBCs (Figure 5). Although SF3 has the lowest DoC (2.68 mm), the DC of SF3 measured at its bottom surfaces of samples with 5 mm in height is not significantly different than the DCs of VB, TECB, Stress Decreasing Resin Flow Plus (SDRFP), and F1B, measured at the bottom surfaces of samples with similar height, 5 mm (Figure 2). The manufacturers claimed the depths of cure for F1B, TECB, and SF3 were 5 mm, 4 mm, and 5 mm, respectively. However, this study measured the mean DoC values for F1B, TECB, and SF3 to be 3.8 mm, 3.5 mm, and 2.7 mm, respectively.

Discussion

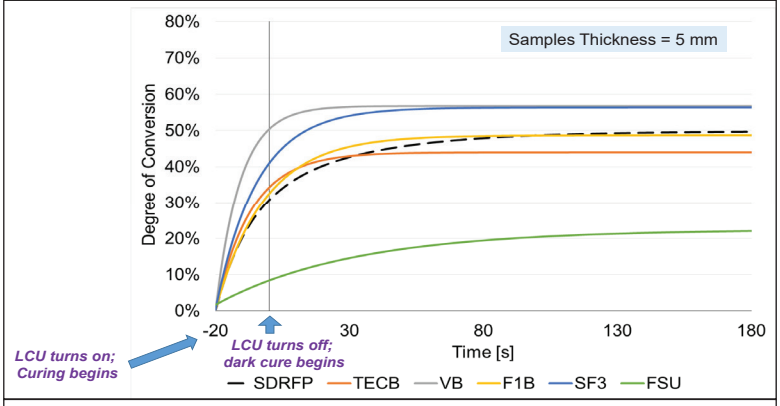
This study investigated five commercially-available and popular bulk-fill RBC brands: Surefil SDR+, Tetric EvoCeram Bulk Fill, Filtek 1 Bulk, Venus Bulk, and Sonicfill 3. Within the limits of this study, significant differences in DC, DoC, and post-cure polymerization kinetics between bulk-fill and conventional RBCs were observed. Hence, the null hypothesis was rejected.

There are several explanations why the performances of DC, DoC, and post-cure polymerization kinetics for bulk-fill RBCs are higher than those of a conventional RBC. One, RBC translucency matters. This is a key parameter in photo-polymerization. In particular, translucency is intimately related to a material's refractive index, whereby it describes how light propagates and attenuates in a solid. According to Taira et al, composites appeared pellucid or less opaque when the refractive index of filler matched that of the polymeric network.[16] In contrast, a high refractive index disparity between the filler and polymeric media often enhances more photo-scatterings and less photo-absorptions.[17] This increase in the scattering coefficient reduces the efficiency of light transmittance and can thereby greatly jeopardized the DC and DoC of a RBC, ultimately resulting in poor clinical performance. For this reason, filler and resin refractive indices need to be optimized so the light penetration depth or the depth-of-cure for RBCs can be maximized.[18] In this study, bulk-fill RBCs are more translucent than the conventional RBC—with VB being the most translucent of them all. Because of this pellucid phenomenon, it is not surprising VB has the highest DoC among the six RBCs evaluated in this study.

Two, DC of RBC can also be influenced by the structure, conformation, and stereo-dynamics of the monomers.[19] Theoretically, it is well understood that the mobility of monomers decreases with increasing molecular weights. Additionally, monomers with bulky pendant side groups are more inclined to experience steric hindrance and chain inflexibility.[19] Sideridou et al showed that the rate of polymerization is dependent on temperature, molecular diffusion, and glass transition temperature (Tg) of the unreacted monomer.[19]

Three, the net effect of heavy molecular weight (MW) and impediment from conformational dynamics is the inflation of RBC viscosity (V). Based on the aforesaid

Figure 6. Degree of conversion as a function of time for various bulk-fill resin-based composites is plotted via 20 seconds exposure to 2031 ± 5 mW/cm² irradiances. The origin corresponds to the beginning of dark cure at which the light-curing unit (LCU) is turned off. The time point, -20 seconds, represents LCU is turned on, and curing begins. The cylindrical height of each resin-composite sample for which curing light traversed was 5 mm thick.



* LCU: light-curing unit; SDRFP: Stress Decreasing Resin Flow Plus; TECB: Tetric EvoCeram Bulk Fill; VB: Venus Bulk Fill; F1B: Filtek 1 Bulk Fill; SF3: Sonicfill; FSU: Filtek Supreme Ultra.

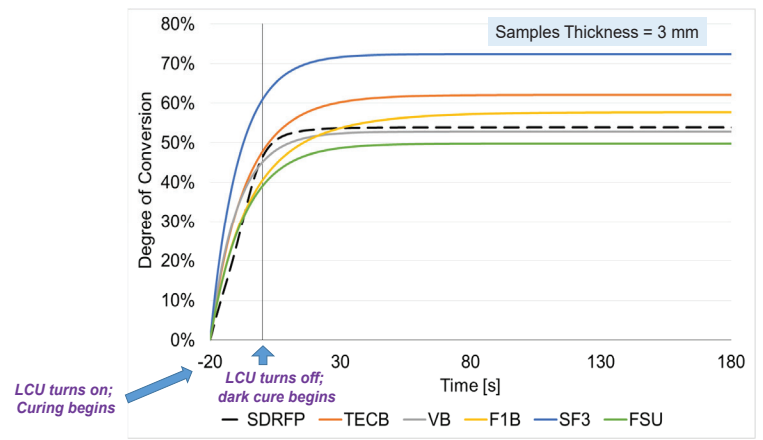
reasons, highly viscous RBCs are more challenging to achieve a greater degree of polymerization than those with less viscous nature like the flowables. For example, monomers such as Triethyleneglycol dimethacrylate (TEGDMA), MW=286.3 g/mol and V=0.011 Pa, and Urethane dimethacrylate (UDMA), MW=470.6 g/mol and V=23.1 Pa, with low molecular weight and low viscosity displayed much higher DC than monomers with high molecular weight such as Bisphenol A glycol dimethacrylate (Bis-GMA), MW=512.6 g/mol and V=1200 Pa, and Bisphenol A ethoxylated dimethacrylate (Bis-EMA), MW=540 g/mol and V=0.9 Pa.[19] Here, the viscosity of Bis-EMA is relatively low in comparison with UDMA, but Bis-EMA is structurally analogous to Bis-GMA. This offset lowers the Bis-EMA's DC to be less than TEGDMA and UDMA.

In this study, perhaps, the reason why VB has the highest DC at post-cure 24 hours is VB contains neither Bis-GMA nor Bis-EMA monomers. However, it is not well understood why TECB, which contains Bis-EMA, Bis-GMA, and UDMA also demonstrates a high DC that rivals with VB after 24 hours of post-curing.

On the other hand, highly viscous RBCs were shown to exhibit reduced volumetric shrinkage; this can result in better marginal adaptation at the interface between restoration and tooth and can assuage cuspal deflection.[20,21] For example, Benneti et al found that highly viscous bulk-fill RBCs like SonicFill and Tetric EvoCeram Bulk Fill have a reduced volumetric shrinkage and a better marginal adaptation than less viscous, flowable bulk-fill RBCs.[22] Similar trends between highly viscous and flowable bulk-fill RBCs were observed in this study. Interestingly, Benneti et al showed that highly viscous bulk-fill RBCs like SonicFill and Tetric EvoCeram Bulk Fill have a reduced DoC, reporting 3.43 mm and 3.82 mm respectively.[22] Similarly, this study found the DoC values of SF3, TECB, and F1B fall short of manufacturers' claims.

Lastly, the shape, size, type of filler, as well as filler content can alter the optical properties of RBC, thereby influencing their DoC and DC. Taira et al concluded when the filler size is larger than the wavelength of the incident light, photons are less attenuated.[16] As the filler size gets bigger in a RBC system, its corresponding translucency, DoC, and DC are also increased. However, with the recent introduction of nano-sized particles, Mitra et al reported that composite systems containing nanofills have superior translucency than microfills.[23]

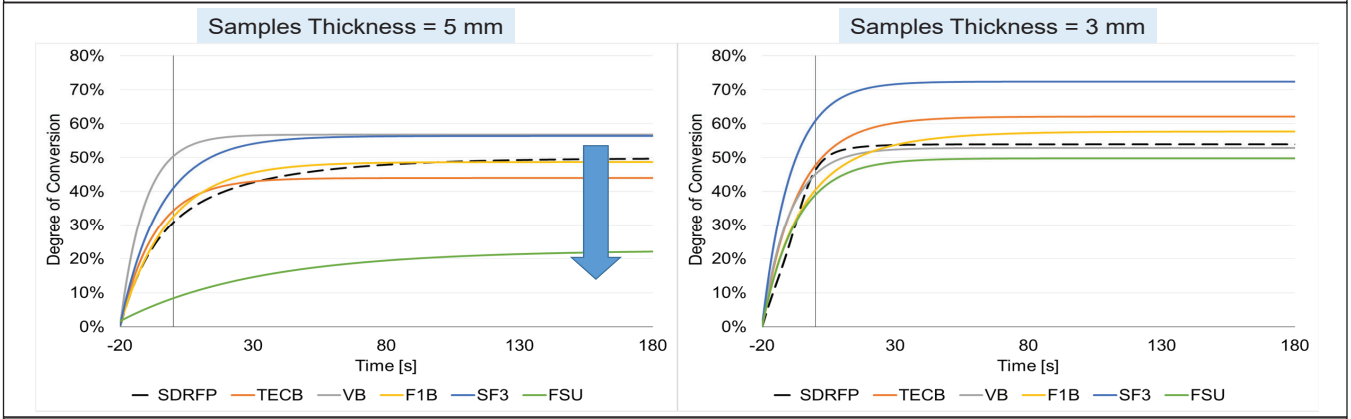
Figure 7. Degree of conversion as a function of time for various bulk-fill resin-based composites is plotted via 20 seconds exposure to 2031 ± 5 mW/cm² irradiances. The origin corresponds to the beginning of dark cure at which the light-curing unit (LCU) is turned off. The time point, -20 seconds, represents LCU is turned on, and curing begins. The cylindrical height of each resin-composite sample for which curing light traversed was 3 mm thick.



* LCU: light-curing unit; SDRFP: Stress Decreasing Resin Flow Plus; TECB: Tetric EvoCeram Bulk Fill; VB: Venus Bulk Fill; F1B: Filtek 1 Bulk Fill; SF3: Sonicfill; FSU: Filtek Supreme Ultra.

Post-Cure Polymerization Kinetics: As expected, the setting reaction that transforms these RBCs from their viscous state to a solid dental restoration involves a complex, free-radical addition polymerization. This reaction,

Figure 6. Degree of conversion as a function of time for various bulk-fill resin-based composites is plotted via 20 seconds exposure to 2031 ± 5 mW/cm^2 irradiances. The origin corresponds to the beginning of dark cure at which the light-curing unit (LCU) is turned off. The time point, -20 seconds, represents LCU is turned on, and curing begins. The cylindrical height of each resin-composite sample for which curing light traversed was 5 mm thick.



** SDRFP: Stress Decreasing Resin Flow Plus; TECB: Tetric EvoCeram Bulk Fill; VB: Venus Bulk Fill; F1B: Filtek 1 Bulk Fill; SF3: Sonicfill; FSU: Filtek Supreme Ultra.*

unlike condensation, has three distinct steps: initiation, propagation, and termination. Figures 6 and 7 show the addition polymerization of the six RBCs through the lens of a sigmoidal exponential function, whose independent and dependent variables are time and DC, respectively.[24] In the initiation stage, all six curves displayed a rapid upsurge in DC, indicating photo-activation occurs immediately. Here, photons are absorbed by the RBC's photoinitiators. Next, the excited photoinitiators along with the reducing agents, typically amine molecules, generate an upsurge of free radicals from which they attack the carbon-carbon double bonds of the monomers, forming reactive building blocks. The yield of the free radicals is highly dependent on the radiant energy of the light curing unit.[25] This is then followed by the propagation step during which reactive methacrylate or non-methacrylate-based monomers interact and successively add onto one another. Consequently, the growth and propagation of polymer chains are achieved. Once the unsaturated monomers are depleted and converted to saturated polymers, polymerization, too, slows. This is demonstrated in Figures 6 and 7. All six RBCs' curves show their exponential upsurges in DC as a function of time gradually wane and relax after the radiant exposure is terminated, and their dark curing processes begin.

Ultimately, the termination step occurs via the combination or the disproportionation process. In the case of a combination, two growing polymer chains react or couple with each other, forming a single nonreactive polymer chain with its molecular weight doubled. In the case of disproportionation, the growth active center is disrupted when a hydrogen atom is transferred from one growing radical chain to the other, resulting in two polymeric fragments, one with a saturated end and the other with an unsaturated end. Here, each of the six RBCs approaches a distinct asymptote in degree of conversion (DC). For a constant sample thickness of 5 mm, VB exhibits the highest DC asymptote, whereas FSU presents the least DC asymptote. However, for a constant sample of thickness of 3 mm, SF3 exhibits the highest DC asymptote, whereas the DC asymptote of FSU remains to be the lowest. In general, the overall DC was higher for thinner samples than for thicker samples (Figure 8).

As the polymeric chains grow in length and number, the physical property such as network hardening, stiffening, and volumetric shrinkage of the RBC is concurringly happening, transforming from more a solid-like to more viscous-like state. All along this process, the mobility of the unreacted, free monomers, radicals, and pendant groups are gradually being hindered due to an increase in polymeric crosslinking and to the solidification of the polymeric network. Past studies have shown that these unreacted monomers may leach out into the saliva and are cytotoxic to the pulpal tissues.[26] However, polymerization can still continue, often well beyond 24 hours after light exposure, albeit at a much slower pace.[27] This process of post-cure polymerization is also known as dark cure.[28]

On average, the degree of conversion for most dental RBCs can exceed 50% within the first minute of photo-initiation.[29] Meanwhile, some of the key physical properties of RBC such as solubility, strength, and fracture toughness is gradually taking shape. An acceptable DC for modern RBCs is 55-75%.[30] Al-Adhal et al found

that everX-Posterior (GC) and Beautiful-Bulk Flowable (Shofu) significantly increased in their DC after 24 hours post-cure, while the DC of Sonicfill did not increase after 30 minutes post-cure.[11]

For any light-activated system, its transformation from a thixotropic gel to a solid is highly dependent on the amount of radiant exposure and the chemistry and absorption coefficient of the RBC system. Hence, the degree of polymeric conversion (DC) and the depth-of-cure (DoC) vary for different RBC brands. Furthermore, RBC's DC and DoC are affected by the highly inhomogeneous profile of the dental light curing unit (LCU). Past studies have shown that the non-uniform spectral emission and radiant exitance from the light-emitting diodes within the LCU can cause inhomogeneous microhardness distribution across the RBC surface.[31,32]

Conclusion

With soaring demands for esthetics, RBCs have become the material of choice for direct restorative dentistry, slowly replacing the use of amalgams and gradually becoming the standard of care. This study explored the post-cure polymerization kinetics of bulk-fill RBCs and compared their DC and DoC. Despite the convenience and time-saving advantage of using bulk-fill RBCs, clinicians should be aware that not all bulk-fill RBCs have equivalent DoC. For example, under 20 seconds of curing time and 1221 ± 5 mW/cm^2 irradiance, the DoC of SF3, TECB, and F1B fail to reach manufacturers' claims. Among the six RBCs tested, VB appears to be the most translucent and exhibits high DoC as well as high DC at a sample thickness of 5 mm. Also, not all bulk-fill RBCs have similar volumetric shrinkage. When using bulk-fill RBCs, clinicians must exercise caution when reducing the number of incremental fills and anticipate challenges related to C-factor and polymerization stress. Care should be taken in prep design, so the effect of volumetric shrinkage and gap formation at the cavo-surface margins—potentially, post-op sensitivity—are lessened.

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