Ultrasonography for Wound Healing Evaluation of Implant-Related Surgeries

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9.1 Introduction

Wound healing is a complex and dynamic process of replacing devitalized and missing cellular structures and tissue layers [1]. The wound healing process can be divided into three phases: inflammatory, proliferation, and remodeling. The inflammatory stage also includes a hemostasis phase [2]. The healing outcome can be either regeneration or repair, depending on whether the lost structures and function are fully or partially restored. In the context of surgical dentistry, there are broadly two categories of procedures: resective and regenerative procedures. As the name implies, a resective procedure is to remove part of diseased oral soft or hard tissue to facilitate the reversal of a disease to healthy status. The healing of most resective cases is inconsequential, as long as patients healing capacity is not compromised. On the other hand, a regenerative procedure is to apply the tissue engineering concept by adding scaffold, cells, and/or signaling molecules to improve or replace biological tissue [3]. This type of procedures requires meticulous surgical handling and post-op care, or the complication rate is high. Common complications are wound exposure, sustained inflammation, and infection, resulting in partial or total loss of the grafting materials and incomplete regeneration. Patient morbidity, time effort, and costs are all considerable to remedy these complications. A rule of thumb is to identify early the occurrence of complications and intervene so adverse consequences can be reduced. Early signs of complications mostly show

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altered soft tissue characteristics, i.e. increased blood flow and water content and reduced collagen amount. Therefore, ultrasound can be very beneficial to evaluate healing of these regenerative procedures, aside from its inherent advantages, e.g. real-time, non-radiation, etc. In this chapter, we will demonstrate ultrasound images of wound healing after the most commonly performed surgical procedures related to implant therapy, including socket augmentation, guided bone regeneration, implant placement, and soft tissue grafting procedures.

9.2 Current Methods to Assess Wound Healing

Vision and palpation are currently the primary methods to examine healing [4]. They are quick and simple to perform. Obvious changes in soft tissue appearance, hue, and size are often indicative of unfavorable healing. For procedures requiring primary intention healing, the flap edges should stay approximated during the entire healing period. At approximately 2 weeks after a regenerative surgery, the soft tissue should reappear in its normal pink color and firm consistency because inflammation should have already subsided. In cases of wound exposure without infection, regenerative materials, e.g. bone grafts and membrane, may be visible at the open wound, along with tissue erythema, edema, and clear exudate. If infection exists, purulence, typically in yellow color, is a very common finding that drains through the wound opening, a fistula, or sinus tract. Apparent signs of inflammation and infection just described above can be confirmed by visual means and palpation. However, visual evaluation may not be sensitive to subtle changes indicative of incipient wound healing disturbance that may later become obvious and detrimental, causing more tissue loss if not controlled. Visual examination is also subjective to examiners' interpretation. Last, visual inspection cannot directly evaluate bone quantity and quality simply because overlying soft tissue obscures the bone.

Bone is primarily evaluated by 2D/3D radiographs. A normally healed ridge after a bone augmentation procedure is comprised of a layer of cortical bone on the surface of the edentulous ridge, cancellous bone, and a marrow space with a minimal amount of residual bone grafts [5]. Because of the addition of bone grafts, not only bone quantity but also quality are changed [6]. Residual bone graft materials may influence implant success. Failed healing includes irregularly shaped crestal bone, soft tissue invagination, and decreased mineralization. Intraoral radiographs can indicate the degree of mineralization and available bone height efficiently; however, the major limitation is that they only provide superimposed image; therefore, the ridge width cannot be revealed. This method is also limited in soft tissue contrast. Three-dimensional radiographs, i.e. cone-beam computed tomography (CBCT), are very useful to evaluate available bone width and height; however, inferior image quality due to artifacts from adjacent metal structures, high cost, and increased radiation dose have to be considered. Table 9.1 summarizes the current methods for wound healing evaluation and the potential roles ultrasound may have.

Table 9.1 Current methods to evaluate healing of socket augmentation, guided bone regeneration, implant surgery, and soft tissue grafting and potential usefulness of ultrasound

Surgical procedures	Current evaluation methods	Ultrasound method
Socket augmentation	Visual examination, palpation 2D and 3D radiographs, Direct open access	• Soft tissue thickness measures
		• Quantitative soft tissue inflammation evaluation
		• Bone width and quality estimation
		• Timing of implant surgery determination
Guided bone regeneration		• Soft tissue thickness measures
		• Quantitative soft tissue inflammation evaluation
		• Bone width and quality estimation
		• Detection of micrometer-sized wound exposure
		• Fixation screw identification
		• Timing of implant surgery determination
Implant placement		• Soft tissue thickness measures
		• Quantitative soft tissue inflammation evaluation
		• Bone width and quality estimation
		• Implant marginal bone level and thickness
Soft tissue grafting		• Soft tissue thickness, height, and quality measures
		• Quantitative soft tissue inflammation evaluation

9.3 Ultrasound as a Novel Tool to Assess Wound Healing

In light of the limitations of clinical examination and radiographic imaging, ultrasound can be used as a first-line device to assess wound healing because it provides cross-sectional images in real-time without radiation. More specifically, ultrasound can evaluate soft tissue thickness and quality, blood velocity and volume in soft tissue, crestal bone surface, and crestal bone width (Table 9.1). Soft tissue thickness is useful to determine tissue phenotype [7]. Tissue thickness is correlated with marginal bone remodeling around implants [8]. Thin phenotype may require an additional soft tissue graft procedure to improve esthetics and implant longevity [9]. Blood velocity and volume are good indicators of tissue inflammation; elevated color flow and power Doppler signals are normal within the first 2 weeks. However, increased signals beyond that time frame may indicate uncontrolled inflammation process and require further investigation. It can also detect micrometer-sized wound exposure because the image resolution of a high-frequency probe, e.g. 25 MHz is less than 100 μm.

Although not being able to image intraosseous structures, ultrasound can delineate crestal bone surface well [10,11]. Ultrasound crestal bone surface can reveal the degree of surface bone maturation and crestal bone width (see Table 9.1). A strong and continuous hyperechoic line is suggestive of complete healing, as compared to irregular, less strong hyperechoic line, suggesting soft tissue invagination and incomplete crestal bone healing.

By observing the extent of bone surface maturation with ultrasound, optimal timing for implant surgery may be objectively determined. A crestal bone width of 2–3 mm in additional to the planned implant diameter is required for an optimal implant surgery. A small bony deficiency may require additional bone grafting at the same visit as implant surgery; however, a large deficiency may require a separate bone grafting procedure before an implant can be placed [12]. Finally, ultrasound can locate fixation screws/tacks that are commonly used to secure an occlusive membrane, making minimal flap reflection possible during screws removal so as to minimize patient morbidity. In the following sections, ultrasound images will be demonstrated specific to healing of socket augmentation, guided bone regeneration, implant surgery, and soft tissue grafting surgery.

9.4 Socket Augmentation Healing

9.4.1 Procedure Description

After tooth extraction, the alveolar ridge inevitably undergoes dimensional decrease, especially the width dimension, compared to the height. To reduce the amount of bone resorption, bone grafting materials, e.g. allografts and xenografts are commonly placed in the socket. Coronally to the grafts, a collagen plug or a non-resorbable/resorbable membrane is placed, depending on the presence of missing

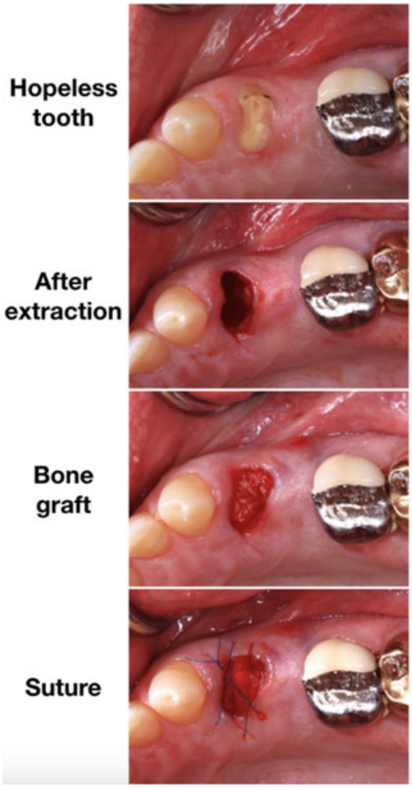

Fig. 9.1 Procedures of socket augmentation. After the hopeless is extracted and the socket is thoroughly debrided, bone particulate graft is placed into the socket. In uncomplicated socket, a collagen plug is placed to seal the socket and non-resorbable sutures are used to stabilize the wound

bone walls surrounding the socket. The wound may be left as second intention healing or less commonly a primary wound closure is attempted. Figure 9.1 demonstrates the clinical procedures. The literature has shown efficacy of this type of treatment. After such a bone grafting procedure, the healing is most commonly assessed at 2 weeks for any early signs of healing failure and for suture removal. If the healing is uneventful, an arbitrary time frame of 4–6 months, the socket, now an edentulous ridge, is evaluated again in preparation for an implant surgery.

9.4.2 Ultrasound Case Demonstration

Ultrasound can be used to evaluate the crestal bone quality after socket augmentation. Figure 9.2 contrasts the two scenarios: (1) the crestal bone was intact (normal healing) and (2) incomplete crestal bone formation (soft tissue invagination). In cases with incomplete socket healing, soft tissue invagination into alveolar bone, intermingled with residual bone particles is a common finding. Soft tissue invagination can be imaged with ultrasound and shows hyperechoic appearance in the socket.

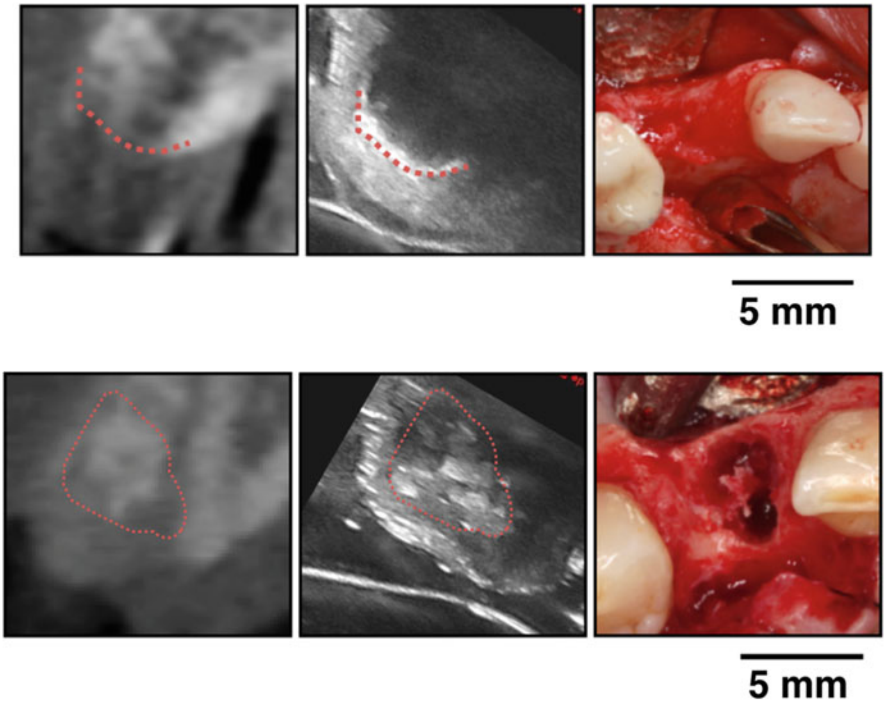

Fig. 9.2 Top: Normal healing with enclosure of the crestal cortical plate. A bright (hyperechoic) line (red dotted line) is shown on the ultrasound (US) image, indicative of intact bone surface. The image is consistent with the CBCT image and clinical photo. Bottom: Impaired healing with soft tissue invagination, encircled by the red dotted line, in the bone and failure of crestal cortical bone formation on the US and CBCT images. The clinical photo confirms this finding after removal of the soft, non-integrated soft tissues and bone particles

Ultrasound may image the socket immediately before and after socket augmentation is performed to serve as baselines for evaluation of the efficiency of socket augmentation (Fig. 9.3).

9.5 Guided Bone Regeneration

9.5.1 Procedure Description

Guided bone regeneration (GBR) is a surgical procedure that applies a membrane, that is either resorbable or non-resorbable, and commonly bone grafts to augment alveolar ridge [13]. After a full-thickness flap reflection, bone grafts of surgeon's choice are placed on the denuded bone. A membrane is then used to cover bone grafts. The membrane may be fixed to the underlying native bone with sutures, tacks, or fixation screws. After that, the flap is released for primary wound closure. The

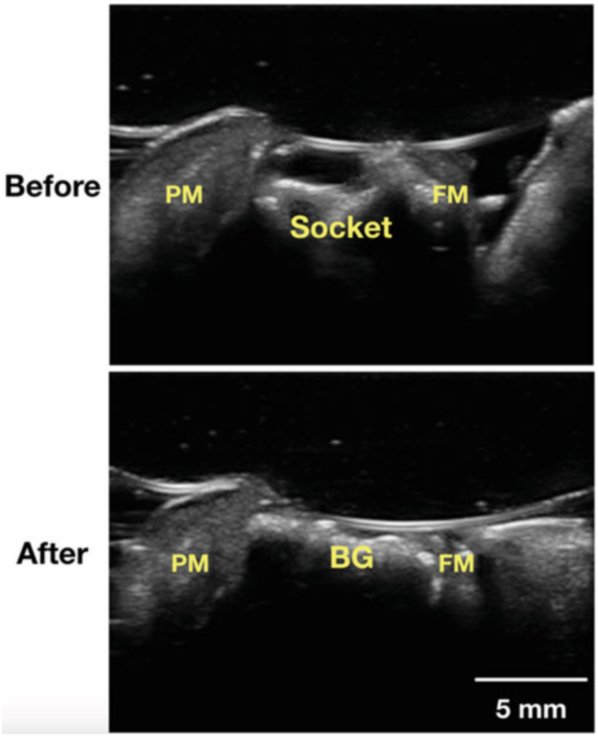

Fig. 9.3 Ultrasound occlusal scan of socket augmentation before and immediately after the bone graft is Placed. *PM* palatal mucosa; *FM* facial mucosa

GBR procedure is summarized in Fig. 9.4. Like socket augmentation, the surgical site is commonly evaluated at 2 weeks to assess early healing and approximately at 4–6 months if uneventful in preparation for implant surgery.

9.5.2 Ultrasound Case Demonstration

Wound healing after GBR procedures can be evaluated by ultrasound. Figure 9.5 shows ultrasound images of a GBR case with a membrane exposure. Ultrasound B-mode images can show the tissue thickness overlying the membrane, bone surface not covered by a non-resorbable membrane, and the membrane. Color flow images show blood velocity and blood vessel density. In cases of inflammation/infection, blood vessel intensity is expected to increase. Research to validate ultrasound for the estimation of the degree of inflammation is needed. Figures 9.6, 9.7, and 9.8 demonstrate healing after the membrane was removed. Crestal bone width and morphology can be evaluated on B-mode images. There is a significant reduction in blood vessel intensity, as shown on color flow images, compared to Fig. 9.5, suggesting resolution of inflammation.

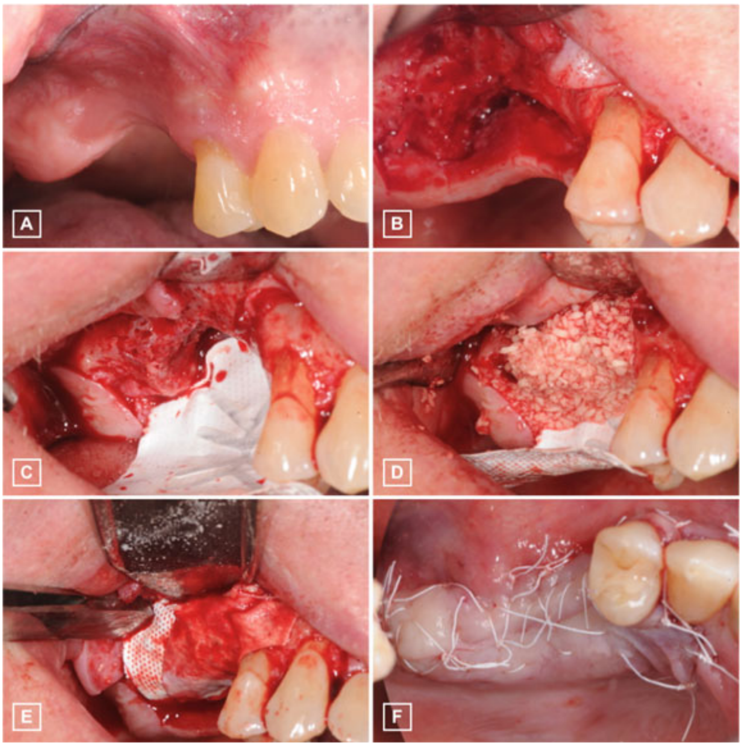

Fig. 9.4 Demonstration of a guided bone regeneration procedure. (**a**) Presence of a ridge defect in need of a GBR procedure before implant placement. (**b**) After a full-thickness flap reflection, the bony defect is evident. (**c**) A non-resorbable membrane is fixed to the palatal bone. (**d**) Bone particulates are placed onto the defect. (**e**) The membrane is folded to the buccal side and fixed. Another resorbable membrane is placed on top of the non-resorbable membrane. This additional membrane is not necessary for every case. (**f**) Primary wound closure is achieved with sutures

9.6 Healing After Implant Surgery

9.6.1 Procedure Description

An implant surgery typically involves a full-thickness flap elevation, osteotomy, and insertion of an implant fixture. After an implant is placed, the flaps are approximated with sutures. In certain cases when the ridge width is abundant, a flapless approach is applied for possible accelerated soft tissue healing. Flap implant surgery has become a standard, predictable procedure. Once integrated with the surrounding bone, which takes approximately 3 months, the implant is ready to be restored. The three most critical factors for surgical success are (1) adequate quantity and quality of hard and soft tissues, (2) optimal implant positioning, and (3) achievement of implant primary stability. Nevertheless, postoperative complications may occur, especially

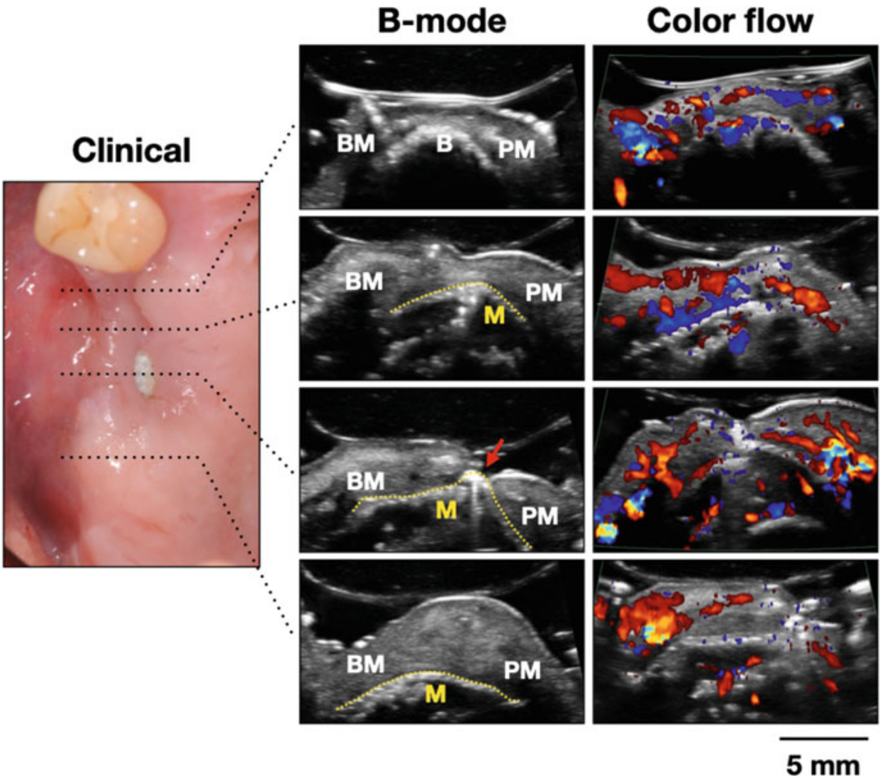

Fig. 9.5 Ultrasound B-mode and color flow images of impaired GBR wound healing due to exposure of the non-resorbable membrane. Images were taken from the occlusal side. *M* membrane; *BM* buccal mucosa; *PM* palatal mucosa. Due to wound exposure and possible bacterial invasion, blood flow as seen on color flow images increases, an indicator of tissue inflammation

when bone graft is placed simultaneously. The most common complication is soft tissue dehiscence/wound opening at the crestal region, which may result in tissue inflammation and infection. The final consequence is loss of crestal bone around the implant. Once the rough implant surface is exposed, pathologic bacteria may populate and proliferate, inducing further bone loss, a disease termed "peri-implantitis" [14]. Additionally, hard and soft tissue undergo remodeling after the surgery. Physiological remodeling is on a smaller scale, associated with acceptable crestal bone loss. However, pathological remodeling can cause excessive bone loss and subsequent soft tissue recession, compromising long-term implant function and esthetics [15]. Bone loss as a result of physiological remodeling may last for approximately a year after placement of a final restoration; pathological remodeling occurs when there is a presence of adverse influences (Table 9.2). Therefore, a careful evaluation of peri-implant structures is crucial during initial healing and subsequently after implants are in function.

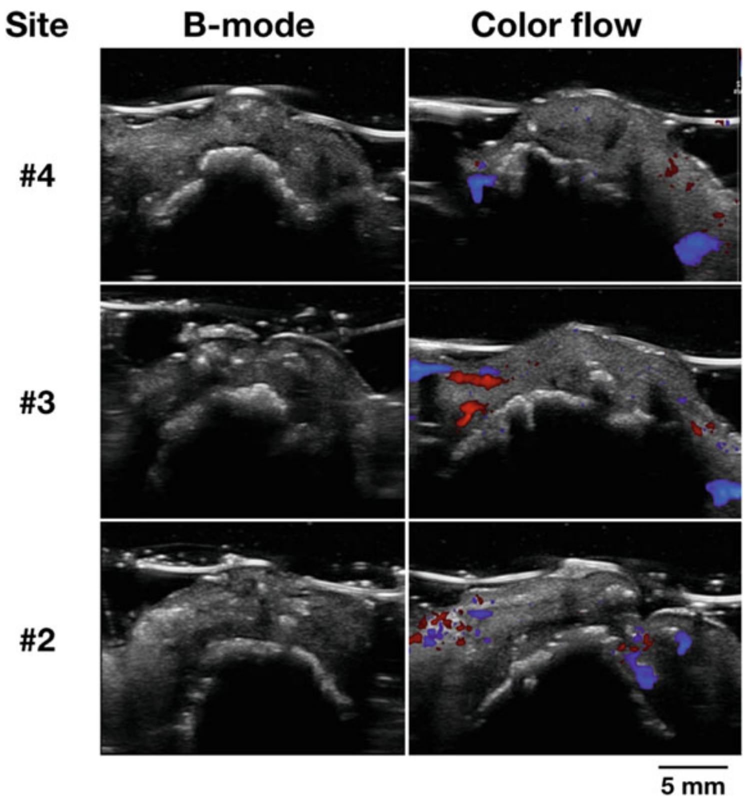

Fig. 9.6 Ultrasound occlusal images of the same case at 1 week after membrane was removed. On the B-mode, there are some residual particles (hyperechoic) in soft tissue. Color flow images show much less blood flow, compared to Fig. 9.5

9.6.2 Ultrasound Case Demonstration

Ultrasound can be used to identify the implant location, the soft tissue thickness, marginal bone level, and marginal bone thickness before the second stage. This information can be useful to assist surgeons in determining the most appropriate second stage surgical approach. If the bone quantity is adequate, a minimally invasive approach, e.g. tissue punch, can be adopted. If the facial plate is too thin, another GBR procedure might be indicated to prevent future biological and esthetical complications. Figures 9.9 and 9.10 show an implant with normal healing and Fig. 9.11 shows an implant with impaired healing. With impaired healing, there is prominent marginal bone loss with the presence of elevated blood flow and possible hypoechoic soft tissue appearance. This hypoechoic feature might be due to loss of collagen content and fluid accumulation in the extracellular matrix.

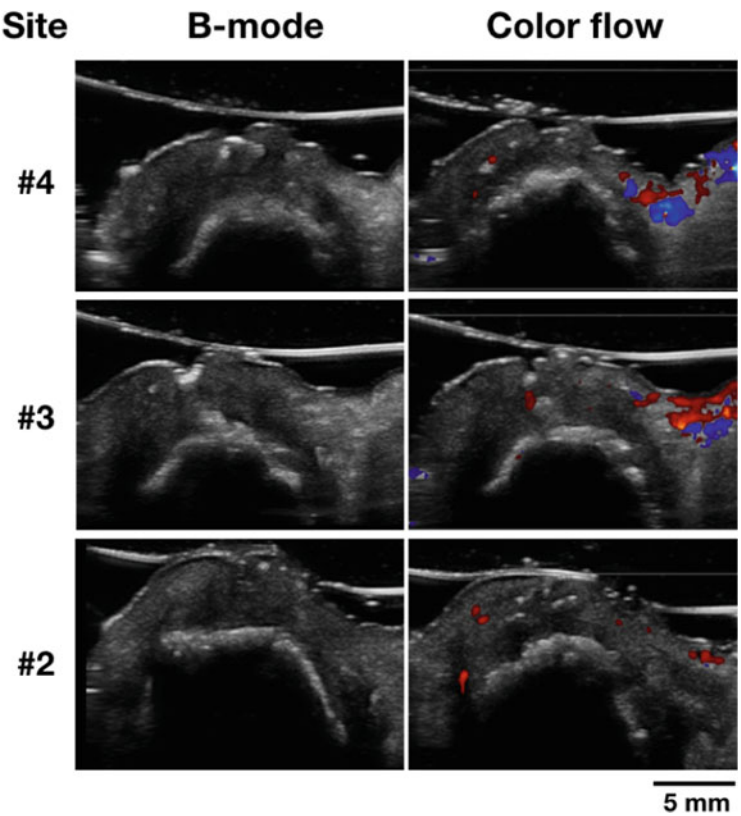

Fig. 9.7 Ultrasound occlusal images of the same case at 1 month after the membrane was removed. On the B-mode images, residual particles are less visible in the soft tissues. Color flow images show normal blood flow, compared to Fig. 9.5, indicative of resolution of inflammation

9.7 Soft Tissue Graft Surgery Around Implants

9.7.1 Procedure Description

Facial mucosal recession, an arising complication, can affect implant function and esthetics. The etiology is not fully known; however, the recession is strongly associated with thin tissue phenotype, inadequate bone thickness, malpositioned implants, and inappropriately designed restorations [9]. Currently such a defect is treated with a soft tissue graft. In Fig. 9.12, after flap reflection, a soft tissue graft, harvested from the hard palate, is placed to cover the exposed implant. Alternatively, an allogenic graft may be used. Then the flap is released coronally to cover the graft for providing vascularization and sutured in place. By adding a graft, the therapeutic goal is to increase soft tissue thickness; the coronally advanced flap is to cover the exposed implant/implant abutment. The initial healing is typically evaluated at 2

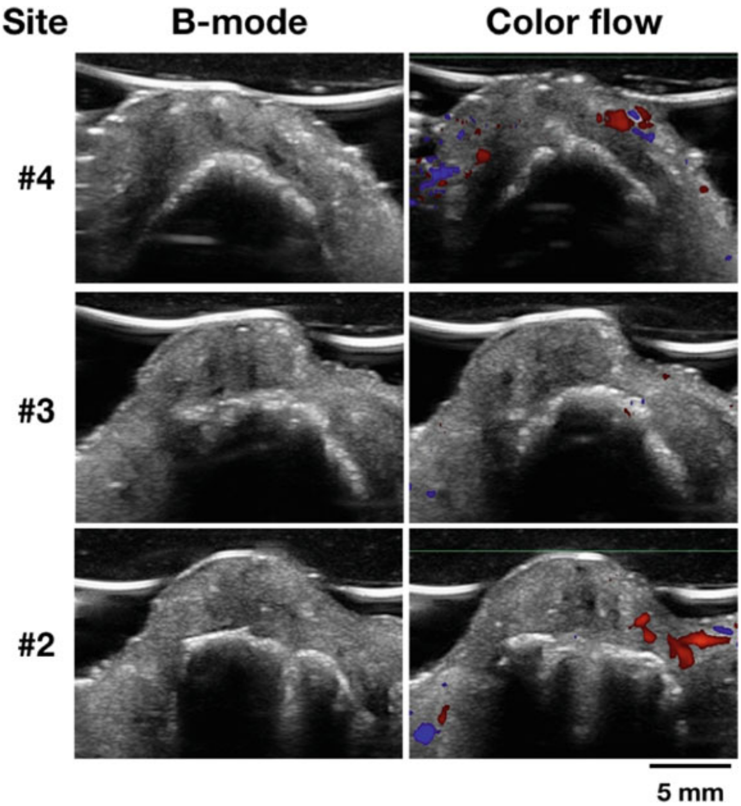

Fig. 9.8 Ultrasound occlusal images of the same case at 2 months after the membrane was removed. On the B-mode images, soft tissue thickness and ridge width can be measured in preparation for the implant placement surgery. The edentulous ridge at tooth #2 location shows discontinuous crestal bone surface and a hyperechoic structure into the bone, indicating some soft tissue invagination into bone in this area. Color flow images show normal blood flow

weeks; however, an earlier visit may be needed. After 1-month, the new mucosal margin level should stay stable. In this case, up to 1 month, the facial mucosa is still slightly erythematic but much reduced in intensity, compared to 1-week follow-up. On the tissue donor site, granulation tissue is dominant at 1- and 2-week follow-ups. At one month, most of the re-epithelialization seems complete. At 3 months, the donor site appears almost normal, except for slight erythema. Figure 9.13 presents the course of healing over 3 months.

9.7.2 Ultrasonography Case Demonstration

Ultrasound can evaluate available tissue volume at the donor site, soft tissue thickness, and mucosal level changes over time after the soft tissue graft procedure,

Table 9.2 Comparisons of physiological and pathological crestal bone loss around implants

Crestal bone loss	Physiological	Pathological
Causes	• Controlled surgical trauma • Normal occlusion • Foreign body (implant) reaction • Normal skeletal remodeling • Others	• Uncontrolled surgical trauma • Excessive occlusion • Inadequate bone quality/quantity • Improper implant positioning • Compromised/impaired wound healing • Pathogen-induced • Others
Duration	Mostly noticeable bone loss ends at 1-year after function	When presence of a cause and can last if the cause is not controlled
Scale of bone loss	Crestal bone stops at either smooth–rough surface border or the first thread	Cumulative and beyond physiological remodeling

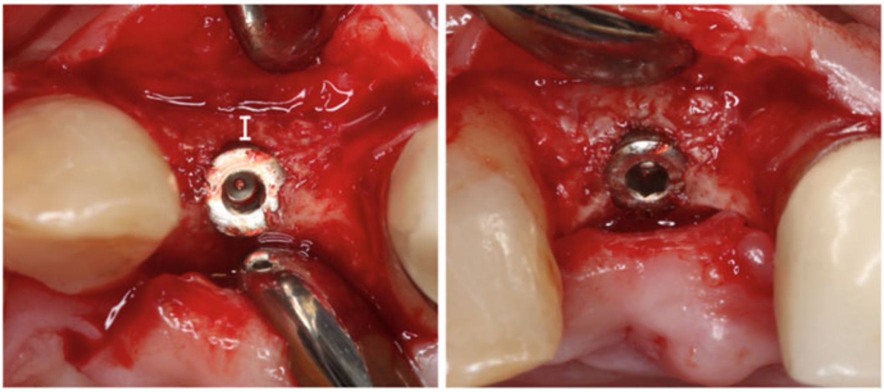

Fig. 9.9 A clinical case with implant #7 undergoing second stage exposure surgery. On the right, a layer of facial bone is present, as indicated by the white bar

and blood flow in various time points. Figure 9.14 demonstrates longitudinal B-mode and color flow images of the same case shown in Figs. 9.12 and 9.13.

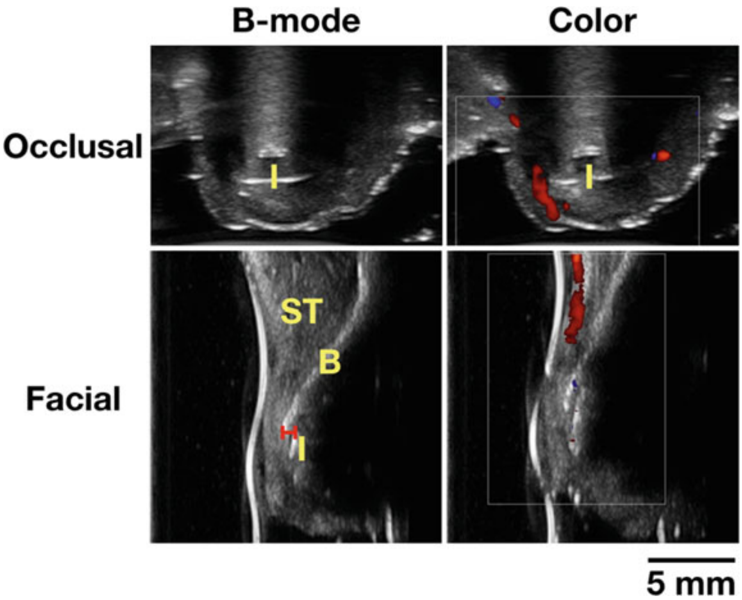

Fig. 9.10 Ultrasound illustration of the same case seen in Fig. 9.9. The images were taken before flap releasing. On the occlusal view, the cover screw has a strong sound reflection and hence hyperechoic. On the facial view, the facial bone thickness can be measured and corresponds to the dimension seen in the clinical photo in Fig. 9.9. Color flow images show normal blood flow *I* implant, *B* bone, *ST* soft tissue

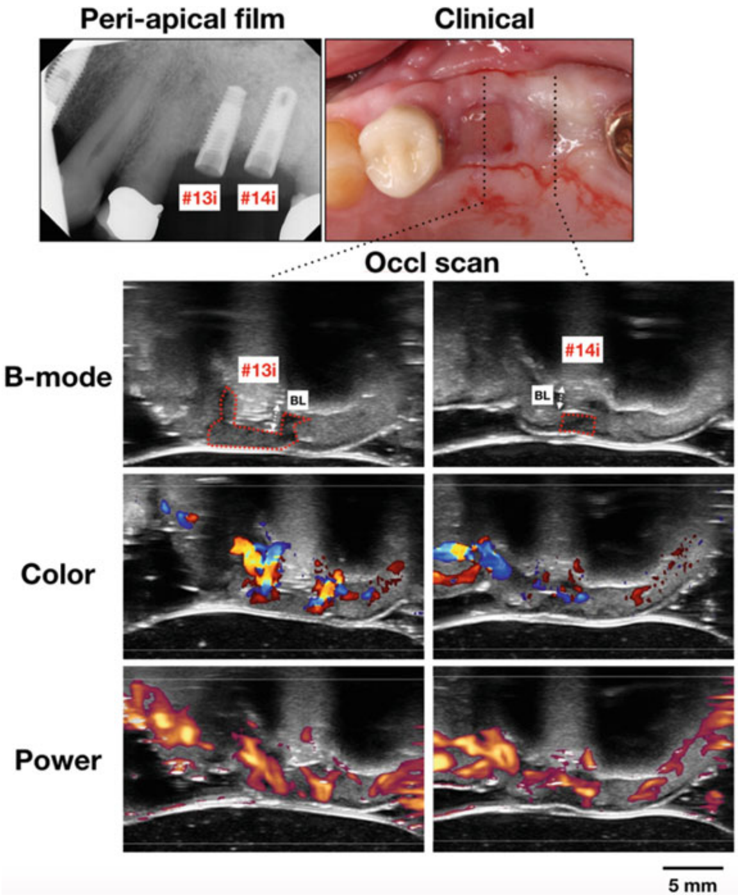

Fig. 9.11 A clinical case with compromised implant healing. The B-mode occlusal scans show intensity changes in soft tissue around the implants, indicating loss of collagen and matrix structures due to inflammation. Bone loss (BL) is evident in this view direction, corresponding to the amount of bone loss on the 2D radiograph. Overt blood flow is seen on color (middle) and power Doppler (bottom) images, indicative of tissue inflammation

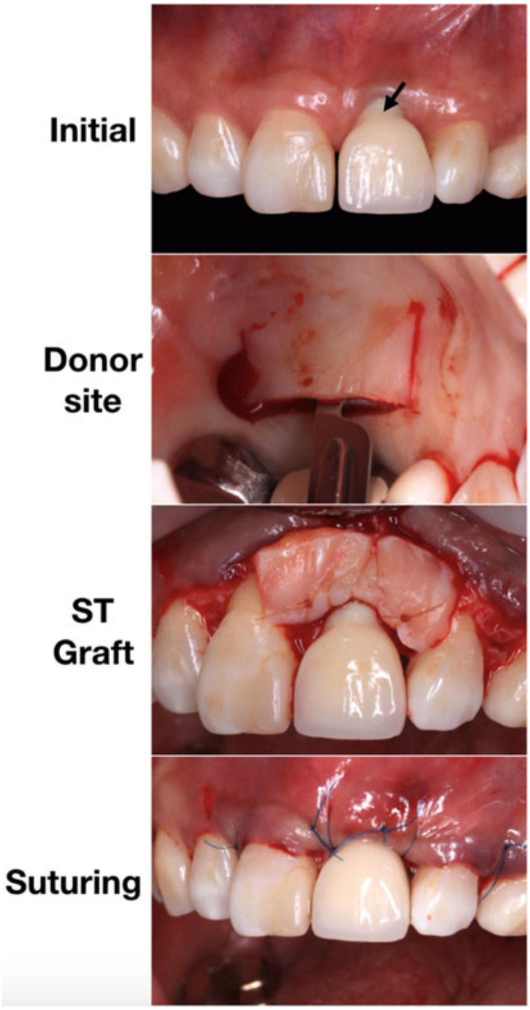

Fig. 9.12 Procedures of soft tissue graft on implant #9. The initial photo is evident of mucosal recession (black arrow). A connective tissue is harvested from the palate (donor site) and this soft tissue graft (ST graft) is transferred to the donor site. The overlying flap is released to cover the graft and secured with sutures. Courtesy of Dr. Lorenzo Tavelli, faculty at the University of Michigan

Fig. 9.13 Clinical photos of the recipient and donor sites at various time points. Even at 1 month, there is still some inflammation present at the recipient and donor sites, indicated by edematous and erythematous tissue appearance. At 3 months, the tissues look normal in color and the recession is largely corrected. Courtesy of Dr. Lorenzo Tavelli, faculty at the University of Michigan

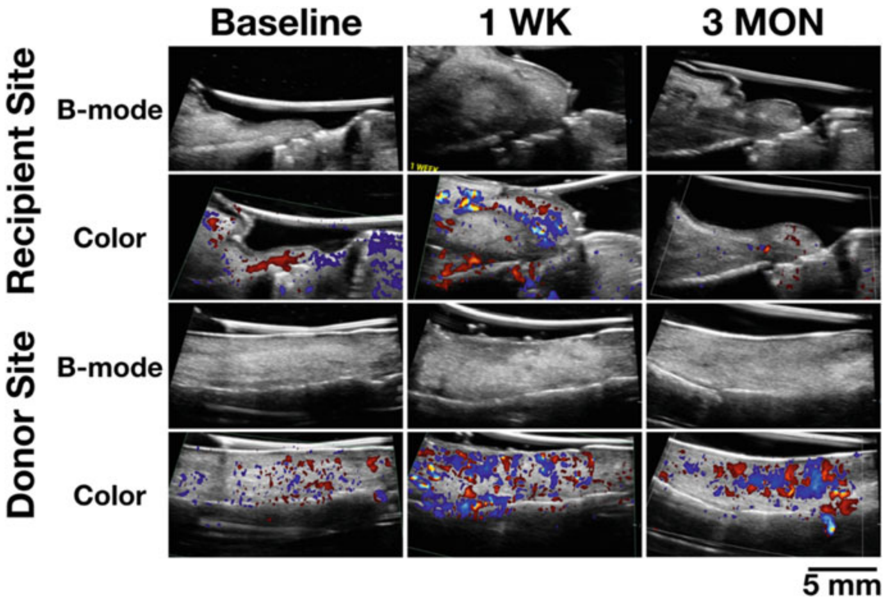

Fig. 9.14 At the recipient site, B-mode shows at 1 week the soft tissue thickness increases significantly due to the additional graft, swelling, and inflammation. At 3 months, the tissue is more condensed yet already thicker than at the baseline, indicative of a successful procedure. In addition, the mucosal margin is more coronally placed at 3 months. The color flow images show increase of blood flow at 1 week and normal blood flow at 3 months. At the donor site, the tissue intensity changes in B-mode images, suggesting remodeling of the soft tissues. In the color flow images, the blood flow increases significantly at 1 week and even at 3 months, suggesting at 3 months the revascularization and healing is still occurring

9.7.3 Conclusions

Current clinical and radiographic examinations are the primary methods to evaluate wound healing of implant-related surgical procedures. Although they can identify apparent healing impairment, they may not be sensitive enough to detect early signs of complications. In addition, visual exams are limited by only soft tissue surface screening. Intraoral radiographs cannot provide cross-sectional images nor tissue activity. This chapter demonstrated the potential use of ultrasound to evaluate healings of socket augmentation, guided bone regeneration, implant surgery, and soft tissue augmentation. Being cross-sectional and functional imaging, it can acquire essential clinical information, e.g. soft tissue thickness measures, quantitative evaluation of soft tissue inflammation, ridge width and quality, and marginal bone level and bone thickness around implants. These pieces of information, along with clinical and radiographic findings, allow for clinicians to grasp a full picture of the healing event that is necessary for making clinical decisions and provide recommendations to the patients. Although at its rudimentary stage, ultrasonography has showed its potential as a useful imaging modality to evaluate tissue healing. Subject variability may influence ultrasound blood flow and velocity measures and has to be taken into consideration. Other ultrasound parameters that are worth investigating for evaluating wound healing are, among others, elasticity and backscatter imaging.

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