The addition of soft tissue replacement grafts in plastic periodontal and implant surgery: critical elements in design and execution


Abstract
Soft tissue replacement grafts have become a substantial element to increase tissue volume in plastic periodontal and implant surgery. Autogenous subepithelial connective tissue grafts are increasingly applied in aesthetic indications like soft tissue thickening, recession treatment, ridge preservation, soft tissue ridge augmentation and papilla re-construction. For the clinical performance of connective tissue graft harvesting and transplantation, a fundamental understanding of the anatomy at the donor sites and a sound knowledge of tissue integration and re-vascularization processes are required. Possible donor sites are the anterior and posterior palate including the maxillary tuberosity, providing grafts of distinct geometric shape and histologic composition. The selective clinical application of different grafts depends on the amount of required tissue, the indication and the personal preference of the treating surgeon. One of the main future challenges is to volumetrically evaluate and compare the efficacy and long-term stability of soft tissue autografts and their prospective substitutes. The aim of this review was to discuss the advantages and shortfalls of different donor sites, substitute materials and harvesting techniques. Although standardized recommendations regarding treatment choice and execution can hardly be given, guidelines for predictable and successful treatment outcomes are provided based on clinical experience and the available scientific data.

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The use of soft tissue replacement grafts has become a substantial element in plastic periodontal and implant surgery. The application of soft tissue autografts has characterized the last 50 years of clinical periodontology, and till today – more than ever – a variety of soft tissue grafting interventions is carried out with two different targets being pursued: increasing the width of keratinized tissue and increasing soft tissue volume. In the beginning of the era of mucogingival surgery, surgical interventions were performed based on the belief that a minimal width of keratinized gingiva would be required to maintain the periodontal tissues healthy and stable (Nabers 1954, Ochsenbein 1960, Friedman & Levine 1964, Sullivan & Atkins 1969, Carranza & Carraro 1970, Hall 1981, Matter 1982). A minimum of 1 mm to 3 mm of keratinized gingiva was believed to be mandatory (Corn 1962, Bowers
In the 1960s, it was assumed that the tissue around teeth adapts to functional requirements when subjected to physical impacts during mastication (Ivaniec 1957, Orban 1957, Bradley et al. 1959, Pfeifer 1963). As a consequence, denudation techniques (Ochsenbein 1960, Bohannan 1962, Corn 1962, Wilderman 1964), periosteal retention procedures (Staffileno et al. 1962) and apical repositioned flaps (Friedman 1962) were recommended to increase the width of the keratinized gingiva. As the role of inherent factors regarding genetic determination of gingival tissues became clear, the tissue around teeth and implants in particular free epithelialized grafts, usually referred to as free gingival grafts (FGG), was proposed instead (Haggerty 1966, Nabers 1966, Sullivan & Atkins 1968, Edel 1974).

When it was subsequently realized that the biological significance of a sufficient wide keratinized gingiva was doubtlessly overrated in the past (Miyasato et al. 1977, Hangorsky & Bissada 1980, Lindhe & Nyman 1980, de Trey & Bermimoul1in 1980, Dorfman et al. 1982, Schoo & van der Velden 1985, Kisch et al. 1986, Salkin et al. 1987), the clinical importance of FGGs to increase the width of the keratinized gingiva more and more decreased. Instead periodontists started to use the FGG for aesthetic corrections like soft tissue recession coverage (Bernimoulin et al. 1975, Miller 1982) and soft tissue ridge augmentation (Seibert 1983) as well as for socket preservation in aesthetically relevant areas (Landsberg & Bichacho 1994). These advancements of soft tissue augmentation procedures were marked by a sense of aesthetics among patients, which had not been present in the dental community in this form before. This meant a fundamental change regarding the indications of soft tissue autografts in periodontology. However, as much as the FGG had proven for increase in the width of keratinized gingiva, as much its limitations, both regarding the quantitative (volume augmentation) and qualitative outcomes (aesthetic integration, surface, colour, scarring), were obvious when it was applied for soft tissue re-construction in aesthetic indications. In search of better alternatives it soon became clear that the predictability regarding the aesthetic outcome was much higher when using a subepithelial connective tissue graft (SCTG) (Langer & Calagna 1980, Langer & Langer 1985, Raetzke 1985, Nelson 1987, Harris 1992, Allen 1994, Bruno 1994). The further development of soft tissue autografts from the FGG to the SCTG represents a paradigm shift, which is conceptually anchored in the literature by the transition from classical mucogingival surgery to plastic periodontal surgery. Today soft tissue augmentation only occasionally means widening of the gingiva or peri-implant mucosa in the context of plastic periodontal and implant surgery. It is rather indicated for soft tissue recession treatment at teeth (Cairo et al. 2008, Chambrone et al. 2010, 2012, Cortelini & Pini Prato 2012) or implants (Burkhardt et al. 2008, Rocuzzo et al. 2013, Zucchelli et al. 2013), for ridge preservation procedures with immediate implants or fixed partial dentures (Esposito et al. 2012, Lang et al. 2012), for soft tissue ridge augmentation associated with implants or fixed partial dentures (Thoma et al. 2009, Schneider et al. 2011, Sanz et al. 2012) and for papilla reconstruction (Nemcovsky 2001, Nordland et al. 2008). Furthermore, it might be recommended for soft tissue thickening to stabilize the gingiva, for example, before orthodontic treatment (Steiner et al. 1981, Wennstrom et al. 1987) or restorative (Ericsson & Lindhe 1984) treatment and to mask discoloured roots or shining through implant components (Jung et al. 2007).

Considering the challenges of soft tissue augmentation procedures in plastic periodontal and implant surgery today, the FGG has consequently disappeared from the aesthetic zone and its scope of application has been limited to procedures increasing the keratinized tissue around teeth and implants in aesthetically irrelevant zones. For that reason, this review dispenses FGGs and concentrates on SCTGs and their potential substitutes for soft tissue recession treatment and soft tissue volume increase. The aim of this review was therefore to analyse the dental literature regarding soft tissue grafting techniques in plastic periodontal and implant surgery and to provide clinical strategies for soft tissue replacement graft procedures. Based on scientific evidence and clinical experience it is supposed to (I) analyse and discuss the advantages and shortfalls of different donor sites and harvesting techniques as related to autogenous soft tissue grafts and (II) to provide clinical guidelines for predictable and successful treatment outcomes and (III) give a global perspective on current and future possibilities with soft tissue substitutes.

Anatomical landmarks

The oral mucosa can be divided into three portions: the specialized sensory mucosa (taste buds on dorsum of the tongue), the lining mucosa (lips, cheeks, vestibule, floor of the mouth, base of the tongue and soft palate) and the masticatory mucosa (gingiva and hard palate) (Orban & Sicher 1945). The masticatory mucosa of the hard palate is composed of three histologic layers: the epithelium, and the subepithelial connective tissue with the lamina propria and the submucosa (Fig. 1). The epithelium is characterized by orthokeratinization and about 300 μm thick, its structure basically corresponding to that of the gingival epithelium. The lamina propria below the palatal mucosa is very coarse tissue. It contains a high proportion of inter-cellular substance, which is produced by fibroblasts. This extracellular matrix is responsi-

![Fig. 1. Clinical view of a thick free epithelialized graft without perosteum harvested from the lateral palate to illustrate the histological composition of the palatal masticatory mucosa: covering epithelium and subepithelial connective tissue including lamina propria and submucosa.](image-url)
able for the mechanical properties of the tissue layer. It consists predominantly of collagen fibrils mainly with type I and II and few type V and VI collagen. Elastic fibres are hardly present. The lamina propria is divided into the papillary portion and the reticular portion. The papillary portion shows finger-like projections that inter-lock with the overlying epithelium whereas the reticular portion consists of thick and dense reticular fibres. The submucosa is a connective tissue layer, which attaches the lamina propria to the periosteum of the underlying bone. Numerous glands, nerves and adipose tissue are present in this tissue layer. Its thickness can vary between patients and within the same individual (Muller et al. 2000). The submucosa is characterized by a rather fatty zone in the anterior and copious glands (Gll. Palatinae) in the posterior area whereas it is in general less pronounced in the posterior than in the anterior part of the palate. In a histologic evaluation of human SCTGs from the anterior palate by Harris, large differences in the histologic composition were found: some grafts consisted almost only of lamina propria and in some grafts the greatest proportion was submucosa with mainly adipose tissue (Harris 2003). The portion of the lamina propria varied between 21.1 and 100% of the graft (mean 65.2%). These results confirm the clinical observation that the dimensions of the different subepithelial connective tissue layers vary substantially from patient to patient.

The thickness of the masticatory mucosa at the palate has been evaluated in different studies. Eger and Muller determined the thickness with ultrasonic devices (Eger et al. 1996, Muller et al. 2000). They found that the soft tissue thickness at the tuberosity area was highest with more than 4 mm, followed by the palatal masticatory mucosa at the second molars and pre-molars with an average of 3 mm. In general, the thickness was found to be higher in men than in women. In a computertomographic study by Song and coworkers, it was found to be $3.83 \pm 0.58$ mm with females having a thinner ($3.66 \pm 0.52$ mm) mucosa than men ($3.95 \pm 0.60$ mm) and an increasing thickness with increasing age (Song et al. 2008). Furthermore, there was a tendency for an increase from the canine to the second premolar, a decrease at the first molar and an increase again at the second molar. The second pre-molar region showed to be thickest with a mean of $3.81 \pm 0.75$ mm and the first molar region the thinnest with $3.13 \pm 0.69$ mm. In a cadaver study by Gapski and coworkers, the soft tissue thickness at the tuberosity came out to be 2.5–4 mm (Gapski et al. 2006). Apparently, the subepithelial connective tissue from the tuberosity area is a very dense, coarse and collagen-rich tissue that seems to contain less fat and glandular tissue, but much more collagen than that from the anterior lateral palate.

The arterial blood supply of the palate is provided by the greater palatine artery (GPA), a branch of the maxillary artery, which emerges from the greater palatine foramen. It runs through a groove lateral to the greater palatine nerve (GPN) and submits branches to the palatal mucosa and the gingiva, continuously decreasing its diameter and ends at the incisive canal, where it Anastomoses with the sphenopalatine artery. The innervation of the mucosa and gingiva at the hard palate is provided by the GPN, which emerges also through the greater palatine foramen and traverses medial to the GPA, subdividing into several branches, which are becoming thinner towards the epithelial layer. Between the GPA and the GPN, a crest is present, which can in most cases be palpated clinically (Benninger et al. 2012).

With respect to potential complications of harvesting SCTGs from the palate, the palatine neurovascular bundle is a very important and clinically relevant anatomical structure to be protected. Therefore, having a general idea of the possible course of the palatine artery is essential. For this reason, different anatomical studies were set up with the objective to work out reliable reference points and guidelines that can be used by clinicians to prevent damage to the GPA during SCTG harvesting in a given clinical situation. In an anatomical study of the GPA and related bony structures of the hard palate in 41 cadavers, Klo-serk and Rungruang found that the GPF was most frequently found in the region near the apices of the second and third molars, in the area where the vertical and horizontal segments of the palatine bone come together (Klosek & Rungruang 2009). Ikuta and coworkers found in a cone beam computed tomography study that the GPF was located in 92 of 100 cases in the third molar region and in an average distance of 7.9 mm from the alveolar ridge (Ikuta et al. 2013), whereas a study in Indian skulls observed the GPF to be in the third molar region in only 73% of the cases (Sharma & Garud 2013). Monnet-Corti and coworkers, who measured the distance of the main branches of the GPA from the palatal gingival margin in 198 plaster models of periodontally healthy patients, found that the average distance from the gingival margin to the GPA ranged from approximately 12 mm in the canine area to roughly 14 mm at the second molar level (Monnet-Corti et al. 2006). The authors concluded that it should be possible to harvest a SCTG measuring 5 mm in height in all patients and 8 mm in height in 93% of patients without a risk of damaging the GPA. However, a cadaver study by Fu and coworkers revealed that the predicted location of the GPA based on the aforementioned study cast measurements tended to be inaccurate and that the predicted distance between the GPA and the cementoenamel junction of the first molars and pre-molars tended to be underestimated (Fu et al. 2011). This is in correspondence to findings by Benninger and coworkers, who measured an average distance of 12 mm (range 9–16 mm) between the first molar and the GPA (Benninger et al. 2012). To establish a guideline for clinicians to localize the GPA, the authors assumed that in most cases the GPA would be found at a distance of 76% of the palatal height measuring from the cementoenamel junction of the first molar. Other evidence suggests that the height of the palatal vault is related to the course of the greater palatine artery: The shallower the palatal vault, the closer the palatine artery gets to the palatal gingival margin (Reiser et al. 1996) (Fig. 2).
Donor site selection

It is beyond all question that among suitable donor sites for intra-oral SCTG harvesting only those come into consideration that promise an adequate amount of obtainable tissue. They should not be associated with major health risks and go along with acceptable patient morbidity. Under these requirements and in consequence of the anatomical soft tissue conditions in the oral cavity two areas of interest for autograft harvesting have emerged as the areas of choice: the anterior and the posterior palate, whereas in the posterior area the tuberosity and the lateral palate can be distinguished.

In general, the grafts from the different eligible sites differ in their geometric shape: grafts from the tuberosity are more voluminous, those from the posterior lateral palate rather thin, whereas those from the anterior palate can often be extensive with a large surface. This has an influence on the indication they are intended for. For example, an alveolar ridge augmentation is rather performed with a voluminous graft from the tuberosity area whereas a recession coverage can also be done with a thin and small dimensioned graft from the posterior lateral palate. Should the clinical situation require changing the geometry of a given graft, the transplant can be modified by folding and suturing grafts from the lateral palate or by slicing and unfolding grafts from the tuberosity area. As the dimensions of the masticatory mucosa at the palate vary substantially from patient to patient (Eger et al. 1996, Muller et al. 2000, Harris 2003, Gapski et al. 2006, Song et al. 2008), it is important for the clinician to quickly overview the amount of available tissue at the possible donor sites. To do so, a good and simple option is using an endodontic needle with a silicon disc applied to it (Studer et al. 1997, Papolantonio et al. 2002, da Silva et al. 2004, Joly et al. 2007). In this context, Zucchelli and coworkers assumed that in addition to measuring soft tissue thickness at the palate endodontic needles might also be used to estimate the composition of the subepithelial connective tissue. The authors believed that due to different penetration resistances towards the needle the transition between lamina propria and the adipose submucosa could be felt in many situations (Zucchelli et al. 2010).

Besides their geometry, grafts from different donor sites vary in their histologic composition (Harris 2003). It may be speculated that these differences not only account for variable volume stability but also influence the physiologic process of graft re-vascularization. From clinical experience, it seems in this context as if subepithelial connective tissue from the tuberosity and the posterior lateral palate was denser and firmer than that from the anterior palate. It can be assumed that it is therefore less susceptible to post-operative shrinkage. On the other hand, this very dense and coarse connective tissue appears to undergo necrosis more easily than that from the anterior palate. It may be hypothesized that compared to the rather loose formation of the subepithelial connective tissue from the anterior palate, the dense tissue from the posterior area does not comply as good with the requirements for graft survival in the course of plasmatic circulation and re-vascularization during the early postoperative phase. As a clinical consequence SCTGs from the posterior palate seem – in contrast to SCTGs from the anterior area – to need being fully covered by a flap to ensure healing by primary intention. It is presently unclear to what extent it might play an additional role in this context if, depending on the employed harvesting technique, the periosteum covering the palatal bone is included in the graft or not.

SCTGs can also be harvested from the palate with covering epithelium according to FGGs, provided that they are deepithelialized extraorally. This approach has the advantage that SCTGs can also be taken in situations with a very thin masticatory mucosa and that the graft preparation itself can be performed more superficially, thereby not violating blood vessels and nerve fibres running in deeper layers. In this way, transplants with more extensive surfaces can be gained in a short amount of time and the allegedly high-quality tissue layer of the lamina propria can be used to full extent as no parts of it remain in the flap at the donor site like in undermining harvesting techniques. On the other hand, this procedure might adversely affect patient morbidity: In several clinical studies it could be demonstrated that a more painful post-operative course could be observed in FGG patients with a palatal wound healing by secondary intention in contrast to SCTG patients where a flap was raised, the graft harvested internally and the wound allowed to heal by primary intention (Farnoush 1978, Jahnke et al. 1993, Del Pizzo et al. 2002, Griffin et al. 2006, Wessel & Tatakis 2008). However, these results are contrary to a recent clinical study identifying influencing factors for pain sensation after FGG removal (Burkhardt et al. in preparation) and a randomized controlled clinical trial (RCT) comparing patient morbidity after FGG and SCTG harvesting procedures (Zucchelli et al. 2010). In both studies it could be demonstrated that post-operative pain was rather influenced by the thickness of the graft and the

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remaining soft tissue at the palate, but by primary or secondary wound healing at the donor site. It can be mentioned as an aside that in the latter study, the deepithelialized autografts consisting of lamina propria only led to a statistically significant higher increase in buccal gingival thickness following recession coverage (Zucchelli et al. 2010). These findings support the aforementioned clinical observation that SCTGs containing presumed denser subepithelial connective tissue are comparatively less prone to postoperative shrinkage. The clinical experience that using SCTGs that are harvested with epithelium and deepithelialized outside the oral cavity seem to bear an increased risk for postoperative scar tissue formation at the recipient site should not be neglected, though. At this point of time any attempted explanation would be speculative in nature, although it would be possible that in contrast to SCTGs from deep subepithelial connective tissue zones SCTGs consisting mainly of a superficial layer of subepithelial connective tissue behave more similar to FGGs with all the negative consequences for the qualitative treatment outcomes outlined above (aesthetic integration, surface, colour, scarring). This might potentially be caused by isolated fragments of epithelium that are left in the graft after deepithelialization, especially due to the papillary inter-locking between the epithelium and the lamina propria. In a study by Harris, SCTGs were manually deepithelialized at the best optical control by the surgeon (Harris 2003). The subsequent histological analysis, though, could demonstrate remaining epithelium in 80% of the grafts. In addition, “more aggressive” morphogenetic stimuli regarding the differentiation of the covering epithelium at the recipient site could be suspected in more superficial layers of subepithelial connective tissue (Ouhayoun et al. 1988). If it would make a difference for this reason to position the superficial side of the graft inwards or outwards in the recipient bed could be an interesting field of future research (Fig. 3).

In summary, it can be stated that – although the actual reasons are largely unknown up to date – grafts from different donor sites seem to have different characteristics that might require selective clinical application and well thought out surgical protocols. The clinical decision where to harvest soft tissue autografts from is presently hardly based on written evidence, but rather relies on clinical experience and depends on the amount of available tissue at the eligible donor sites, the indication in which the transplant is supposed to be used and last, but not least on the personal preference of the treating surgeon. If it would be speculative in nature, although it would be possible that in contrast to SCTGs from deep subepithelial connective tissue zones SCTGs consisting mainly of a superficial layer of subepithelial connective tissue behave more similar to FGGs with all the negative consequences for the qualitative treatment outcomes outlined above (aesthetic integration, surface, colour, scarring). This might potentially be caused by isolated fragments of epithelium that are left in the graft after deepithelialization, especially due to the papillary inter-locking between the epithelium and the lamina propria. In a study by Harris, SCTGs were manually deepithelialized at the best optical control by the surgeon (Harris 2003). The subsequent histological analysis, though, could demonstrate remaining epithelium in 80% of the grafts. In addition, “more aggressive” morphogenetic stimuli regarding the differentiation of the covering epithelium at the recipient site could be suspected in more superficial layers of subepithelial connective tissue (Ouhayoun et al. 1988). If it would make a difference for this reason to position the superficial side of the graft inwards or outwards in the recipient bed could be an interesting field of future research (Fig. 3).

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Harvesting techniques

The clinical procedure of SCTG harvesting from the palate is often characterized by the remarkable challenge of obtaining the largest volume of tissue possible on one side while minimizing post-operative pain and reducing the risk of complications on the other side. To meet these requirements, various procedures for soft tissue autograft harvesting in plastic periodontal and implant surgery have been developed and described in the literature:

SCTG harvesting from the lateral palate

The different SCTG harvesting techniques from the lateral palate vary basically in the particular position of the donor site, the number and type of surface incisions and in the flap design for gaining access to the graft. In principle, they can be subdivided into techniques that provide SCTGs with or without a remaining collar of keratinized epithelium. Relating to the group of SCTGs with epithelium, Langer and Calagna as well as Langer and Langer introduced a harvesting method based on a rectangular incision design with two horizontal and two vertical incisions resulting in SCTGs with an epithelial collar of about 2 mm width (Langer & Calagna 1980, 1982, Langer & Langer 1985). Subsequently, Harris used a very similar approach and modified the technique by limiting the vertical incisions to a minimal dimension, barely enough to get access to the underlying donor tissue (Harris 1992). Raetzke, finally, abstained from vertical incisions completely and used two converging horizontal crescent-shaped incisions resulting in a wedge-shaped SCTG with an epithelial collar (Raetzke 1985). However, the disadvantage of all these techniques obtaining SCTGs including parts of the epithelium was – beside the aforementioned negative consequences for the qualitative-aes-
thetic treatment outcomes – that the donor site could not be completely covered with the flap and was therefore partially healing by secondary intention. Due to the rigidity of the palatal masticatory mucosa this could only be avoided if SCTGs were harvested without epithelium. In consequence, Edel introduced a trap-door approach without removing epithelium from the donor site (Edel 1974). By undertaking one horizontal and two vertical incisions, an access flap could be raised, the graft removed and complete wound closure achieved. However, particularly in cases with unfavourable relations between flap base and pedicle length flap sloughing could be observed causing unnecessary discomfort for the patient (Edel 1974, Harris 1994, 1997). This is why Hürzeler and Weng proposed a single-incision technique for SCTG harvesting from the lateral palate later on (Hürzeler & Weng 1999). The execution of only one horizontal surface incision followed by an undermining flap preparation seemed to positively affect post-operative healing and patient morbidity compared with the trap-door technique (Del Pizzo et al. 2002, Wessel & Tatakis 2008). In the following, three distinct and obviously frequently applied techniques to harvest SCTGs from the lateral palate will be proposed: SCTG harvesting from the anterior palate, SCTG harvesting from the posterior lateral palate and SCTG harvesting from the lateral palate by obtaining a graft with epithelium corresponding to a FGG that is deepithelialized extraorally. In this respect ideally those surgical protocols should be picked out that have scientifically proven to be the presently best possible treatment options. However, at the time being it is in this context hardly possible to choose one approach over the other one based on scientific evidence. For this reason, those clinical procedures were selected that seem to reflect a contemporary mindset and presently seem to be based upon sound clinical experience if SCTGs are harvested from the lateral palate. The subsequent SCTG harvesting step by step descriptions are based on clinical recommendations given in two recently published textbooks (Zuhr & Hürzeler 2012, Zucchelli 2013).

SCTG harvesting from the anterior palate

The procedure starts according to the single-incision technique with a horizontal incision along the row of teeth starting from the mesial border of the first molar to the lateral incisor, 2.0 mm apical to the gingival margin, 1.0–1.5 mm deep. All the remaining incisions are undermining below the mucosal surface. With regard to post-operative pain, it seems to be the main challenge from a surgical point of view to achieve primary wound healing at the palatal donor site. In this context, it appears to be essential to guarantee an adequate postoperative blood supply for the access flap and therefore prepare a partial-thickness flap of uniform thickness and proper dimension. For this reason, it is mandatory to perform the initial horizontal incision with a scalpel held strictly perpendicular to the palatal surface. To ensure that the following split-thickness flap preparation will provide a flap of sufficient dimension throughout, it is important to gradually increase the angle of the blade until it is parallel to the palatal surface by making repeated distal to mesial movements, mainly with the tip of the scalpel. Care must be taken to ensure that the flap preparation is not substan
tially extended more than 10 mm apical from the cementoenamel junction of the maxillary posterior teeth. If placed roughly 2 mm from the cementoenamel junction, the initial incision can be safely extended apically to a depth of approximately 8 mm without a risk of damaging the great palatine artery. As the cutting portion of a No. 15 scalpel blade is approximately 8 mm in length, it can serve as a gauge for safe graft harvesting on this occasion. After that the size of the graft is defined by executing two horizontal and two vertical incisions inside the created envelope. They should be extended to the bone and overlap at intersections. It might be advisable to place the coronal internal incision roughly 1.0–1.5 mm apical to the initial horizontal incision. This ensures that the access flap will rest on a well-perfused connective tissue surface instead of on bone or periosteum after surgery, which might improve the predictability to achieve healing by primary intention. Depending on the clinical indication and how much tissue is available, SCTGs can be obtained with or without periosteum. Grafts with periosteum are harvested by blunt dissection using a periosteal elevator. For graft removal without periosteum, an additional offset incision is carried out above the periosteum by sharp dissection with a scalpel blade. Although leaving periosteum on the bone has probably positive consequences in terms of post-operative wound healing, clinical experience has shown that SCTGs with periosteum have superior mechanical stability, which might be an advantage relating to the clinical handling of those grafts in certain situations. For the following wound closure parallel and crossed horizontal sling sutures are recommended. The placement of this type of sutures around the maxillary posterior teeth has a wound compressing effect that might be beneficial particularly in terms of promoting hemostasis and primary adaptation of the wound margins (Zuhr & Hürzeler 2012) (Fig. 4).

SCTG harvesting from the posterior lateral palate

The harvesting procedure is carried out at the first and second maxillary molars and usually contains one horizontal and two vertical incisions according to the trap-door approach. Depending on the soft tissue thickness at the donor site and the size of the graft to be harvested one or in individual cases even both vertical incisions can be omitted. While the horizontal incision is performed 1–2 mm apical of the gingival margin, the two vertical incisions should extend 1 mm further than the intended apicocoronal dimension of the graft offering access to the apical incision line in the connective tissue later on. A split-thickness flap is then prepared parallel to the external mucosal surface by watching the blade working from outside under the flap. By doing so, the goal is to create a flap of uniform thickness, whereby the releasing incisions can be used as flap thickness guides. Now the horizontal incision of the
to the size of the area to be grafted, 

At first, two horizontal and two vertical incisions are performed according to the size of the area to be grafted, therefore providing the donor site for SCTG harvesting from the lateral palate (Zucchelli 2013) (Fig. 5).  

The routine use of surgical stents after harvesting SCTGs from the lateral palate is recommended for many reasons. First, the stent applies pressure to the wound, which seems to promote post-operative flap adaptation and wound healing. Second, the covering epithelium on the upper part of the graft is consequently removed extraorally. The donor site is closed with an external horizontal mattress suture anchored to the periosteum. Additional single interrupted sutures can be used to completely close the wound (Zuhr & Hürzeler 2012) (Fig. 7).

Independently of the selected donor site and the applied SCTG harvesting technique, it takes a certain amount of time from the moment when the graft is taken from the palate until the wound at the palatal donor site is closed. In the meantime care should be taken to prevent graft dehydration, for example by storing the SCTG in gauze soaked in physiologic saline until further use. Extraoral modification in SCTGs is often necessary. A proven way to do this is to first spread and press the graft on a wet glass slab using a surgical forceps. A fresh scalpel blade is then applied to cut the graft to the desired size and shape and to thin the SCTG as needed. Due to the possibility to act as a barrier to plasmatic circulation and re-vascularization during the early phase of healing fat and glandular tissue remnants detected on the graft should be removed (Sullivan & Atkins 1968).

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stent enables a rapid and effective response to intra-operative or post-operative bleeding. Third, the stent not only protects the palatal donor site from mechanical irritation but also seems to enhance patient comfort considerably during the first postoperative days. The results of a RCT by Thoma and coworkers indicate that the application of a collagen matrix at the palatal wound might additionally enhance soft tissue healing and re-epithelization at early time points if an extraorally deepithelialized FGG was harvested (Thoma et al. 2012). The use of a surgical stent is not required after SCTG harvesting from the maxillary tuberosity.

The amount of tissue needed for defect re-construction is potentially greater than the amount of tissue available, even if harvested from both sides of the palate. Therefore, it is sometimes necessary to harvest subepithelial connective tissue from the palate at two different times. Harris and coworkers could demonstrate that this approach causes no significant problems if the second procedure is performed after a 2- to 3-month interval (Harris et al. 2007).

**Tissue integration and volume stability**

In contrary to vascular or pedicle grafts, free grafts are avascular and have no direct blood supply. Therefore, the survival of vital, tissue-specific cells in a free autologous graft depends on an early and adequate blood supply from the recipient bed and the overlying flap by means of plasmatic circulation and, later on, by means of re-vascularization of the graft.

The healing of FGGs has been studied in a variety of animal experiments (Oliver et al. 1968, Jansen et al. 1969, Nobuto 1986, 1987, Nobuto et al. 1988). It can be assumed that their results regarding the basic concepts of soft tissue autograft integration can at least principally be transferred to the healing process of SCTGs: During the initial phase of healing, the grafted tissue survives exclusively by avascular plasmatic circulation from the recipient bed. Apart from their limited intra-cellular energy resources, the grafts are entirely dependent on the influx of oxygen and metabolites within the extracellular fluid, the driving force behind this diffusion process being the con-
cannot be detected anymore (Gargiulo & Arrocha 1967). The results of the above-quoted animal experiments could partially be confirmed in a clinical study by Mörmann and coworkers (Mörmann et al. 1975). Under the use of fluorescein angiography, the post-operative diffusion and re-establishment of capillary blood circulation could be investigated. The authors observed the formation of capillary loops between the seventh and 14th post-operative day and concluded that blood circulation in FGGs is re-established primarily by capillary budding.

**Wound healing and clinical outcomes in avascular beds**

When using SCTGs to cover soft tissue recessions at teeth or implants, part of the recipient site will be the avascular root or implant surface. Consequently, graft survival depends on a sufficient blood supply originating from the vascular recipient bed adjacent to the recession defect and the covering flap (Fig. 8). In an experimental study by Guiha and coworkers, artificially created gingival recessions were treated under the use of SCTGs harvested from the palate (Guiha et al. 2001). Histological evaluation was performed at 7, 14, 28 and 60 days after surgery demonstrating re-vascularization of the grafts by capillary proliferation originating from the periodontal pre-existing vascular network, the supra periosteal plexus and the overlying flap. The transplanted tissues seemed to be vascularized completely after 14 days and after 28 and 60 days demarcation zones between graft and flap or periosteum could not be identified anymore. In contrary, a few 2-week specimens showed a bigger dimensioned blood clot at the interface between graft and recipient bed and/or graft and flap obviously not allowing blood vessels to penetrate to the graft. The authors assumed the re-vascularization and healing process to have been delayed in these areas presumably due to a less than optimal adaptation of the graft to the recipient bed. Those parts of the graft not being in contact with the root surface and not covered by the flap were not vascularized at all.

Basically, small areas of SCTGs not completely covered by an overlying...
flap – a practice occasionally performed based on experimental (Karring et al. 1974) and clinical studies (Donn 1978, Mackenzie & Fusseneg 1983, Ouhyoun et al. 1988, Borghetti & Louise 1994, Bouchard et al. 1994, Cordioli et al. 2001) to enlarge the width of keratinized tissue particularly in root coverage procedures – though, seem not to entail an increased risk for graft necrosis (Raetzke 1985). In this context, Yotnuengnit and coworkers investigated 15 patients scheduled for recession treatment (Yotnuengnit et al. 2004) based on the envelope technique (Raetzke 1985). They measured the areas of the SCTGs being covered by a flap in relation to the areas left exposed over the originally denuded root surfaces and identified a minimum ratio of 11:1 that should not be substandarded if the goal was complete root coverage. The results of a clinical investigation by Al-Zahrani and coworkers indicated that in this connection the surface orientation of the SCTG had no significant effect on the clinical outcomes of either root coverage or height of keratinized tissue (Al-Zahrani et al. 2004). Burkhardt and Lang assessed the outcomes of gingival recession coverage using SCTGs in a clinical study (Burkhardt & Lang 2005). In a split-mouth design, root coverage was accomplished by conventional macrosurgery on one side and by microsurgery on the other. Fluorescence angiography was performed to evaluate the course of healing immediately after surgery and 3 and 7 days later. The authors could show that the vascularization of the microsurgically treated sites was superior to that of the macrosurgically treated ones immediately after surgery and after 3 and 7 days post-operatively. They could also demonstrate a statistically significant superiority of the microsurgical technique, based on the percentage of root coverage one year after treatment. As it can be assumed that the re-vascularization process is driven by numerous signalling pathways, more recent research focused on the question to what extent growth factors might improve the healing process of SCTGs. In a clinical study, Lafzi and coworkers evaluated the use of vascular epithelial growth factor in conjunction with SCTGs from the palate for gingival recession treatment (Lafzi et al. 2012). In fact they observed better clinical outcomes when the growth factors were used, although not statistically significant. A study by Jankovic and coworkers comparing platelet-rich membranes with SCTGs for recession treatment observed enhanced wound healing in the first group with similar treatment outcomes except for less gain in keratinized tissue width (Jankovic et al. 2012). Although Cheung and coworkers also found similar outcome measures for platelet-concentrated grafted (Cheung & Griffin 2004), a RCT by McGuire and coworkers resulted in statistically significant recession depth reduction, root coverage and recession width reduction favouring the SCTG (McGuire et al. 2009a). Two other studies (Huang et al. 2005, Keceili et al. 2008), in which platelet-rich plasma was added to SCTGs in recession coverage, found no difference in clinical outcomes compared with SCTGs alone, except for more gain of keratinized tissue under the implementation of growth factors in the study by Keceili and coworkers.

Up to date, the knowledge about the physiologic proceedings of graft re-vascularization is mainly based on histological studies. This has recently changed due to the availability of new technologies in combination with innovative scientific models to further investigate the healing process of free soft tissue autografts. One promising, forward-looking model was introduced by Lindenblatt and coworkers allowing to perform continuous in vivo monitoring of skin graft healing by repetitive intravital microscopy (Lindenblatt et al. 2008). In an experimental study, the authors were able to show for the first time a temporary angiogenic response within the capillaries of the skin graft obviously representing a reaction to reperfusion and supply of the hypoxic graft with proangiogenic factors (Lindenblatt et al. 2010). In another animal experiment of the same working group, an early ingrowth of angiogenic wound bed vessels into the existing vascular channels of the skin graft and subsequent centripetal replacement of the existing graft vessels could be indicated (Calcagni et al. 2011).

Soft tissue healing against a covered root or implant surface typically results in healthy gingival or mucosal conditions without clinical signs of inflammation and pocket formation. Different scientific investigations studied the quality and nature of the new tissue attachment to previously denuded root surfaces after a combined therapy with pedicile soft tissue grafts and SCTGs. While only a few experimental studies (Weng et al. 1998) and human histologies (Harris 1999, Goldstein et al. 2001) could demonstrate a true new connective tissue attachment with new cementum, new bone and inserting PDL fibres in larger quantities, the majority of scientific evaluations found that only the most apical and lateral parts of the recession defects healed by regeneration with new connective tissue attachment, whereas the main body of the previously exposed root surfaces healed with a long junctional epithelium and connective tissue adhesion (Harris 1999, Bruno & Bowers 2000, Ghiha et al. 2001, Majzoub et al. 2001, McGuire & Cochran 2003, Cummings et al. 2005, McGuire et al. 2009a,b). High effort was taken in the past to develop chemical root conditioning agents promoting wound healing outcomes with more new connective tissue attachment. Citric acid, tetracycln HCL, fibrin glue associated with tetracycln HCL and sodium hypochlorite were used in combination with scaling and root planing to demineralize the root surface and – in doing so – expose the collagen fibres of the dentine matrix and allow their inter-locking.
with those in the covering connective tissue. However, the results of animal experiments and controlled clinical trials indicated that chemical root surface demineralization cannot improve wound healing outcomes and cannot be considered as beneficial for root coverage procedures compared to mechanical biofilm removal only (Rocuzzo et al. 2002, Oates et al. 2003, Cortellini & Pini Prato 2012). Whether the combination of SCTG and root surface conditioning with ethylenediaminetetraacetic acid before application of enamel matrix derivate (EMD) can influence the type of attachment on the root surface after gingival recession treatment is presently unclear and needs further scientific verification (Rasperini et al. 2000, Carnio et al. 2002). The clinical observation of a so-called “creeping attachment” which refers to a soft tissue maturation process with a certain coronal migration of the gingival margin at SCTG-treated sites over time, cannot not be explained at present. (Agudio et al. 2009, Pini Prato et al. 2010). Two clinical case documentations reported on external root resorption after root coverage with SCTGs (Hokett et al. 2002, Carnio et al. 2003). The fact that this is indeed a severe but not a common complication after gingival recession treatment might be explained by the early formation of a root-protective barrier, namely a new connective tissue attachment in the most apical part and a long junctional epithelium in the more coronal part of the treated root surfaces. It goes without saying that if instead of natural roots SCTGs are placed against artificial surfaces of implants or restored teeth new connective tissue attachment cannot be expected. It can be assumed that the established type of attachment is slightly different between restored tooth and implant and from material to material, and is characterized by connective tissue adhesion and – primarily – by a long junctional epithelium (Berglundh et al. 1991, Abrahamsson et al. 1998, Gomes et al. 2005, Martins et al. 2007). Although subgingival restoration margins seem to be detrimental to gingival and periodontal health over a long period of time (Schatzle et al. 2001), short-term data from clinical studies could not reveal more pronounced gingival inflammation and plaque accumulation if class V restorations made of different tooth coloured filling materials were covered with coronally advanced pedicle flaps (Lucchesi et al. 2007, Santamaria et al. 2008). Santamaria and coworkers evaluated in a RCT the treatment of gingival recessions associated with non-curious cervical lesions by SCTGs with a coronally advanced flap alone or in combination with the fabrication of resin-modified glass ionomer restorations. Six months after surgery there was no statistically significant difference between test and control regarding percentage of root coverage. Furthermore, no clinical signs of inflammation could be detected in both groups. The authors credited the results with the biocompatibility of the filling material, the well fabricated and polished restorations and the good compliance and oral hygiene of the patients (Santamaria et al. 2009).

In gingival recession treatment, the combination of coronally advanced flaps and SCTGs is presently recommended as the treatment modality of choice (Cairo et al. 2008, Chambrone et al. 2012, Cortellini & Pini Prato 2012), whereas on the other hand uncertainty exists about the real effect of the graft: Cortellini and coworkers compared in a RCT coronally advanced flaps for gingival recession treatment with and without the additional application of SCTGs (Cortellini et al. 2009). The presence of a SCTG under the flap was associated with a reduced soft tissue contraction during the early phase of healing leading to a significantly greater amount of sites completely covered at 6 months. These results can be interpreted in a way that the presence of a SCTG might stabilize the flap in a coronal position and therefore serve as an “anchor” for the covering flap during the initial wound healing period. A variety of clinical consequences would follow if this hypothesis was confirmed: SCTG harvesting for gingival recession treatment would be less demanding for the surgeon in the majority of the cases and go along with a decreased risk of damaging the GPA during the harvesting procedure. In addition, more recessions could be treated at the same time if necessary as the required grafts per recession could be comparatively small and rather thin. Furthermore, the nutritional exchange between wound bed, SCTG and covering flap might be improved during the early wound healing period by this type of grafts – an aspect that might in particular play a role if the covering flap is thin (Hwang & Wang 2006). In this sense Zucchelli and coworkers modified position, size and thickness of SCTGs and recommended the use of about 1 mm thick grafts that were positioned in a distance apical of the cementoenamel junction that corresponds to the pre-operative width of keratinized tissue with a mesiodistal extension of the recession width plus 6 mm and an apicocoronal dimension calculated as the distance from the cementoenamel junction to the bone crest minus the pre-operative height of keratinized gingiva. In a RCT using coronally advanced flaps in combination with SCTGs for recession treatment, the authors compared the conventional type of graft with the novel approach. Although differences between the two treatment modalities were not statistically significant regarding percentage of root coverage, aesthetic results and patient-centred outcomes were superior with the small dimensioned and apically positioned graft (Zucchelli et al. 2003). If for any reason the SCTG failed to anchor the overlying flap and undesired flap retraction occured during the early wound healing phase the SCTG might, on condition that it is positioned at the level of the cementoenamel junction, act as a “protector” beyond it and still allow healing by primary intention and successful root coverage. This clinical presumption can be supported by the results of a clinical study by Bouchard and coworkers comparing coronally advanced and envelope flaps in combination with SCTGs for gingival recession treatment (Bouchard et al. 1994). Although treatment outcomes were similar with respect to root coverage a significant increase in keratinized tissue height was surprisingly observed in both groups. These findings could be expected in the envelope flap group where the most...
coronal parts of the SCTGs were not covered by the flaps, but not in the coronally advanced flap group where instead the overlying flaps covered the SCTGs completely (Mackenzie & Fusenig 1983, Ouhyoun et al. 1988, Borghetti & Louise 1994, Cordioli et al. 2001). The authors assumed that these results might be caused by a tendency of flap retraction during wound healing in the coronally advanced flap group leaving the most coronal parts of the graft uncovered. The fact that slightly exposed areas of a SCTG usually do not undergo necrosis and maintain primary adhesion to the root surface might explain the observed gain in keratinized tissue height and elucidate the possibly existing protector effect of SCTGs (Yotnuengnit et al. 2004). Current scientific investigations seem to furthermore suggest a positive SCTG effect by “increasing marginal soft tissue thickness”. Zuhr and coworkers compared in a RCT a modified tunnel technique with SCTG from the anterior palate versus a coronally advanced flap with EMD for root coverage (Zuhr et al. accepted for publication). The application of an innovative three-dimensional measuring technology for treatment outcome evaluation allowed in particular to quantify the thickness of the marginal soft tissues established above the formerly exposed root surfaces and in this way analyse its influence on recession treatment outcomes. Twelve months after surgery, mean soft tissue thickness was 1.69 ± 0.63 mm and 0.91±0.18 mm, respectively, increased gingival thickness was clearly associated with better surgical outcomes in terms of recession reduction and root coverage, whereas a mean marginal soft tissue thickness of 1.44 mm was necessary to achieve complete root coverage with a confidence of 95% (Rebele et al. submitted for publication). In a cohort of six SCTG patients within the same study population healing dynamics were evaluated by means of volumetric observations with the post-operative volume gain at 1 month being regarded as baseline value. The treated sites showed a mean shrinkage of 1/4 of the augmented volume after 3 months, amounting to 1/3 after 12 months corresponding to a mean maintenance of 74% of the augmented volume after 3 months and 64% after 12 months respectively. With regard to post-operative soft tissue volume changes, the healing process seemed to be accomplished after 6 months (Rebele et al. submitted for publication). With respect to long-term stability after recession treatment it can further be speculated if the SCTG can provide a positive contribution by “thickening the marginal soft tissues” (Nickles et al. 2010, Pini Prato et al. 2010), by the long-term effect of a “creeping attachment” (Agudio et al. 2009, Pini Prato et al. 2010) or by a combination of both. Anchoring the overlying flap, protecting healing by primary intention, increasing marginal soft tissue thickness or inducing creeping attachment – further progress regarding soft tissue recession treatment with combined procedures will, to some extent, definitely be dependent on a better understanding of the true SCTG effect. It is beyond all doubt that more transparency in this context will substantially influence future research and clinical developments.

Wound healing and clinical outcomes in vascular beds

If in contrast to soft tissue recession treatment SCTGs are used for soft tissue volume build-ups in terms of ridge preservation procedures, soft tissue ridge augmentations or papilla re-constructions, the prerequisites for uneventful and fast wound healing processes are comparatively favourable as the blood supply for graft integration is provided by both – the overlying flap and the recipient bed (Fig. 9). Although the terms osteoconduction, osteoinduction and osteogenesis originate from concepts of bone regeneration and bone healing, the underlying principles might also be used to qualify the healing and regeneration processes associated with soft tissue grafting. Equal to bone grafts the “ideal” soft tissue graft should exhibit an optimal potential for tissue-specific conduction and induction as well and contain the largest number of cotransplanted vital cells possible. In principle, SCTGs seem to have good characteristics with respect to the above-mentioned requirements for grafting materials. The organic extracellular matrix could serve as a space-holder and the relatively loosely arranged collagen fibres within the matrix might ensure that plasmatic circulation in the initial post-operative period and the subsequent re-vascularization process can start early and proceed relatively unimpeded (tissue-conductive character). Consequently, the chances that a large number of living fibroblasts in the graft will survive (tissue-genetic potential) and continue to produce tissue-specific endogenous proteins (tissue-inductive properties) by receiving an adequate supply of oxygen and nutrients quickly enough seem to be relatively good. This thinking model might at least in part allow to explain the successful application of SCTGs in plastic periodontal and implant surgery today. It might in addition be used to elucidate the aforementioned clinical observation that SCTGs from different donor sites and harvested with different techniques seem to provide different properties regarding healing response and volume stability. Furthermore, the clinical presumption can be supported that among the available SCTGs those appear to have a better wound healing response that seem to undergo remarkable shrinkage, and vice versa. Considering its significance for soft tissue augmentation procedures in plastic periodontal and implant surgery, it is remarkable that volumetric aspects have been hardly evaluated in the literature. Thus, to the best of our knowledge only two clin-
ical studies on volumetric changes after soft tissue ridge augmentation procedures with a follow-up period of 3.5 months (Studer et al. 2000) and 12 months (Schneider et al. 2011) presently exist. Studer and coworkers compared in a controlled clinical study SCTGs and FGGs for soft tissue ridge augmentation by quantitative volume assessment. Impressions were made before treatment and also at 1 and 3.5 months after surgery to measure the volume changes on dental casts with a validated projection Moiré system. Volumetric assessment after 3.5 months revealed significantly greater volume gain with SCTGs in comparison to FGGs (Studer et al. 2000). Schneider and coworkers evaluated the dimensional changes of peri-implant tissues obtained by hard and soft tissue augmentation. Impressions were taken before treatment, after implant placement and guided bone regeneration, after soft tissue augmentation with SCTGs, immediately after crown insertion and 1 year later. After the cast models were scanned and digitally superimposed, a mean buccal tissue gain of 1.27 ± 0.67 mm could be determined after the surgical procedures. One year after crown insertion, a mean loss of 0.04 ± 0.31 mm in the labial direction was recorded. Guided bone regeneration conducted more to volume gain than soft tissue grafting. Moreover, in one-third of the implants, the soft tissue augmentation did not contribute to the increased buccal volume at all (Schneider et al. 2011). Besides that long-term data on volumetric stability of soft tissue augmentations are missing completely. This might partly be explained by the fact that in the past only very complicated measurement technologies like the optical projection Moiré method used by Studer and coworkers were available (Studer et al. 2000). However, the introduction of the aforementioned recently developed new measuring methods employing three-dimensional optical scanning and subsequent virtual superimposing procedures with a previously unforeseen precision in the quantitative evaluation of volumetric changes (Windisch et al. 2007, Fickl et al. 2008, Strebel et al. 2009, Thoma et al. 2010, Schneider et al. 2011, Thalmair et al. 2013, Zuhr et al. accepted for publication, Rebele et al. submitted for publication) offers new perspectives in this connection: If ongoing progress and development regarding soft tissue augmentation procedures in plastic periodontal and implant surgery is the goal, to volumetrically evaluate and compare the efficacy and long-term stability of eligible soft tissue replacement grafts will be one of the main challenges for the future (Fig. 10).

The above-mentioned scientific investigations give a deep insight into the fundamental physiologic processes and the healing chronology of free autogenous soft tissue grafts. In this respect, some factors of clinical relevance can be identified that should be respected to accomplish successful and predictable treatment outcomes if SCTGs are used in plastic periodontal and implant surgery. In the first place, the best possible blood supply from the recipient bed and the covering flap should be provided for graft survival: incision-and flap-design (Mormann & Ciancio 1977), thickness of the flap (Hwang & Wang 2006), complete graft coverage (Harris 1994, Studer et al. 2000) and an atraumatic surgical proceeding (Burkhardt & Lang 2005) seem to play an important role. Furthermore, it should be kept in mind that the risk of graft necrosis might increase with graft thickness (Miller 1985, Borghetti & Gardella 1990). Besides, those care should be taken that the blood clot between wound bed and transplanted tissue is post-operatively as thin as possible to minimize diffusion distance and capillary proliferation length, and that the graft is embedded stable and immobile in the recipient site by tension-free flaps and appropriate suturing techniques (Allen & Miller 1989, Pini Prato et al. 2000). In this context, a gentle wound compression immediately following surgery might have a positive effect and in-depth patient instructions on post-operative physical rest of the intra-oral wound area might also play a role.

**Soft tissue substitutes**

Soft tissue augmentation procedures with autogenous grafting materials have significant disadvantages. First and foremost, the amount of available tissue is limited and in the majority of clinical situations, a second surgical site is needed to obtain a sufficient quantity of autograft material, which increases the burden on the patient and the morbidity of the surgical procedure considerably (Farnoush 1978, Del Pizzo et al. 2002, Griffin et al. 2006, Soileau & Brannon 2006). Against this background, it is quite evident that the search for suitable soft tissue substitutes is currently at the centre of enormous efforts by scientists and manufacturers, for the good of the patient.

Yet, the development of adequate soft tissue substitutes turns out to be complicated: SCTGs are undoubtedly considered as the gold standard for soft tissue volume augmentations in plastic periodontal and implant surgery to date. However, the term “gold standard” suggests a well-defined, consistent standard of harvesting procedure. However, in fact there seems to be no standardized protocol for SCTG removal from the palate. As elucidated above different available donor sites and harvesting techniques result in inconsistent types of SCTGs that vary in their histological composition potentially influencing their clin-
clical characteristics. Furthermore, it is difficult to develop alternatives to SCTGs as long as their true impact on successful treatment outcomes is not entirely clear. In some indications the actual role of the graft is obviously the volume increasing effect, for example, in soft tissue ridge augmentation procedures. In other applications like, for example in soft tissue recession treatment in contrast the true nature of the SCTG is – as mentioned before – not quite as clear. As long as the SCTG is not clearly defined and as long as important information regarding the true effect of the SCTG is lacking it will be very difficult to develop substitutes that are supposed to measure up with the current gold standard. Not least on these grounds it needs to be realized that for the time being the development of SCTG substitute materials is still in its infancy.

In principal, three basic soft tissue substitute materials of different origin can be distinguished: allogeneic (of human origin), xenogeneic (from another species, e.g. of porcine or bovine origin), and alloplastic (of artificial origin) materials. At the moment a variety of available products are on the market, whereby it needs to be mentioned restrictively that only a few of them have proved scientifically documented success.

In the late 1980s acellular dermal substitutes were introduced to the dental market. The best-researched type is the acellular dermal matrix (ADM), an allogeneic substitute that consists of a freeze-dried connective tissue matrix, without epithelium and cellular components, which is obtained from tissue banks by a standardized, controlled manufacturing process. It contains type I- and III-collagen bundles and elastic fibres, which seem to be degraded and replaced by host tissues during the wound healing and integration process (Wei et al. 2002, Cummings et al. 2005, Scarano et al. 2009). With respect to root coverage procedures, a systematic review by Cairo and coworkers revealed considerable heterogeneity in clinical outcome measures after 6–12 months and concluded that adding ADM to coronally advanced pedicle flaps did not improve clinical results compared with coronally advanced flaps alone and was inferior to the combination of coronally advanced flap and SCTG (Cairo et al. 2008). Even though, in addition, sufficient long-term data are missing it needs to be stated that the application of acellular dermal substitutes seems to be presently widespread and accepted by many clinicians as an approved alternative to SCTGs in gingival recession treatment (Gapski et al. 2005, Cairo et al. 2008, Moslemi et al. 2011, Schlee & Esposito 2011). As on the other hand, only few short-term observations from clinical case series exist, scientific evidence is weak if ADM is supposed to be used for soft tissue ridge augmentation procedures (Thoma et al. 2009). Care needs to be taken, moreover, if bigger dimensioned grafts are required: Folded or layered ADM might impede vascularization and lead to extensive shrinkage (Batista et al. 2001, Wei et al. 2002). Ethical concerns being an allograft from human cadavers and the pretended risk of disease transmission are remarkable counterpoints of the material frequently subjected by patients.

Later on tissue-engineered cellular dermal substitutes, including cellular components and tissue-inducing substances, came to the centre of scientific attention. Wilson and coworkers investigated the safety and effectiveness of living human fibroblasts cultivated on polymer scaffolds compared with autogenous SCTGs for gingival recession treatment (Wilson et al. 2005). The 6-month results were promising with no statistically significant differences between control and test group. Jha- veri and coworkers, who applied autologous fibroblasts on ADM scaffolds, found similar outcomes compared with SCTGs in their investigation (Jhaveri et al. 2010). Despite these promising findings, the critical cost-benefit ratio seems to presently interfere with further investments in this type of substitute material. To what extent in the context of tissue-engineered soft tissue substitutes growth factors in the form of platelet-rich fibrin membranes or platelet-concentrated grafts could be applied to replace SCTGs for gingival recession treatment is also a matter of current scientific investigations (Cheung & Griffin 2004, Murata et al. 2008, Aroca et al. 2009, Griffin & Cheung 2009). Carney and coworkers investigated the combined effect of recombinant human platelet-derived growth factor (rhPDGF) applied on ADM, with the aim to promote faster re-vascularization of the ADM network (Carney et al. 2012). After a 6-month healing period, they found no statistically significant differences in the clinical outcomes, showing no benefit from adding PDGF to ADM. McGuire and coworkers conducted a RCT to compare coronally advanced flap procedures for gingival recession treatment through a growth factor-mediated approach with either beta-tricalcium phosphate (β-TCP) + 0.3 mg/ml rhPDGF-BB with a bioabsorbable collagen wound healing dressing or SCTG. Moreover, recession defects were created in six teeth, each requiring extraction for orthodontic therapy, and treated with the same treatment modalities. Nine months after surgical correction, en bloc resections were obtained and examined histologically and by the use of micro-CT. In the RCT, statistically significant results favouring the SCTG were found regarding recession depth reduction 6 months after surgery. Histologic and microcomputed tomography examination revealed evidence of new cementum, PDL with inserting connective tissue fibres and supporting alveolar bone in all sites treated with rhPDGF-BB + β-TCP, whereas neither SCTG-treated site exhibited any signs of periodontal regeneration (McGuire et al. 2009a).

Recently, xenogeneic soft tissue substitutes in the shape of bilayered porcine-derived collagen-based matrices were introduced. Although these materials were originally introduced to promote keratinized tissue regeneration (Sanz et al. 2009, Herford et al. 2010, Nevins et al. 2011, Lorenzo et al. 2012), they were subsequently adopted for root coverage procedures. Clinical outcome measures were promising in short-term view and a certain potential for soft tissue thickening was observed, although a lower percentage of root coverage was recorded compared with coronally advanced flaps in combination with SCTGs (Cardaropoli & Cardaropoli 2009, McGuire
& Scheyer 2010, Cardaropoli et al. 2012, Jepsen et al. 2013) (Fig. 11). A new type of collagen matrix intended to be used as a SCTG substitute for large volume augmentations was recently investigated in an experimental study by Thoma and coworkers (Thoma et al. 2010). Soft tissue ridge augmentation was performed with either the substitute or SCTGs from the lateral palate. Impressions were taken before augmentation and at 28 and 84 days. In a forward-looking way, the obtained casts were optically scanned and the digital images analysed. As volumetric analysis demonstrated no statistically significant differences between both groups the authors concluded that the experimental collagen matrix might be a suitable device for soft tissue volume augmentation and might serve as a substitute for autogenous soft tissue to augment localized alveolar ridge defects. More clinical and in particular long-term studies will be needed to confirm these promising results.

Finally, eligible soft tissue substitutes must be non-infectious and biocompatible. They should provide good tissue integration behaviour with tissue-conductive characteristics. Their mechanical properties should assure good clinical handling and physical stability. They should be economically efficient and documented success must be given. It will undoubtedly be of great importance to develop soft tissue substitutes that can replace autogenous grafts in the near future. However, to completely dispense with the need of autografts for soft tissue volume augmentation in plastic periodontal and implant surgery, future substitutes should in addition feature tissue-genetic and tissue-inductive properties. The extent to which these properties might be improved, for example by adding autogenous cells and synthetic growth proteins or bioactive substances and the degree to which innovative medical technologies such as tissue engineering might allow to use substitute materials more than to date remain to be seen. The next generation technology should aim for soft tissue substitutes that are at least as good as or even better than SCTGs for soft tissue volume augmentation by vascularizing quickly, for instance by implementation of a pre-fabricated vascular network (Calcagni et al. 2011), by allowing for healing by secondary intention, and ideally by showing no post-operative shrinkage at all. Like SCTGs from different donor sites are at this stage utilized in various indications, it is conceivable that there is a need to develop a variety of substitute materials with distinct properties deployed in varying clinical situations at the end.

Summary and conclusions

The predominant interventions in plastic periodontal and implant surgery are augmentation procedures frequently performed by the use of soft tissue replacement grafts. Although written evidence lacks relevant data for the most part, the present review demonstrates clearly that among available augmentation materials autologous SCTGs are considered as the gold standard for soft tissue volume augmentation to date. However, there is a restrictive core of critical elements that could be identified within the scope of this article and that can be summarized as follows:

- The term “gold standard” implies a well-defined and consistent standard of harvesting procedure. Different donor sites at the palate that can be selected and varying harvesting techniques that can be applied, though, result in different kinds of SCTGs that vary in their histological composition obviously leading to different characteristics that might require selective clinical application.
- Up to date, the clinical decision where to harvest SCTGs from is hardly based on scientific evidence but rather depends on the amount of available tissue at the eligible donor sites, the indication in which the transplant is supposed to be used and in particular on the personal preference of the treating surgeon.
- Independent of the selected donor site the clinical procedure of SCTG harvesting from the palate is basically characterized by the challenge of obtaining an adequate amount of tissue while minimizing postoperative pain and reducing the risk of complications at its best.
- The limited amount of grafting tissue and the increased patient morbidity are substantial disadvantages of autogenous SCTGs. For this reason, the search for suitable soft tissue substitutes is currently at the centre of numerous efforts by scientists and manufacturers and will be an important field of future research – for the good of the patient.
- Many questions with regard to graft healing and volumetric stability remain presently unknown – this relates to soft tissue substitutes, but to autologous SCTGs as well. Patient-centred outcome measures, quantitative threedimensional and qualitative-aesthetic assessment of treatment results as well as long-term follow-up data are hardly available at present.
- Thus, more research is needed to further progress and increase knowledge regarding soft tissue volume augmentation procedures in plastic periodontal and implant surgery. At the end, the goal cannot be considerably different from developing appropriate soft tissue substitutes for all conceivable indications and by doing so rendering soft tissue autografts unnecessary and eliminating their clinical application to the best possible extent.

References


Fig. 11. Scanning electron microscope image of a commercially available xenogeneic collagen matrix. The bilayered design is supposed to provide tissue-conductive properties and good clinical handling (courtesy of Peter Schüpbach).


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Clinical relevance

**Scientific rationale**: Soft tissue augmentation procedures are increasingly performed in plastic periodontal and implant surgery. Standardized guidelines regarding donor sites and harvesting techniques can hardly be given to date, but recommendations for predictable treatment outcomes can be developed. The aim was to provide a narrative review of the literature concerning the use of soft tissue replacement grafts.

**Principal findings**: Subepithelial connective tissue grafts are considered as gold standard. Many questions regarding graft healing and volumetric stability are presently unknown. The limited amount of grafting tissue and the increased patient morbidity make the search for suitable soft tissue substitutes an important field of future research.

**Practical implications**: The available donor sites provide grafts of distinct shape and composition. Which donor site is chosen depends on the amount of required tissue and the indication. Harvesting and transplantation procedures should follow certain advices to allow the best healing and tissue integration possible.