The Current Status, Evolution and Future of Facial Reconstruction

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Facial reconstructive surgery aims to establish anatomic normality as closely as possible following disfigurement to optimize functional and esthetic outcomes and the potential for normal psychosocial patient reintegration. The purposes of this article are to outline the current status of facial reconstruction and reflect upon possibilities for its future development. Current reconstructive methods include the use of non-vascularized grafts, non-microsurgical vascularized flap transfers, microvascular free tissue transplantation, and their combinations. Whatever the method chosen, the principles of reconstruction for each facial region or esthetic subunit should be respected.

Most facial defects can be addressed satisfactorily with the described techniques. Reconstructions for total or subtotal facial defects, however, remain disappointing. Current reconstructive techniques and principles continue to become more refined, providing improved outcomes. In the future, composite tissue allotransplantation and tissue engineering of vascularized composite tissue constructs may also be applicable for facial reconstruction, in particular for total or subtotal facial defects that appear outside the limits of current reconstructive methods. *(Chang Gung Med J 2008;31:441-9)*

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Physically, the face is the most prominent visible part of the body and provides a person's sense of identity. Functionally, it animates emotion, communication and intellect, and provides the essential access routes to the respiratory and gastrointestinal systems. Cognitively, the region is the sole source of vision, hearing, taste and smell. Thus, facial disfigurements, whether congenital (eg. cleft lip/palate) or acquired (eg. trauma, disease processes and their treatment), have the potential to cause multiple problems and psychosocial dysfunction.[1-3]

Facial reconstructive surgery aims to establish anatomic normality as closely as possible on an individualized basis to optimize functional and esthetic

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outcomes. Given the multifactorial effects of facial disfigurement and reconstruction, psychosocial and functional rehabilitation specialists, patient motivation and family support are critical to the successful holistic management of these patients.

The purposes of this article are: (1) to provide an overview of the principles and current surgical methods useful in facial reconstruction, (2) to reflect upon directions along which established reconstructive techniques might evolve further, and (3) to consider methods that remain largely experimental but may contribute important improvements for facial reconstruction in the future.

Grafts, local flaps and pedicled flaps for facial reconstruction

The surgical restoration or construction of facial normality should follow Gillies' classic principle of utilizing "like" tissues. This applies to the facial skin envelope, neuromuscular dynamic functions, the bony and cartilaginous supportive framework and soft tissue volume. Balance and proportion combine to create the esthetically pleasing face, which can be divided usefully into several facial esthetic subunits,[4,5] such as the periorbital region, the nose, auricles, forehead and commissural structures.

Many smaller and less complex facial defects can be addressed with local or regional flaps that provide a suitable match for facial tissue characteristics such as color, contour, texture, pliability, thickness and the presence or absence of hair.[6] Any flap may be classified as predominantly having a random or axial pattern blood supply.[7] Many skin flaps that are used to reconstruct smaller, full-thickness defects on the face, such as Z-plasty, W-plasty, V-Y advancement, rhomboid flaps and bilobed flaps, are considered to have random pattern circulations. Axial pattern flaps are based on an anatomically defined configuration of vessels called "pedicle vessels"; these comprise at least one arterial supply and one vein for drainage. Flaps range from simple advancements of skin and subcutaneous tissue to axial pattern composite flaps that may contain any combination of tissue types.[6]

The choice of flap is predominantly determined by the characteristics of a given defect. A nasal defect, for example, can be assessed according to the anatomical layers that are affected, such as the inner nasal lining, the architectural bony and cartilaginous support structure, and the external soft tissue coverage.[8] The goals of nasal reconstruction are to maintain a patent airway and achieve an optimal esthetic appearance.[8] The latter can be achieved by respecting the following nine esthetic subunits of the nose described by Burget and Menick: the nasal dorsum, tip, columella, sidewall (two), ala (two) and soft triangle (two).[9,10] Small defects in some locations, such as the glabella, heal satisfactorily by secondary intention, whereas healing by secondary intention in other areas, such as the tip and ala, will cause unfavorable distortion or notching of the tissues.[11] Full thickness skin grafts harvested from the pre- or post-auricular and supraclavicular regions may provide a suitable tissue match for skin defects with a healthy graft bed. Small chondrocutaneous composite grafts harvested from the ear have been used to reconstruct three-layer defects, but their survival relies tenuously on a well-vascularized wound edge.[12]

Useful local flaps for reconstruction of small cutaneous nasal defects (usually less than 2 cm in diameter), which exploit the laxity of adjacent skin, include the banner, bilobed, dorsonasal, nasolabial, glabellar and cheek flaps.[13] Use of a forehead flap (based on the supraorbital or supratrochlear vessels from one or both sides) is an excellent method for nasal reconstruction (Fig. 1).[13] The temporomastoid flap can transfer ample posterior auricular and/or mastoid skin based on the superficial temporal artery for total nasal coverage, and can include some auricular cartilage when required.[14]

Reconstruction of nasal support is important for esthetic nasal projection and for airway patency. Midline support, provided by the nasal bones, the anterior edge of the nasal septum and the medial crura, and lateral support on both sides can be reconstructed using cartilage (eg. from nasal septum, auricle or costal cartilage) and/or bone grafts (eg. from the calvarium, iliac crest or rib). Like skin grafts, they require a well-vascularized bed to survive and should be introduced at the time of lining and skin reconstruction. Local septal flaps may also be useful for midline support.

The nasal lining needs to be restored to protect the structural support and to prevent contraction through scarring.[15] Various folded flaps have been described that address the external skin and internal lining at the same time. Alternatively, a local flap providing the external skin can be resurfaced on its

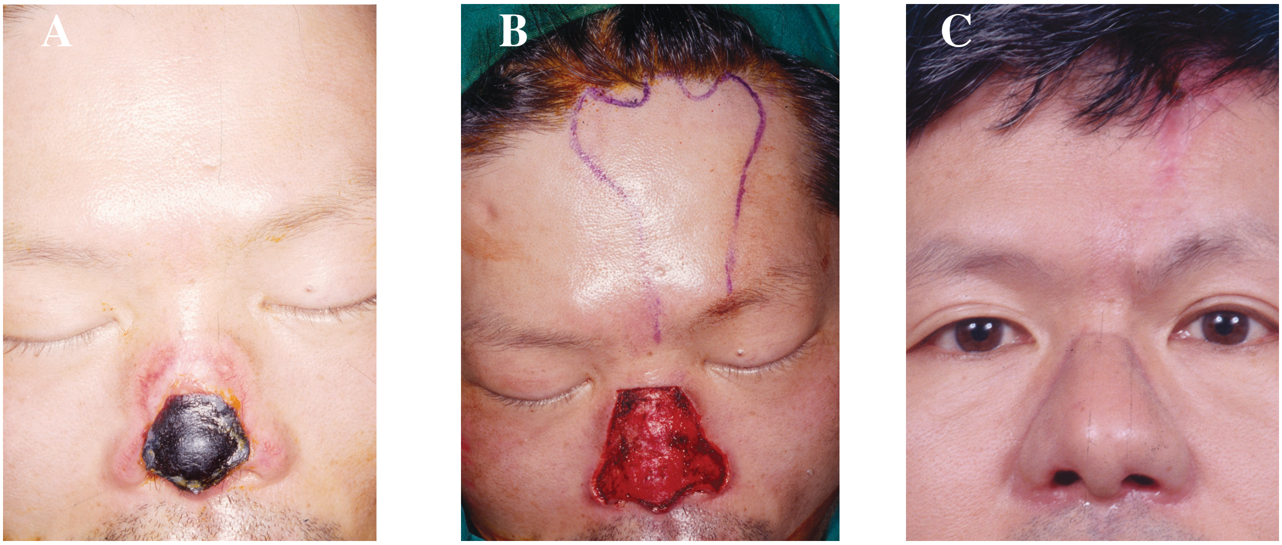

Fig. 1 Nasal reconstruction with a forehead flap. (A) Frostbite injury to the nose. (B) Defect following debridement. An island pedicled left forehead flap has been designed according to the geometry of the defect. (C) Esthetic result after six months.

underside with a full thickness skin graft. Local mucosa can also be advanced into the defect, or mucosa from a distant site, such as the oral cavity, can be grafted into place.

Defects of any other facial structure are reconstructed using similar principles. The topography, anatomic composition and esthetic subunits of the defect are assessed and local flaps designed accordingly. Each structure of the face has its own unique reconstructive principles that should be respected.[16,17]

Microvascular free tissue transfer for facial reconstruction

In the past, regional pedicled flaps, such as pectoralis major or deltopectoral flaps in combination with local flaps and non-vascularized grafts provided the only means by which larger or more complex facial defects could be reconstructed. Unfortunately, these patients were often plagued by significant donor site morbidity, extensive scarring and contractures causing functional problems.[18] Microvascular free tissue transfer (MFTT) was introduced in the 1960s and 1970s and has since matured into a reliable reconstructive option that has revolutionized the ability of surgeons to address increasingly difficult defects with improved outcomes.

A MFTT, usually referred to as a “free flap”, is an autogenous vascularized transplant. Any axial pattern flap with pedicle vessels of a suitable diameter can be transferred as a free flap. This involves three main steps: (1) complete detachment, with devascularization, of the flap from the donor site, (2) revascularization of the flap with microvascular anastomoses between the flap pedicle vessels and recipient site vessels to nourish the flap with a new arterial supply and venous drainage, and (3) an intervening period of flap ischemia. Numerous large studies have demonstrated free flap survival rates exceeding 95%.[19-22]

Free flaps have several generic advantages. They can be designed to incorporate a wide variety of tissue types that can be oriented in many configurations to improve inset.[22] They can be harvested from almost any region of the body (to maximize tissue availability and suitability for the defect) and often promise fewer surgical stages and reduced time to complete rehabilitation compared to regional reconstructions. Improvements in free flap selection and harvesting techniques continue to reduce donor site morbidity.[23,24] There are two broad indications for MFTT for facial reconstruction. Firstly, MFTT is indicated when the size or complexity of the defect is outside the reconstructive bounds of conventional techniques involving local flaps, regional flaps and/or various grafts and, secondly, when MFTT can offer definitive advantages over these techniques. Recent developments have led to greatly refined MFTT facial reconstructions. The evolutionary process in mandibular reconstruction[25-29] for example, is applicable to other parts of the facial skeleton and soft tissues.

Reconstruction of facial regions - step-wise evolution of mandible reconstruction

The mandible esthetically shapes the lower third of the face and functionally contributes to swallowing, chewing and speaking. A segmental mandibular defect, or inadequate reconstruction of such a defect, may therefore cause esthetic, functional and psychosocial morbidities. The various historic mandibular reconstructive methods are limited by being non-vascularized or pedicled to surrounding tissues.[30] MFTT, particularly of the fibula osteoseptocutaneous flap, has superseded these methods by offering single-stage reconstructions and improved results.[29-32]

At Chang Gung Memorial Hospital, a step-wise approach to refine available techniques has recently been applied to mandibular reconstruction, especially the anterior mandibular segment. This segment is subjected to the greatest moment forces during biting and is a critical determinant of esthetic facial height. When using a standard single-barreled fibula osteoseptocutaneous flap to reconstruct this region, the surgeon is faced with a reconstructive dilemma. The cross-sectional height of the fibula is approximately half that of the anterior mandibular segment, so if the facial height is restored from the esthetic perspective, there will be a functional price paid by the compromised lower position of osseointegrated dental implants.[33,34] If dental function is considered more important, as is usually the case, a significant shortening of the facial height is required to place the dental implants into the plane of the native alveolar ridge, but this compromises facial esthetics.[35] Efforts to address both considerations exemplify the step-by-step approach to reconstructive refinement and evolution.[36]

The first method involves insetting the fibula more superiorly (to provide adequate alveolar ridge height for osseointegrated dental implants) and the addition of a low-profile reconstruction plate aligned with the inferior mandibular margin for esthetic contouring of the lower face.[35,36] However, a patient who undergoes this reconstruction might still be bothered by palpability of the lower reconstruction plate if the covering tissue is inadequate. In response, a second refinement has increased the available thickness of the fibula bone by folding it into a double-barreled configuration (Fig. 2).[34,37] This can simultaneously improve both the esthetic facial height as well as the positioning of osseointegrated dental implants (Fig. 3).[37] However, double-barreling the fibula limits the available length of bone for reconstruction. Consequently, a third refinement has evolved, involving the incorporation of the distraction osteogenesis technique.[36,38,39] Here, a single strut of fibula bone is intentionally placed in an esthetic lower position (initially compromising the height of the alveolar ridge) but subsequently osteotomized in a transverse direction and distracted vertically to increase the height of the neo-mandible.[36] Overall, this has resulted in both improved facial height and improved dental positioning without limiting the length of available fibula bone for reconstruction.

A

B

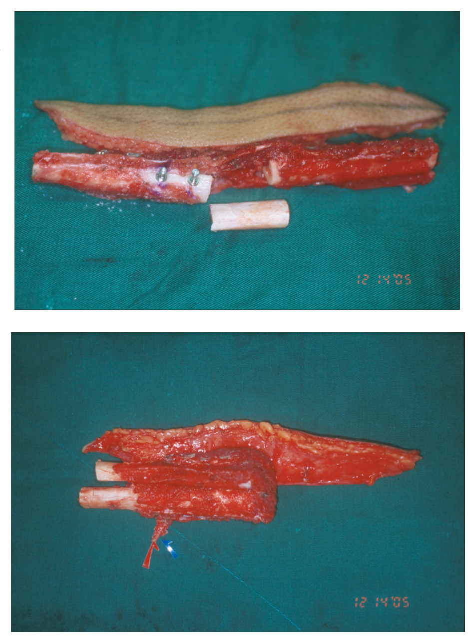

Fig. 2 Double-barreled free fibula osteoseptocutaneous flap. (A) The fibula bone has been osteotomized into three segments. The middle segment (approximately 3 cm in length) has been carefully dissected while protecting the periosteal blood supply, and then discarded. (B) This permits double-barreling of the fibula to increase the available thickness of the bone. Note the osseointegrated implants; these have been placed primarily into the upper of the two fibula barrels for dental rehabilitation.

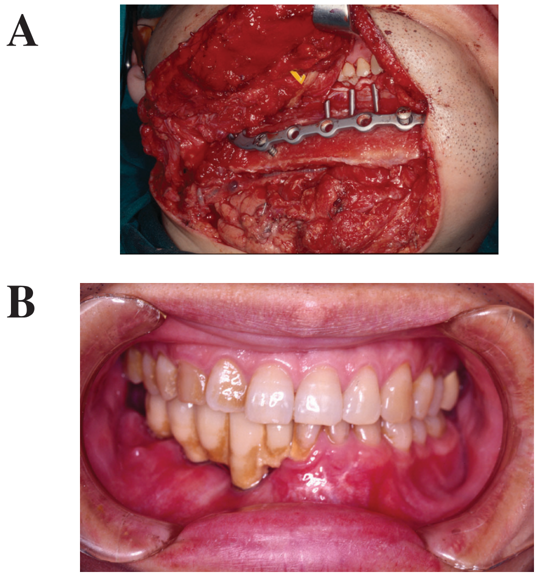

Fig. 3 Osseointegration of dental implants. (A) Waxing screws are useful when aligning the mandibular and maxillary dental arches during placement of osseointegrated implants. (B) As a result, accurate dental occlusion and rehabilitation can be achieved.

Facial reconstruction techniques - the evolution of tissue harvest and flap design

The principles of step-wise refinement can be applied to any region of the face. Approaches may include a number of newer techniques or concepts. Some are outlined below.

Perforator flaps

A perforator flap can be defined as one that is based on a pedicle that has been skeletonized from its intramuscular course by retrograde intramuscular dissection, thereby excluding the muscle from flap harvest.[24] One example of this is an anterolateral thigh flap based on a perforator vessel that traverses the vastus lateralis muscle.[22] If the same flap is based on a pedicle that has no intramuscular course, it is not a perforator flap by the definition.[24] By excluding the muscle during flap harvest, donor site morbidity is decreased and the bulk of the flap can be reduced to improve flexibility during flap inset.[22] The contour and tissue match for facial reconstructions can therefore be tailored more readily by using perforator flaps. Prior to the introduction of perforator flap dissection techniques, the harvest of skin flaps sometimes had to be abandoned when the pedicle vessels were found to enter the belly of an important muscle. Perforator flaps can be transferred as either pedicled or free flaps.

Free- style flaps

A recent extension to the perforator flap harvest is the free- style flap concept.[23,40] Using the same techniques and principles, one can design a flap in almost any desirable cutaneous territory depending on audible Doppler signals.[23,40] The key advantage of using free -style flaps for facial reconstruction is increased flexibility when choosing donor skin and subcutaneous tissue characteristics. They are also axial in pattern and can be transferred as pedicled or free flaps.[23,40,41]

Chimeric flaps

Chimeric flaps have separate components that share a common source vessel.[42,43] Since the vascularity of different flap components can be preserved by isolating their vascular supplies, the individual components can be freed from one another to increase their mobility and thus improve flap design and inset. This technique can be applied, for example, when reconstructing a compound or composite facial defect; the reconstructive problem can be solved with one multi-component chimeric flap based on only one pair of anastomoses.[42,43]

Flap prefabrication by vascular induction and/or prelamination

Vascular induction involves introducing a new blood supply into a chosen volume of tissue by (1) transferring a pedicle into that volume of tissue, (2) neovascularization of that tissue by the transferred pedicle, and (3) transfer of that tissue based only on its implanted vascular pedicle.[44] This method allows the design of flaps in more discrete regions of the body or in areas of skin excess, and the creation of new flaps in areas that do not have defined axial vessels but have a superior tissue match for facial defect requirements.[45] Prelamination involves the addition of one or more extra layers of tissue to an existing flap.[45] For example, a customized multilayered free flap can be created for a specific composite facial defect by skin grafting or by implanting the donor site with mucosa or cartilage. The benefits of this approach have been elegantly demonstrated for the reconstruction of complex nasal lining and extensive composite midfacial defects.[15,45]

Prostheses and camouflaging techniques

No matter what method of facial reconstruction is chosen, facial scarring remains an unavoidable fact of tissue healing. Simple, commercially-available cosmetic products can be used to improve the results of facial reconstructions by camouflaging the visible scars. This straightforward approach can yield dramatically improved esthetic results, as recently demonstrated for severe facial burn reconstructions.[46] In addition, some defects that are impossible to reconstruct, such as the loss of an eye, can be replaced with an esthetic prosthesis.[47] This is also useful when treating disfigured patients who would rather not undergo an operation.

Future considerations - total and subtotal facial reconstruction

Despite the application of these tremendous advancements and refinements to facial reconstruction, the results of total and subtotal facial defects remain inadequate.[48,49] The psychosocial impact of these defects and residual disfigurements following attempted reconstructions are often devastating. Microsurgical replantation provides the best outcomes and should be attempted whenever possible.[50,51] In situations where the tissues can not be replanted or the defect can not be reconstructed satisfactorily with MFTT (due to its extensiveness and/or complexity) two evolving approaches, although still largely experimental, might offer some hope for afflicted patients, tissue engineering and composite tissue allotransplantation (CTA).

Tissue engineering

The application of tissue engineering to facial reconstruction has some promise. The technique aims to produce tissues that mimic those that are naturally occurring by bringing together three essential ingredients into a bioreactor, cells, growth factors, and a scaffold to given structure.[52] Individual tissue types can be engineered quite consistently, including muscle, tendon and bone, some with complex morphology.[52,53] Indeed, tissue engineered bone has been used to augment the height of a mandible reconstructed with a free fibula osteoseptocutaneous flap and to replace the avulsed distal phalanx of a thumb.[54,55] Famously, mice have been used to engineer the elaborate shape of a human ear; this technique has potential for clinical application.[52,53] A few groups have been looking into tissue engineering composite vascularized tissues, but this technique is very much in its infancy.[53,56] Increasingly complex constructs will require embedded blood vessels to ensure their viability and microsurgical skills will be necessary to anastomose the embedded pedicle vessels of engineered composite tissue constructs to the patient's vasculature.[53,57] One research group has recently announced an interesting approach to solving the problem of vascularizing tissue engineered constructs.[56] By combining the techniques of tissue engineering and prefabrication by vascular induction, they were able to vascularize engineered auricular constructs and then transfer them as free flaps in rats.[56] Once two major obstacles are overcome, the engineering of composite tissue constructs and embedding them with a vascular pedicle, it might be possible to engineer vascularized facial tissue constructs from autologous cells for reconstructive purposes.[53]

Composite tissue allotransplantation

Although total facial reconstruction using cadaveric donor facial tissues has not yet been attempted, CTAs of the partial face have recently been performed in France and China.[58,59] The early esthetic result of a partial facial CTA performed in France in 2005 has generally been judged as favorable.[58,59] Sensory function returned quickly, with the tip of the nose sensate by the 14th week and the oral mucosa requiring local anesthetic for biopsies within two months.[59] Motor return was less dramatic during the initial recovery period.[59] These cases have at least confirmed the feasibility of facial CTA in humans. Several centers around the world are preparing to perform total facial CTAs.[58]

However, there remain several ethical barriers to facial CTA becoming a wide-spread clinical practice, notably surrounding issues regarding: (1) the toxicities of the required non-specific life-long immunosuppression, and (2) fall-back options should a facial CTA fail in either the perioperative period or in the longer term.[58] It has been argued that the potential benefits of facial CTA in select patients can outweigh the risks. The principle ethical barrier is related to the risk-benefit ratio of a procedure that is performed for a condition that is not life-threatening but carries potentially fatal risks from immunosuppression. CTA-related research has consequently intensified, addressing methods to reduce these risks, including the search for a safe method of transplantation tolerance induction in humans, reducing the complication profiles of available immunosuppressants and developing novel, more specific immunosuppressant therapies.[58,60-62] Other important areas of research address issues of informed consent, surgical techniques of facial CTA harvest and insetting, and predicting outcomes on a case-by-case basis.[62-64]

The successful development of a safe and reproducible protocol of donor-specific tolerance induction for CTA in humans could dramatically change facial reconstructive surgery. With an acceptable safety profile, it is conceivable that total or subtotal facial defects would no longer be the only indication for facial CTA and that less complex defects may preferably be reconstructed with cadaveric parts rather than by autologous tissues that inherently cause donor site morbidity.[65]

Conclusions

The impact of facial disfigurement varies considerably between patients and cultures. Regional and MFTT reconstructions of the facial soft tissues, dynamic functions and skeletal framework have benefited from step-wise refinements that will continue. Techniques currently confined to the laboratory or to clinically unique situations may provide promise to refine reconstructions even further. For total or subtotal facial defects, cadaveric facial CTA is an option that should be embraced following the establishment of a more acceptable risk profile.

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