The *Surgical Art Face*©: Developing a bespoke multimodal face model for reconstructive surgical education

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Abstract

Surgical and educational challenges exist in relation to the teaching of facial reconstructive surgery due to the complexities of the facial landscape and training models available. This chapter will describe the development and implementation of alternative modes of teaching facial reconstructive techniques in a multi-disciplinary setting, pioneered by *Surgical Art* (www.surgical-art.com), through of use of a bespoke multimodal training model – the *Surgical Art Face*©

1.1 Introduction

The face is a complex hybrid structure with non-homogeneous layers that differ between facial sub-units. Anatomical variation and the specific characteristics of each layer are unique to an individual and present challenges to the surgeon. Reconstructive surgeons are often considered 'sculptors of the flesh', however, they do not work with rigid materials like a sculptor of marble or stone. Instead, the surgeon works with living, moving, ageing and evolving 'clay'.

In facial reconstructive surgery, the surgeon needs to take an approach whereby they adapt to variations in anatomical form, movement and ageing, and consider their effect on the overall topography of the facial landscape. Obtaining an in-depth understanding of facial lines, tether points and facial contours aids a surgeon in guiding the reconstructive process, and repairing defects using tissue recruited during reconstructions more creatively.

Surgical reconstructive procedures climb a ladder of complexity. The lowest rungs of complexity include leaving a wound to heal by secondary intention and direct closure of skin, and the procedures advance in difficulty as the rungs of the ladder are climbed to include skin grafts and the movement of vascularised tissue in the form of local flaps or distant flaps. Regardless of the surgical procedure, it is critical to bear in mind how the skin creases and folds, the surface topography, the muscle layers of the sub-unit operated on, and the symmetry of the body, in order to achieve a functional and refined aesthetic outcome.

Facial flap operations are surgical and aesthetic challenges due to the cosmetically sensitive nature of the face. Flaps involve transferring tissue from one area of the face to an (often) adjacent defect. These flaps, composed of skin and other component structures, are designed using geometric principles that are customised per individual, and are one of the most elegant examples of the marriage of art, geometry and surgery. In performing these operations there exists the potential to cause asymmetry and distortion to the facial topography, however, if done sympathetically the functional and aesthetic results can be very satisfactory.

The transformation from a trainee surgeon, who relies on geometry and pre-prescribed standardised measurements, to an experienced surgeon who is able to artistically use the patient's facial topography to create a bespoke operation can be a long process of training and development. Whilst the cadaver remains the Holy Grail of teaching models, it is a costly and resource limited teaching tool. To overcome these technical, aesthetic and financial challenges, whilst maintaining the key elements of the face, Isle of Man based *Surgical Art* has designed a training model known as the *Surgical Art Face*© to aid and enhance this learning process.

1.1.2 Reconstructive surgery

Plastic surgery and reconstructive surgery are interchangeable names for the specialty of medicine that attempts to return form and function to a part of the body that is affected by trauma, tumour and congenital conditions or for aesthetic purposes. The term 'plastic' surgery is derived from the ancient Greek adjective "*plastikos*", meaning 'to mould' or 'to give form' (Macionis, 2018). The first mention of plastic repair dates back to 3000BC in the translation of an Ancient Egyptian medical text – the Edwin Smith Papyrus (Shiffman and Di Giuseppe, 2012), referring to the reconstruction of a broken nose. Whilst the current spectrum of plastic surgery is a relatively new phenomena, its roots can be firmly traced back to circa two millennia in India, where arts and craft techniques and materials were used to recreate missing parts of the face (Bennett, 1983).

Sushruta was an Indian Physician considered by many as the *Father of Plastic Surgery* and his writings '*The Sushruta Samhita'* is considered one of the most important texts on surgery from the ancient world (Champaneria, *et al.*, 2014). It was here that rhinoplastic methods (as we understand them today today) began. However, there was little understanding of these surgical advances in the western world until the 1400s. It was then that the first European Surgeon, Sicilian Branca de'Branca, restored a lost nose by taking adjacent tissue from the cheek (Keil, 1978). His son, Antonia Branca, furthered this reparative surgery by taking a flap of skin from the upper arm and attaching it elsewhere on the body. This concept of transferring tissue from one part of the body to the other, by connecting the two with local flaps was named the 'Italian Method' (Keil, 1978). It needed the patient to be positioned or strapped into a position to allow the tissue to revascularise at the new site before being disconnected from its origin. Branca also reconstructed lips and ears, all of which were documented in Gasparo Tagliacozzi's '*De Curtorum Chirurgia per Insitione'* in 1597 (Keil, 1978). Tagliacozzi further improved on the 'Italian Method' that the Branca family had developed and was known as one of the first Plastic Surgeons, writing *"we restore, rebuild, and make whole those parts which nature hath given, but which fortune has taken away. Not so much that it may delight the eye, but that it might buoy up the spirit, and help the mind of the afflicted"* (Tagliacozzi, 1597). Soon after Tagliacozzi's death reconstructive methods such as these were abandoned until the end of the 1700s.

It was in 1794 that the Indian rhinoplasty methods came to the attention of European surgeons. British surgeons travelled to India to see these being performed, with some like Joseph Constantine Carpue staying to study local plastic surgery methods (Lock, 2001). In 1815, Carpue performed the first major surgery of the western world, using instruments first described by Sushruta and modified for modern use (Lock, 2001).

The most significant advances in modern plastic surgery have been achieved in the last century, instigated by the advances in warfare that occurred over the two world wars. Sir Harold Gilles, generally considered the father of modern day plastic surgery, was a New Zealand born otolaryngologist who worked in London caring for soldiers injured in World War 1 by reconstructing large facial defects caused by gunshot wounds (Chambers and Ray, 2009). Through World War I Gilles and his team performed over 11,000 operations on over 5,000 victims of artillery fire (Chambers and Ray, 2009) using both historic and modern surgical principles that connected tubed vascularised tissues to large defects.

Gilles was often accompanied by a General Surgeon and later a Slade Professor of Fine Art at University College London, Henry Tonks. Tonks became a Lieutenant in the Royal Army Medical Corps and worked for Gilles illustrating the injuries of soldiers prior to surgery and after their subsequent reconstructions (Biernoff, 2010). These portraits, created in chalk pastels, were recognised as the first images to reflect the brutality of modern warfare and also the aesthetic and psychological aspect of reconstructive surgery. They are often used as an example to highlight the merging of art and science. Suzannah Biernoff, a Reader in Visual Culture in the Department of History of Art at Birkbeck College, University of London writes that "*Like the 'strange new art' of facial reconstruction, Tonks' drawings blur the line between art and medicine, and, by disturbing the conventional categories of medical illustration and portraiture, they highlight the ambiguities that lie at the heart of those representational practices*" (Biernoff, 2010).

Medical illustrations, both two-dimensional (2D) and three-dimensional (3D), have the power to educate and transfer knowledge of anatomy and surgery through passive observation. By physically drawing the patients throughout their surgical journey, Tonks was not only documenting the injuries and procedures but he was also learning more about the three-dimensionality of the face and the person it belonged to. Medical illustrations also have the ability to only show what is required to be seen. Dorothy Davison, one of the founding members of the Medical Artist Association of Great Britain (MAA) was once quoted saying that the "*medical artist can be particularly useful in elucidating obscure and difficult points, for she never draws the obvious: that is photographed*" (John Rylands Library, 2017). Through artistic practices we are not only able to 'see' the face in new ways but we can also selectively highlight information and bring this to the attention of the viewer. These are crucial factors to consider when creating a surgical simulator such as the *Surgical Art Face*©.

1.1.3 Reconstructive Ladder

Reconstructive surgery is a wide-ranging discipline, working with most body systems, from head to toe, from skin to bone, and everything in between. The plastic surgeon uses a spectrum of options to help heal, repair, rejuvenate or replace parts of the body that are lost to disease, trauma or time. Below is a list of options, graded by complexity, called the 'reconstructive ladder' (Simman, 2009):

- Healing by secondary intention with dressings only.
- Direct closure involving edge to edge wound closure where there is adequate skin to allow this.
- A skin graft where skin is harvested from another area, disconnected and secured to the wound to help it 'take' or reintegrate with the body. This can take the form of a superficial removal of the layers of skin called a 'split skin graft' or a 'full thickness skin graft', utilizing the full depth of skin.

- Tissue expansion where skin and other tissues are “stretched” with a balloon or expander placed under them. This stimulates tissue growth, eventually providing enough skin for closure of the wound.
- Local flap(s) where local available tissue is partly disconnected, retaining a blood supply, is inserted into the defect using geometric and artistic principles.
- Free tissue transfer or autotransplantation where one part of the body is carefully dissected, disconnected and reconnected to another part of the same individual by separating it from its source vessels and then reconnecting the blood vessels at the new site using microsurgery. The part that is moved can contain skin, fascia, fat, muscle, bone, other organs or a combination of these. It can provide both form and/or function.

More recently the rungs of this reconstructive ladder (figure 1) have been extended, with advances in medicine, surgical techniques and technology, allowing for:

- Allotransplantation, which is free tissue transfer but from one individual to another.
- Robotics where a robotic device is used to enhance the body either externally or by integrating with the body.

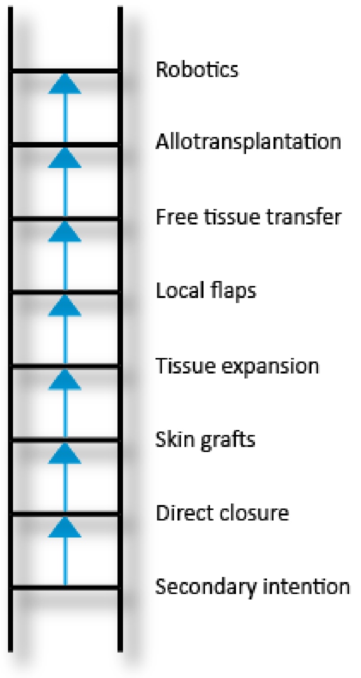

Figure 1: The reconstructive ladder is a stepped progression of reconstructive options that are considered when addressing a tissue defect that may be congenital or acquired from trauma, tumour or for aesthetic reasons.

The description of these available options as a ladder could imply that the surgeon utilises the options of the ladder from the most basic to the most complex in an incremental manner until the desired result is reached. This is not the case. The ladder is simply a guide of options, and when assessing the wound and planning for reconstruction, the surgeon will work through the choices available from the simplest to most complex (Simman, 2009). The 'reconstructive elevator' (figure 2) described by Gottlieb and Krieger (1994) describes the process by which the surgeon bypasses one or multiple rungs of the ladder to reach the ideal option for the reconstructive challenge faced (Glat and Davenport, 2017). The aim of modern surgery is not to simply get the wound healed but rather to replace the missing tissue with the closest matching tissue in an attempt to return both form and function.

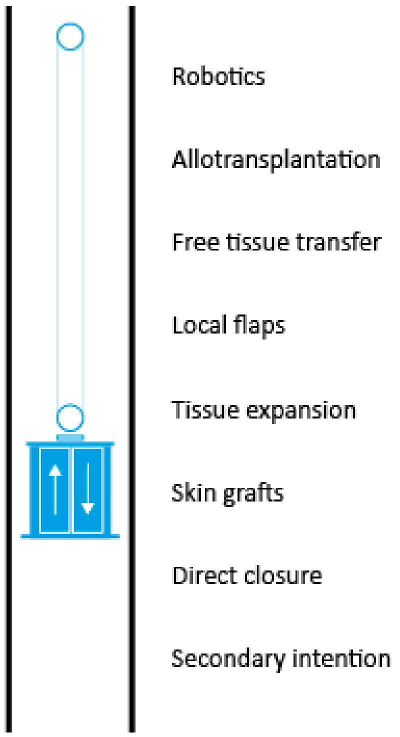

Figure 2: The 'reconstructive elevator' described by Gottlieb & Krieger (1994) is an adaptation of the reconstructive ladder highlighting the philosophy of selective choice based on form and function without necessarily exploring every 'rung' of the ladder.

1.2 Facial reconstructive surgery

In countries with a significant Caucasian population, the majority of facial surgeries are performed for skin cancer excision and reconstruction, followed by surgery for trauma, aesthetic reasons,congenital conditions such as cleft lips/palates and conditions requiring cranio-facial surgery. In most skin cancer reconstructions, the malignant lesion or tumour is excised and the area reconstructed. The choice of rung from the reconstructive ladder is based on a variety of factors but at a minimum the wound is either closed directly, with a skin graft or by using a local/regional flap. It is less common for free tissue transfer to be needed after skin cancer excision. This surgical choice - the assessment the surgeon makes of the reconstructive 'challenge' at hand and the intended path to wound healing - is one of skilled decision making that considers risk, disease, anatomy, procedural complexity and patient expectation (Sandberg, 2016).

1.2.2 What knowledge and skills do facial surgeons need?

To make an effective surgical choice and to execute it successfully, the surgeon needs a breadth of knowledge and skills. When considering facial surgery, the need for this understanding is even greater as the face is arguably the most visible and cosmetically sensitive part of the body. For any form of facial reconstruction, the surgeon must possess a number of skills to deliver an effective and aesthetic outcome; from analysis of the patient and the condition all the way through to the surgical execution of the reconstruction and the post-operative scar modulation or, in some cases, scar revision. Here we describe the required skills that an effective facial surgeon should possess; some of which overlap with other surgical disciplines. The list is not exhaustive and does not take into account the assumed generic skills of critical analysis, communication, and leadership:

> ***Clinical anatomy skills***
>
> The surgeon needs a detailed understanding of clinical anatomy, specifically the anatomical forms that will be engaged with directly and in the surrounding area. Skin cancers and other lesions “affect both function and aesthetics, which are based on complex anatomical features” (Marur, *et al.* 2014). Every potential risk and danger area must be anticipated, and the potential impact the structures in the surrounding facial sub-units needs to remain at the forefront of the surgeon's mind. This is ‘selective knowledge’ that has been distilled from practical experience of operating in the specific anatomical area.
>
> ***Facial topography knowledge***
>
> ‘Facial topography’ is a term that has been described by a number of surgeons and researchers including Gruber, Levine & Levine (2013), however, *Surgical Art* uses the term ‘facial topography’ to describe the contours and undulations of the face when teaching the aesthetic approach to facial surgery. An understanding of the rise and fall of the facial landscape is important in defining the ***chiaroscuro*** of the face - areas of highlights and shadows. It is a critical exercise in understanding sites of volume and how they change over time, and how to use shadows to hide scars and enhance other areas where highlights are desired. As

demonstrated in figure 3, sculpting the human face using clay or wax helps to give the trainee a haptic and visual reinforcement of facial topography. This understanding provides a foundation to reconstruct the functional face and still retain the character of the face.

Figure 3: Facial topography: an understanding of the contours of the face. Examples of training with clay at *Surgical Art*.

Understanding of facial lines, units and sub-units, and incision lines

Lines of skin are a product of inherent skin anisotropy, muscle movement and facial tethering to deeper layers. In 1861, Karl Langer used a round tipped awl to create defects in skin but these stretched and created axial patterns based on skin tension (Langer, 1978). The lines that resulted from mapping these axial defects are termed Langer's Lines. Later, Kraissl (1951) based his lines perpendicular to the underlying muscles and using photographs to help map these lines or wrinkles. Borges (1984) described Resting Skin Tension Lines (RSTL), which are mapped by the straight lines formed when skin is pinched in one direction, and S-shaped when pinched in other directions. This description is useful when exploring lines in a youthful face where there are no wrinkles. When these lines are used as incision guides, the wound experiences minimal stretch and scars heal optimally. Also, because these lines are parallel or within natural crease lines, scars are hidden better. Whilst these lines are unique to every individual, they do follow a general pattern, and can be considered as the "facial grid" or "roadmap" (figure 4).

In addition, the face is also divided into anatomic and aesthetic components known as 'sub-units' (figure 4), which are intended to help the surgeon respect the functional and aesthetic boundaries within the face, to avoid either a functional complication or aesthetic failure. Within the subunits there are some accepted facial landmarks that should avoid being distorted, including the hairline, eyebrow, eyelid, nasal tip, nasal ala, earlobe, philtrum, vermillion, and oral commissure. In contrast to these landmarks, there are facial units that provide an ideal source of tissue recruitment for local flap reconstruction whilst still respecting the facial unit boundaries, including cheek, neck, forehead, chin and submenton (Patel and Sykes, 2011). The plastic surgeon must understand and use these dual “facial grids” in synchronicity with one another to maintain the functional and aesthetic harmony of the face.

Figure 4: On the mask, the left side of the face has been divided into facial subunits and the right is patterned with resting skin tension lines.

Knowledge of anisotropy, skin laxity & tethering

The skin of the face, not unlike other parts of the body, displays elasticity in varying degrees that is related to age and skin quality but is also ‘direction dependent’. This property of directional dependence is termed ‘anisotropy’. Isotropic materials display the same properties in all directions while anisotropic materials display different properties in different directions. Anisotropy has been documented in other biological tissues like the transversalis fascia of the abdominal wall (Kureshi, *et al.* 2008). In skin, anisotropy is based on the skin’s attachments to deeper structures, like fascia or bone via retaining ligaments and other fibrous connections which tether the skin (Alghoul and Codner, 2013). These connections to the underlying tissues influence the capacity of the skin to be 'moved' in different directions. The quality and relationship of the different planes is also not static and changes with age and in response to disease and surgery. The face therefore displays anisotropy that varies in every individual and in changing circumstances. The analysis of an individual's facial anisotropy along with skin laxity is critical in selecting the most appropriate type of reconstruction and in designing local flaps.

Understanding of local flap design

Local flaps are an elegant reconstructive option that have seldom been taught outside of the operating theatre. It is, however, an important skill that bridges the disciplines of surgery, geometry and art. The ability to design the appropriate geometrical pattern (the local flap) to fill a ‘hole’ (the tissue defect) and understanding the pattern of movement without the added ‘complication’ of anatomy, is itself a steep learning curve. The process of local flap reconstruction applies this concept of geometrically designed patterns and uses tissue adjacent or near to a defect, which can be moved into the area previously occupied by a defect. The application of this process on the human form requires a combination of surgical and anatomical understanding, and artistic flair to create a harmonious result (Patel and Sykes, 2011).As part of the decision-making process into the choice and design of local flaps the following key components are considered:

1. Vascularity - traditionally local flaps are based on random pattern blood supply with no named specific blood vessel feeding the flap. Instead an appropriately wide base is selected that allows a rich network of blood vessels to enter the flap at different levels within and below the skin, and even through other tissues that can be incorporated within the local flap, such as muscle. However, there are some local flaps that are based on a named vessel or that can be designed to incorporate a named vessel.
2. Uni/Bi/Multi-directional laxity – the surgeon assesses the tissue around the defect to gauge laxity and availability of tissue that can be recruited into the defect.
3. Shape and long axis relating to Resting Skin Tension Lines – the shape and long axis of the defect plays a crucial role in the choice and design of the local flap. We refer to certain axes as favourable or unfavourable, which has a profound effect on the choice of flap design and orientation.
4. Adjacent functional or aesthetic landmarks – the surgeon has to take into account the proximity of the defect to a landmark organ or aesthetic line when designing a reconstruction. Although a number of reconstructive choices may work for the same defect, a skillful surgeon will choose a design that will least interfere with a functional or aesthetic landmark. For example, the lower eyelid.
5. Thickness of the skin – the quality and thickness of skin is important but does not preclude the use of a local flap with a different thickness of skin and subcutaneous tissue, to that of the defect site.

6. Hair Pattern – hair pattern is an important matter of consideration, especially in areas where loss or distortion of hair can be obvious and disabling, for example the eyebrows. It is also important for the surgeon to consider the aesthetics of facial hair and to attempt to replace like for like, not just in terms of hair bearing skin but also factoring in direction and quality of hair, where possible. Other areas where hair is an important consideration in reconstruction is the hairline, moustache/beard, and sideburns.

The three primary flaps are transposition, advancement, and rotation flaps. Based on the key factors above, transposition flaps are used primarily when there is minimal tissue available from any direction. The other critical component in deciding to use a transposition flap is the vascularity. A flap design which incorporates a known vessel into it is likely to survive all the way to its tip, but also can be raised on a much narrower pedicle. Typical sites for transposition flaps are the scalp, where hair pattern is also an important consideration that needs to be factored in.

Advancement flaps are best applied when there is either a uni or bi-directional laxity available or affordable and the axis of the defect is at its widest perpendicular to the RSTLs. Both components are important factors in making reconstruction by advancement flap achievable. We have observed that the reach of this type of flap is heavily dependent on the laxity of tissue available, with a huge spectrum of variation amongst individuals, and therefore the trainee surgeon will need to learn to gauge defects in individuals, preferably pre-operatively but sometimes intra-operatively. This flap allows the surgeon to avoid distortion perpendicular to its direction of movement, which is a critical feature that can be used in cosmetically sensitive areas like the forehead, where it is important to avoid lifting one eyebrow, thus changing the quality of the patients face and expression completely. Thickness of the skin and vascularity are less important in these situations as these are considered random pattern flaps, fed by blood vessels at multiple levels and by the network of vessels over the wide flap base.

In the third primary flap type – rotation flaps – there is limited uni or bi-directional laxity but small amounts of multi-directional laxity that can be recruited from a large surface area. A typical site for this flap is the scalp. This flap must be designed significantly larger than the defect as it works on the recruitment of small quantities of tissue from a large arc of rotation, to feed the much smaller defect. Vascularity and hair pattern are important considerations in this flap.

We have characterised other flaps as secondary flaps with tertiary variants. These are beyond the scope of this chapter but broadly fall within the design parameters defined by the three primary flaps described above. Figure 5 demonstrates the Abbe-Estlander Flap that uses a combination of rotation and transposition (Ebrahimi, *et al.* 2011).

Figure 5: The Abbe-Estlander Flap – using part of the upper lip to create a tissue defect of the lower lip. Image courtesy of Jessica Irwin©. Produced as part of a collaborative project with *Surgical Art* during her MA Art in Science study at Liverpool John Moores University.

Facial reconstruction experience

Transferring the broad clinical understanding of reconstruction and applying this to the facial topography, skin lines, facial units, laxity, and tethering of the human face, combined with the design and application of local flaps is a critical step in the surgeon's developmental journey. The ability to merge these individual facets of training is the goal of this facial reconstructive education process.

The surgeon must learn to apply direct closure principles in respect of facial 'gridlines', to understand skin/tissue qualities in different parts of the face/head and thus make informed judgments on the appropriate reconstructive option, type & thickness of graft and finally to design and apply local flaps that adapt to the convexities and concavities of the face, and the varying functional and aesthetic sub-units.

A final, but crucial, aspect of this learning process is the ability to apply this holistic approach to an individual's unique facial characteristics and form, the individuals use of their face and their expectations of surgery. The *'plastic surgery compass'* described by Sandberg (2016) must be balanced and weighed up with the surgical options, risk and the defect/disease/enhancement in question.

Creative skill

The trainee surgeon is taught to apply techniques with prescribed detail for surgical design and incision all the way to closure and dressing. This standardisation provides an important framework, especially for the less mature surgeon. We refer to the surgeon in this phase of training as the 'engineer' surgeon. As surgeons progress, they use the principle of this analytical, prescribed process and adapt it to their personal flair, based on their own experience - an accumulation of hundreds if not thousands of operations - to become an 'artistic' surgeon. We consider the 'artistic surgeon' to be one who has evolved, not purely with surgical knowledge and experience but also with a broader maturity and understanding of the body, the disease and the surgical solutions. However, a surgeon’s transformation from engineer to artist, through this process, is inconsistent and unpredictable both in terms of time and quality.

We believe that this evolution from engineer to artist is critical but more significantly the rate and quality of this transformation is down to the type of training received. A multi-disciplinary approach to training is vital and for the most part unrecognised in traditional surgical education, which typically includes an apprenticeship with senior surgeons in the specialty or sub-specialty.

1.2.3 What is the ideal simulation tool to train surgeons to perform facial surgery?

There is no question that the living human face is the ideal model for planning facial reconstruction, and that the living patient’s dynamic tissues are the perfect canvas to design a surgical plan. In addition to this, the patient not only provides a body but also a mind with personality, character, and an expectation of what the surgeon should achieve. However, access to the patient for surgical planning as a learning tool is not always possible, and when such opportunities arise, they can be stressful learning processes, usually with an awake patient under local anesthetic, and where the inevitable mistakes of learning cannot be afforded. This otherwise ideal model is followed closely by the human cadaveric face; however, this is a limited resource primarily due to cost implications both for the trainee and training provider. Whilst it would be ideal to have <u>one</u> easily available, cost effective and simple to manufacture model to teach the skills described above, this unfortunately does not exist. However, there are a number of different training models that are used at different stages of the learning process:

Biological models - porcine skin

Porcine skin has been extensively used in skin research and surgical training (Hassan, *et al.* 2014). Although there are many biological and healing similarities between porcine skin and human skin, porcine skin has limitations for surgical training. It is a reasonable model for basic skin suturing and harvesting split skin graft training as it has a thick dermis and can tolerate trauma at the hands of a trainee surgeon. The face however has a much thinner and more pliable skin that is delicate and allows a significant amount of movement, and displays the property of anisotropy. Porcine skin does not simulate these properties and so the elegance of facial local flap techniques are not well simulated on this model alone.

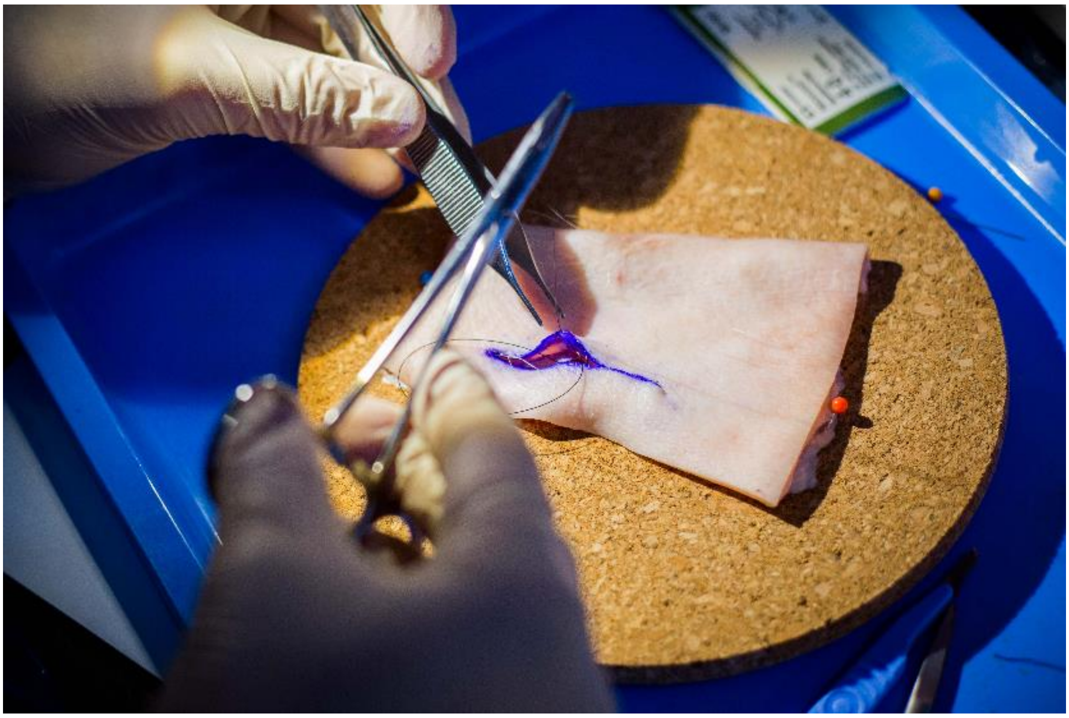

Figure 6: A *Surgical Art* porcine skin training model being used during a 'Plastic Surgery Skills' training course.

Biological models - chicken skin

Chicken skin on the other hand is very elastic and pliable. However, the skin is very thin with minimal dermis which does not allow dermal suturing and can sometimes tear. The chicken model works very well when used as a full carcass to train surgeons in the principles of local flap design. This model has been developed by *Surgical Art* and can be used to demonstrate and practice the full spectrum of local flap types.

Figure 7: A *Surgical Art* chicken skin training model being used during a ‘Local Flaps and Skin Graft’ training course.

Biological model - excess human skin in theatre

Ibrahim, *et al.* (2016) describes the use of excess human skin that is usually discarded during surgery to be used by the trainee after surgery, away from the operating field. This approach, which intends to be economical is an excellent albeit limited resource for the trainee. More often than not, the tissue that is made available is not facial skin and will not have the same properties, however, it is excellent for skin suturing techniques but limited for facial local flap techniques beyond the understanding of flap concepts.

Synthetic models - sponge

Sponge is the most popular material for suturing demonstration and practice. There are a wide variety of synthetic sponges available for varied applications. A number of these sponges have been used as available or specifically designed for surgical training. They are effective models for teaching basic concepts of flaps and patient education (Villafane, *et al.* 1999) but do not have the refinement to be considered a close simulation of local flap reconstruction.

Synthetic models – single layer silicone face

Silicone face models often have excellent facial topography and can be coloured or textured to provide a close simulation of the human form. Using prosthetic technology this model can be developed even further to provide a very aesthetic simulation (Liew, et al. 2004). These models are excellent devices for patient education and teaching facial contours and surface qualities but lack anisotropy and only allow uniform movement, which is not a feature of the living face. A further drawback is that this model can only be manufactured by skilled professionals, such as medical prosthetists, and thus will have higher cost implications.

Synthetic models – double layer silicone face

The silicone face created by Powell, *et al.* (2019) has been developed using a two layer silicone model of different grades to represent the skin and subcutaneous fat and placed on a 3D printed base as a support. The model, although life-like and multilayered, again does not have the property of anisotropy built into it.

We have not directly used all of the above models but base our opinions on the qualities tested and presented by the manufacturing teams and researchers. There is no doubt that the appeal of biological tissue models is the *feel* of handling real tissue with all its complexity and whilst synthetic models can simulate the shape of the face well, they lack the quality of facial anisotropy.

1.3 Development of the *Surgical Art Face*©

Surgical Art, originally a UK based organisation and now located on the Isle of Man, was conceived as a vehicle for change in surgical education, and a way to deliver a novel philosophy:

- To provide a multi-disciplinary approach to teaching anatomy, disease processes, and reconstructive concepts and surgery with the intention to provide the surgeon with a wider perspective, and therefore be equipped to deliver comprehensive solutions.
- To employ the creative training models used in these varied, often non-medical disciplines to develop its own relevant training models. This adaptation injects creativity into an otherwise rigid training system.
- The immersion of both the principles and practice of other disciplines. This has been trialed with success in the *Surgical Art* studio-laboratory (figure 8), which is a non-clinical environment to promote receptivity and innovation.

It is within the bounds of this philosophy that the concept of the *Surgical Art Face*© was conceived.

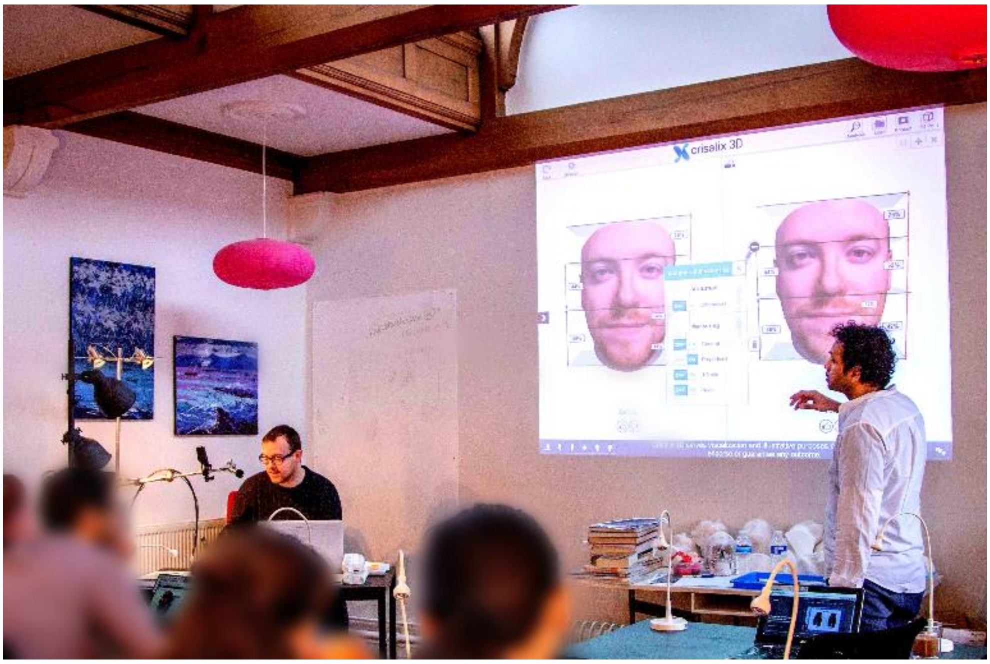

Figure 8: Mark Roughley and Partha Vaiude using a 3D facial scanner and digital manipulation software during a course in the *Surgical Art* studio-laboratory.

The face has been depicted differently by a variety of professionals namely the sculptor, the mask maker, the medical artist, the forensic facial anthropologist, the beautician and the surgeon.

> The **sculptor** understands artistic anatomy and sees the face as a combination of positive and negative spaces, contours and textures. They work to recreate the relationships between the different biological tissues that produce an overall appearance and imprint or express personality through often hard and rigid but malleable materials.

Fig 9: The sculptor - working in 3 dimensions has the freedom to explore each facial subunit with creativity as is seen with Athar Jabber's stone carvings (https://www.atharjaber.com/). The surgeon can be taught the effect of subtle changes in each subunit thus rendering a major change in the overall impression. Images courtesy of Athar Jabber.

The **mask maker** takes an impression of the face and creates a mask. They enhance facial contours in their designs to introduce a character, create an emotional affect, or to strengthen or soften the face. They use facial shaping, colour, pattern and texture to create an artistic, historical or theatrical depiction of a person.

Fig 10: The mask-maker's perception of the face. Note the similarities in this Venetian mask to facial subunits and surgical designs. The mask shown here is created by Angela and Victor of Schegge Art & Craft, Venice.

The **medical artist** might use their understanding of human anatomy to build models of faces for teaching and training purposes. As anatomists themselves or alongside anatomists, medical artists study the anatomical structures and rich network of vessels and nerves beneath the skin. They understand the interplay of the different structures and layers and how their complex relationships work in a functional face. Historically, wax moulages or ceroplastics were created by medical artists who demonstrated extraordinary craft skills to produce hyper-realistic models for educational purposes (Ballestriero, 2010). They possessed a clear understanding of the human anatomy often learned by observing dissections firsthand, and the models could be tailored to create bespoke models that showed the relationships between muscles and vessels, demonstrate the appearance of diseases on hard and soft tissues, and highlight the subtle differences in anatomical variation between individuals for example.

The **forensic facial anthropologist** interprets the face from inside out and builds the face of an individual from interpretations of skeletal human remains. They construct the face using wax, clay or 3D software from replicas or 3D scans of the skull. Following an assessment of the skull morphology the muscles, fat, skin and facial features are modelled using established scientific methods. The forensic facial anthropologist applies knowledge of anatomy and morphology determination to accurately reconstruct faces of the dead for presentation to public audiences (Wilkinson, 2010). These depictions are primarily used for forensic identification purposes or to bring us closer to historical figures from our past.

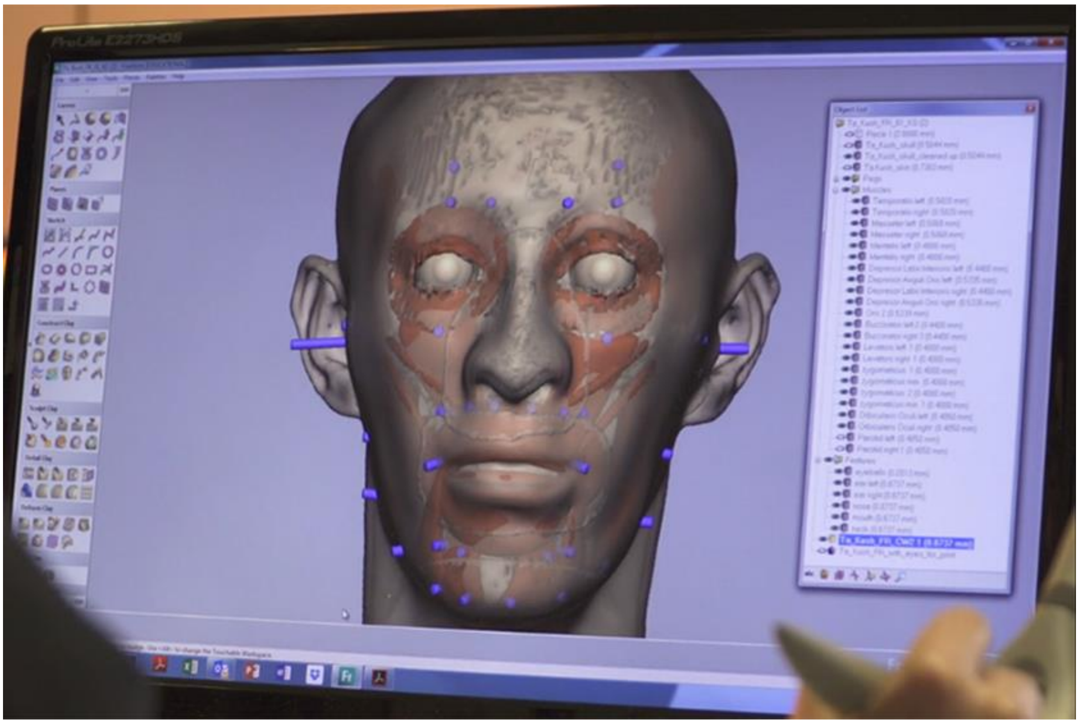

Fig 11: A forensic facial anthropologist reconstructing the face of an ancient Egyptian mummy using the 3D software 'Geomagic Freeform' and a haptic interface device. Image courtesy of Face Lab at Liverpool John Moores University.

The **surgeon** negotiates the different layers of the face, respecting form and protecting function, retaining vascularity and nerve supply. They move parts of the face, often to replace missing or diseased segments, with healthy and carefully chosen local or distant components. The surgeon sees the face from outside in, and in most operations the surgical approach is from skin to bone.

The **beautician**, more precisely the contouring expert, does not physically change shape but uses colour, highlights, shading and even texture to achieve similar albeit impermanent results. They use their understanding of the face to camouflage scars, enhance the quality of skin, increase or decrease volume and lift or move certain features.

Fig 12: Beautician teaching contouring during a *Surgical Art* course - using highlights and shadows to adjust the appearance of facial contours and volume.

These professionals approach the face from different perspectives, however, multiple components of their practice overlap. This cross-disciplinary overlap can foster novel multi-disciplinary collaborations where professionals can learn from each other and innovation flourishes. Multi-disciplinary collaborations often arise in reflexive spaces, such as the *Surgical Art* studio-laboratory, where there are opportunities to "*understand, critique and evolve the dominant discourses of the parent disciplines*" by bringing together different but potentially similar disciplinary practices to tackle challenges (Marshall and Bleecker, 2010). In doing this, there are also un-disciplinary opportunities to understand or experience new or different ways of working with ideas, processes or materials. This might require re-learning ways of thinking and doing or the creation of new vocabularies but the outcomes often benefit all involved. We have adopted this multi-disciplinary, cross-pollination approach to enhance the training programmes at *Surgical Art.*

In comparing and evaluating the practices of these varying disciplines and their approaches to the face, we recognise the incredible complexity of the living human face, which is impossible to recreate fully as an affordable and accessible simulation model. In designing the *Surgical Art Face*© it was decided that it was critical to first tease out the individual components of reconstructive surgical training requirements, and then to identify the most effective available models to address these training needs. The *Surgical Art Face*© needed to:

- simulate contours of the face
- simulate anisotropic properties of the face
- be able to be drawn on and wiped off for multiple uses
- be cut, reshaped and sutured
- be cost and time efficient to produce
- be made without technical or artistic skills
- be mounted for ease of use

The *Surgical Art Face*© model has moved through a number of different iterations with input at each stage from sculptors, medical artists, forensic facial anthropologists and surgeons.

Surgical Art Face© Version 1

Initially a silicone-only face was produced using different grades of widely available silicone. These cost-effective silicones were cast using a face mould. Different thicknesses of silicone were used to create varying levels of pliability and anisotropy in the face. The silicone thickness did not mirror that of the skin in different subunits of the face but was based on facial pliability. The resulting face had excellent contours but lacked adequate anisotropy and the capacity to be sutured effectively, with sutures often tearing through the silicone layers. This model was considered inadequate for comprehensive training.

Surgical Art Face© Version 2

In version 2 the addition of fabric to the silicone to enhance the anisotropic properties of the model was explored. Several fabrics were identified that displayed different degrees of anisotropy, with different capacities of adhering to silicone. A second experimental model was developed using small pieces of anisotropic fabrics embedded on to one side of the silicone face, which worked with varying levels of success. The fabric undoubtedly enhanced the anisotropy of the silicone ‘skin’ but the major drawback of this approach was the tendency of the fabric to peel away from the silicone when handled and sutured.

Surgical Art Face© Version 3

The issue of fabric extrusion was resolved with the application of silicone from both sides of the silicone skin in the third iteration of the model. Silicone was used as in version 1 but with varied thickness to further enhance anisotropy. The face moved better but the different fabric components felt 'detached'.

Surgical Art Face© Version 4

Taking this into account, version 4 incorporated a complete fabric sheet that was the same size as the face with silicone on both sides, with silicone thickness selected from the development of versions 1 and 3. This was effective and was further enhanced by pre-tensioning the fabric before it was embedded. This concept was adapted from the *Surgical Art Z-Plasty Simulation Model* ©, which uses pre-tensioned anisotropic fabric embedded in silicone on an embroidery ring to simulate a tight scar. This is then released using a technique called Z-Plasty.

Version 4 of the *Surgical Art Face*© (figure 13) is the model currently used for training reconstructive surgeons.

Figure 13: Inspecting a completed *Surgical Art Face*© before its use in training (left). The *Surgical Art Face*©, after been used for different drawing and surgical exercises (right).

1.4 Facial surgery simulation using the *Surgical Art Face*© in multi-disciplinary settings

Training surgeons to assimilate generic concepts and techniques is possible with simulation models. However, this does not allow for individuality both in terms of the patient's anatomy or condition but also the surgeon's preferences. Every patient presents with individual facial characteristics and clinical problems that are unique to them. These need to be analysed carefully and a bespoke surgical design devised for that person. For the most part, this can be achieved by studying the face at rest and with directed or palpated movement.

Every surgeon has their own interpretation of a patient's face and knowledge of how they will tackle the reconstructive challenge, and therefore will approach it differently. In training, these two components can only be explored with a real patient and not with a model. We acknowledge the limitations of the *Surgical Art Face*© but also its strengths and have developed a system to use the *Surgical Art Face*© in combination with other activities such as anatomical wax modelling of facial musculature and drawing on the faces of human participants during *Surgical Art* training sessions. In these multi-disciplinary sessions, participants might:

1. Build a wax anatomical model using a cast of a human skull, guided by a forensic facial anthropologist and/or medical artist
2. Simulate sculpting of facial topography and understand facial lines and subunits in conjunction with the wax models, living faces, colour mapping exercises and the *Surgical Art Face*©
3. Simulate clinical scenarios by overlaying the *Surgical Art Face*© on top of the wax models
4. Simulate skin laxity, affordability and tether points through interactions with living faces and editing of the *Surgical Art Face*©
5. Engage in contouring exercises with living faces through the application of makeup guided by a beautician
6. Simulate local flap design and surgery using *Surgical Art's* biological chicken models
7. Simulate facial local flaps using the *Surgical Art Face*©
8. Explore creativity in facial reconstruction design and surgery using the *Surgical Art Face*©

Surgical Art training sessions take place in non-clinical, studio-laboratory settings and in the following sections we detail a number of activities that occur during a number of different training sessions.

Using the *Surgical Art Face*© to understand facial anatomy and topography - 'understanding the terrain'

This training activity involves the analysis of skeletal morphology and the sculpting of wax muscles onto a plaster cast of a skull, with the aim that the muscles morphologically fit the skull. Established methods used by anatomical and forensic facial reconstruction practitioners are followed. For *Surgical Art* courses we follow the Manchester Method of forensic facial reconstruction devised by Richard Neave and Caroline Wilkinson (Wilkinson, 2010) that builds the face from skull to skin, and the Superficial Musculoaponeurotic System (SMAS) that focuses on the watershed layer of anatomical structures that defines tissue planes and generates facial expression. The fat, vessels, nerves and facial ligaments are also sculpted; acting as a revision exercise before the *Surgical Art Face*© is draped on top. This system uses the *Surgical Art Face*© in a collaborative manner for surface anatomy and enables discursive understanding points of subcutaneous tethering between skin and muscle with retaining ligaments. The objective of the exercise is to learn the clinical anatomy and contour of the face through the 'assembly' of the face from skull to skin.

Figure 14: Learning anatomy by building a face on a plaster cast of a human skull; layer by layer using modelling wax (left). The *Surgical Art Face* © mounted on the wax face to perform exercises (right).

Using the *Surgical Art Face*© to learn the lines of the face – 'understanding road maps'

A living human volunteer is used to demonstrate facial lines (RSTLs) through drawing exercises on their face. RSTLs are not visible at rest in a youthful face but can be seen as the face ages, and these are referred to as static rhytids. These facial lines can be enhanced in all faces with active movement, for example, by asking the volunteer to smile, frown etc. and are referred to as dynamic rhytids. They can also be produced by passive movement, for example, the surgeon manipulates the skin to elicit facial skin creasing as described by Borges (1984). Hair patterns and previous scars are also important factors to consider in this analytical process. The lines define the *facial grid* which we describe as the '*roadmap for surgery*'. Every face is slightly different and this variation is best appreciated on a human subject. However once these lines are drawn on the subject they are then transposed onto the *Surgical Art Face*© to practice the grid pattern. The objective of the exercise is to learn the lines of the face with individual variations.

Figure 15: Facial lines drawn on a human subject (left) to identify and map individual variation before this understanding is applied to the *Surgical Art Face*© (right).

Using the *Surgical Art Face*© to understand facial units and subunits – 'understanding town planning'

Once the *Surgical Art Face*© has RSTLs depicted (as seen in figure 15) it has the overall road map of the face. However, the face is not a uniform structure, both in form or function. The face is divided into units and subunits from both an artistic and a surgical perspective (figure 4). The understanding of the different units and subunits is important to help plan reconstructions that are contained within subunits, so as not to cause functional or aesthetic asymmetry. The subunits often have a specific component either as major facial sensory organs or other anatomically discreet functions. The objective of this exercise is to learn the different facial units and subunits, and to understand the boundaries or borders that should be respected when reconstructing.

Figure 16: Facial lines and subunits explored using colour exercises and beads on the wax face (left) before this knowledge is applied to the *Surgical Art Face*© (right).

Using the *Surgical Art Face*© to learn surgical facial reconstruction – 'mapping the journey'

Once the trainee has grasped the concepts of direct closure, skin grafts and local flaps by using basic models like sponge, pig skin and chicken skin models, they can apply learned concepts to the *Surgical Art Face*©. The trainee will explore each facial unit/subunit and the suitable reconstructive options such as local flaps that can be used without aesthetically or functionally distorting other facial units.

This session starts with approaching each sub-unit individually, working first within the sub-unit and then exploring the challenge of bridging over into another sub-unit. It is important for the trainee to understand the dynamics of the site being reconstructed and how this may differ greatly a few millimeters away in one direction, generating a different reconstructive design which maybe entirely different in the opposite direction.

The three primary local flap movements or their secondary variations can then be used creatively based on the type of movement desired and the effects, be them major or minor, on the surrounding tissue. This process starts by drawing defects on the *Surgical Art Face*© at sites of typical reconstructive solutions. At this point the trainee assesses the distribution of tension that the flap will exert on the surrounding tissue, especially on functional or aesthetic landmark areas, to assess the potential distortion and the functional or aesthetic issues that arise from this distortion. An element of initial distortion is accepted in certain areas to allow tissue stretch and scar modulation, which completely or partially neutralises the effect. This is an important part of the training programme where faculty can use both the mask and volunteers to demonstrate the effects of different tissue movements in different sub-units, producing varied results.

The trainees then cut out the disease (defect) on the *Surgical Art Face*© and apply the concepts taught to design the reconstruction which is then performed by raising the flap segment and moving it into the area of disease/defect. Once positioned at its final site the tension of the flap is assessed and the order of the flap inset is then practiced. This order usually starts with closure of the donor site or, in certain flaps, anchoring the point of maximum tension to a less mobile point to help hold the flap in place. The flap is then fully inset.

The next step of the training is creative design in bespoke terrain, where human volunteers are used and tissue defects are drawn on their faces using skin pencils in different sub-units or bridging two sub-units. First, they are drawn at the site of typical reconstructions, followed by more complex sub-unit junctions or functional and cosmetic junctions. The trainee starts by mapping the face as described in section 1.4 before analysing each tissue defect and its site in a bespoke manner. Different flap options are explored, their pros and cons discussed, and a final reconstructive design drawn on the volunteer’s face. As these tissue defect sites are randomly chosen for each volunteer, a large number of potential variations in tissue defects both in terms of size, shape and location are explored and every trainee presents their reconstructive solutions to the group.

Figure 17: Using the *Surgical Art Face* © to learn facial reconstruction after foundation exercises are completed

Figure 18: Using the *Surgical Art Face* © to learn facial reconstruction after foundation exercises are completed.

1.6 Conclusion

The innovative *Surgical Art Face*© version 4 is the product of collaborative engagements and teaching approaches, using inputs from surgeons, sculptors, medical artists and facial anthropologists, plus experts from a number of other disciplines. It is a cost-effective training model that does not need specialist expertise to produce. The model allows trainees to understand the face and its relevant components both technically and artistically. It recreates in 3D the topography of the face, both for demonstrations and practice, and is highly effective in the training of facial anatomy, facial topography, RSTLs and facial units/subunits to build an understanding of facial roadmaps for surgical planning. Finally, it can be 'operated' upon to deliver haptic training for a surgeon.

The *Surgical Art Face*© plays a critical role in almost every step of the *Surgical Art* training program and is highly regarded by trainees and faculty alike. More than 500 *Surgical Art Faces*© have been made and used in surgical training to date of this publication with overwhelmingly positive feedback. It is a user friendly and multi-functional device that is envisaged to play a significant role in medical education. It can also be used for patient education to describe scars from simple to complex reconstructions and has been used successfully in public engagement events.

Whilst the *Surgical Art Face*© has been used effectively in training scenarios it has its limitations. These are aesthetic, functional and cost related. Currently the training models are time-consuming to produce and there is a lack of refinement and difficulty in maintaining standardization, which effects more sensitive facial sub-units like the peri-orbital and nasal regions. Our vision is to use the principles set out in this chapter to further enhance the *Surgical Art Face*© through collaboration and technological transformation. We will continue to engage with mask makers, sculptors, beauticians and forensic anthropologists to develop a 3D digital construct that can be 3D printed. Through a research exercise and innovation process we will evaluate the current *Surgical Art Face*© through self-evaluation and evaluation of feedback obtained from trainees to further develop a more functional and aesthetically appropriate training model. Version 5 of the *Surgical Art Face*© will be constructed using a combination of 3D face scanning, complex 3D modelling to embed facial anisotropy capabilities directly between layers that make up the face model, and 3D printing of the final model as one or more piece(s). The overall aim is for 3D printed face models to be printed en-masse but also more easily customized to present anatomical variations between models. Whilst this research and development process is undertaken the *Surgical Art Face*© version 4 will continue to work harmoniously in tandem with other training models, and the greatest model of them all - the living human face.

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