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A Two-Stage Training Program for Auricular Framework Fabrication Practicing Using Three-Dimensional Printing Silicone Ribs and Porcine Costal Cartilage

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Background: The manufacture of cartilage framework is a key element in the success of total ear reconstruction. Appropriate training can improve cartilage curving and fabricating skills, which is especially helpful for the novice clinicians. Based on threedimensional printing silicone model and porcine rib cartilage, the authors have designed a 2-stage training program to improve skills and cosmetic cognition for ear reconstruction.

Methods: The training program includes 2 successive stages. In the first stage, trainees completed observation of framework fabrication, design and sculpturing practice on silicone rib models. Porcine costal cartilages are used for fabrication in the second stage. After that, the framework was put in a latex glove connected with a suction to simulate the skin cover procedure in operation.

Results: At the end of the training program, all trainees could fabricate an ear-shaped cartilage framework successfully. Their cosmetic cognitions of the ear have also improved.

Conclusions: Based on three-dimensional printing silicone model and porcine rib cartilage, the authors have designed a 2-stage training program to improve trainee's carving techniques and cosmetic cognition for ear reconstruction. The authors believe that this training program is helpful in training, practicing and teaching activities of framework fabrication in total ear reconstruction.

Key Words: Porcine costal cartilage, surgical training models, three-dimensional printing silicone model, total ear reconstruction

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The manufacture of a cartilage framework is a key element in the success of total ear reconstruction. It requires high level of manual dexterity and artistic technique when carving the harvested costal cartilage.[1] Because of the long and steep learning curve, result of the surgery is always a single choice either "success" or "failure."[2] Although the cognition at structure and aesthetics of human ear could be improved by observation or sketch, the fabrication of cartilage framework still needs repetitive practice and enough experience.[3]Therefore, it is critical to find a reliable model for repetitive practice and experience accumulation. Based on three-dimensional (3D) printing silicone model and porcine rib cartilage, we have designed a 2-stage training program to improve trainee's carving techniques and cosmetic cognition for ear reconstruction.

MATERIALS AND METHODS

The First Stage

Trainees observe the cartilage harvesting, carving and sculping procedures under an expert's supervision in the operation room. Then, every trainee gets a template which was made from transparent film that matched anatomy of a volunteer's ear and 3D printing silicone models matched the geometries of adult rib cartilages. The trainees are asked to put the template on the silicone models to practice different designs. After that, they use the silicone ribs to practice framework fabrication (Fig. 1).

The Second Stage

Several porcine rib cartilages were purchased from the legal market and distributed to each trainee. Trainees use the porcine rib cartilages to fabricate framework and then put the framework in a latex glove, which connected with a suction to simulate the situation that skin over the framework in a real operation (Fig. 2C).

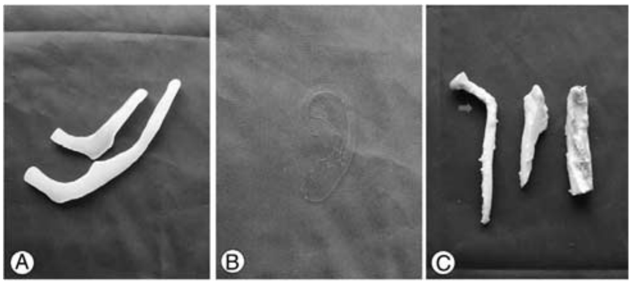

FIGURE 1. (A) The three-dimensional printing silicone costal cartilages. (B) The template made from transparent film. (C) Porcine costal cartilages are straight in most part. The arrow indicates the bend near the bone-cartilage junction.

RESULTS

From September 2018 to December 2020, 13 trainees have been included in this program. All trainees had given this training program positive feedbacks, including recognition of ear aesthetics, cartilage carving skills, and the necessity of this training (as shown in Supplementary Digital Content, Table 1, http://links.lww.com/SCS/D905).

At the end of the first stage, all trainees were familiar with the principles of framework fabrication. In addition to this, they have also mastered the procedures of carving and sculpturing the silicone rib, which lay a ground work for further practice on cartilage. In the second stage, trainees could directly feel not only the consistency and flexibility of costal cartilage, but also the tactile of carving and fabricating on real cartilage. Moreover, with the cover of latex glove in a vacuum situation, the details of framework could be clearer because of the contrast of light intensity. At the end of program, the participants were able to successfully carve a much better cartilage framework (Fig. 2A-B).

DISCUSSION

The first mention plastic surgery of the ears documented in The Edwin Smith surgical papyrus at 3000 BC. And the earliest record about reconstruction of partially or totally amputated auricle arise from the Sushruta Samhita, which involved fifteen methods in the 5th century BC. In 1838, Eduard Zeis stated the 2 primary challenges in reconstruction of auricle: supporting frame and effective skin coverage.[4] After that, plenty materials had been used as the supporting frame such as petroleum jelly, autologous bones, nasoseptal cartilage, allogenic auricular cartilage, ivory, and maternal auricular cartilage.[4] In the early 20th century, Schmieden reported the first case of framework produced by autologous costochondral cartilage. Tanzer[5] is considered as 1 of the modern pioneers of ear reconstruction. He reported a 6-stage ear reconstruction procedure based on autologous costochondral grafts in 1959. After that, most materials used for framework had been obsoleted, the main materials used were autologous costal cartilage, polyethylene and silicone in the post-1980s era. In 1991, Dr. Brent[6] published his reconstructive approach with autologous costal cartilage. This method was widely used and modified. Refined from Tanzer and Brent's methods, Nagata, Firmin and other luminaries further improved the technique by modifying the process and the method of cartilage sculpture.[7-9] In the meanwhile, the refined tissue expanding method was widely used by Dr. Zhuang in China.[10] In 1997, Cao et al[11] published a report that they have constructed a bovine chondrocyte derived ear-shaped cartilage on the back of mouse by tissue engineering approach. In 2018, Jiang's group[12] reported the first clinical application of tissue engineered framework, which was shaped in a laboratory instead of manual works by surgeons in operation room. This tissue engineering product would be a promising future in this field. However, as lack of large similar cases, autogenous costal cartilage is currently the most widespread used material for ear reconstruction. Thus, the sculpture of cartilage is still the pivotal process in this surgery.

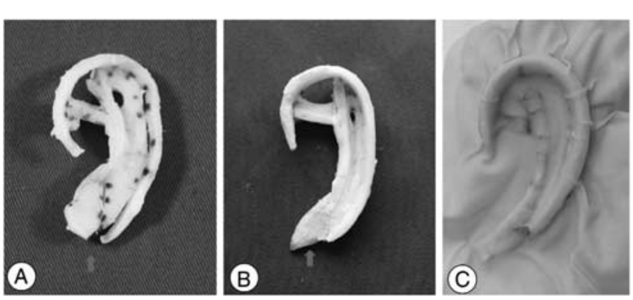

FIGURE 2. (A) The cartilage framework fabricated by 1 of the trainees at the beginning of second stage. (B) The cartilage framework fabricated by the same trainee after the training program. (C) The cartilage framework contained by a latex glove connected with a suction, which could exhibit more details of the framework.

The outcomes of total auricular reconstruction are highly dependent on the framework, which was manually fabricated by the surgeon. A surgeon should feel comfortable with the fabrication procedure before embarking on real cases. However, the long learn curve could well be at the expense of the patients.[13] By reasons of foregoing, it is very important to develop models to facilitate the teaching and training of framework fabrication.

An array of materials has been sought in an attempt to emulate the costal cartilage (as shown in Supplementary Digital Content, Table 2, http://links.lww.com/SCS/D905). Brent practiced carving and sculpturing procedures on potatoes and carrots, but these vegetables are hard to curve and lack of elasticity[14]; Cadaver cartilage can reflect the anatomy of real costal cartilage, but it is often calcified and the resources are limited. Synthetic material models, such as polylactic acid, polyvinyl chloride, and acrylic polyurethane, are often low cost and easily available.[15-17] However, there are still some limitations hinder their widespread applications, such as hard to fabrication, low elasticity, and hard to simulate the geometries of costal cartilage.[18] There is a commercially model (Medicon, Tuttlingen, Germany) which is based on adult rib, but it is too costly to repetitive practice. Silicone models have good elasticity and faithful texture.[18] With 3D printing technology, the shape of human costal cartilage can be easily simulated.[19] However, carving on silicone is not such convenience, and the tactile are far from the real cases.[20]

In our department, we have designed a 2-stage program, which includes 3D printing silicone models and porcine rib cartilages. Objectives in the first stage are very clear which include familiarity of different design, improving cognition of auricular subunits and principles of framework fabrication. Because of the different texture between silicone and cartilage, further training is still needed for the trainees even they can construct a framework smoothly with the silicone ribs. The feedbacks from the trainees had proved the necessity of further training in the pork costal cartilages. All of them thought the carving tactile was different between silicon and cartilage, and refused to use silicone substitution instead of real cartilage (as shown in Supplementary Digital Content, Table 1, http://links.lww.com/SCS/D905).

We use porcine rib cartilage as training model in the second stage. The movement of scalpel and suture needle in porcine cartilage is nearly as same as human cartilage. This would decrease the risk induced by different tactile between training models and human costal cartilage. Moreover, all frameworks will be judged with the cover of latex glove in a vacuum situation. This could reflect more details of framework and help trainees to improve their skills (Fig. 2C).

Some Indian clinicians use bovine scapular cartilage as training material for ear reconstruction.[21] They considered the porcine costal cartilages are curved and short, and the conjoint area is limited for designing the base of the framework. However, in our opinion, most part of the porcine costal cartilage is straight. There is just 1 obvious bend near the bone-cartilage junction (Fig. 1C). In addition to this, we usually use single cartilage to form the base of framework, instead of the conjoint area mentioned by Indian doctors. Thus this "limited area" would not trouble us. However, there are still some limitations of porcine rib cartilage model. First, this model cannot be used in regions with special religious faith; Second, contrary to the smooth arc on human costal cartilage, the bend angle on porcine rib cartilage is too sharp, so we have to abandon this part in our practice. Thus, the original cartilage we used was too straight for the base of framework. So, we always need to suture another piece of cartilage on the framework for better shape (Fig. 2A-B); The last, human costal cartilages are flatter, porcine rib cartilages are rounder and thicker which may need to be thinned before use.

Reconstructed concha provide support for the top framework, which could make the auricranial angle of reconstructed ear close to or equal to the normal ear. In real cases, we use cartilage leftovers to fabricate concha. In simple terms, leftovers in the carving procedure were carved into strips. Then, these strips were overlay and fixed under the scapha and antihelix with wires. However, we have not included concha reconstruction in our training. On the 1 hand, concha reconstruction would be easy if trainees could finish a framework skillfully. On the other hand, we use nylon sutures in the fabrication procedures instead of steel or titanium wire to low the cost. Nylon sutures cannot provide enough strength for concha reconstruction. In addition to this, more cartilage could be saved for replicated practice if the concha reconstruction procedures were omitted.

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