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True-Color Face Peeled Images with Botulinum Toxin Injection Sites and Anatomic Landmarks

Imágenes de Color Verdadero de Rostros Sin Piel con Puntos de Inyección de Toxina Botulínica y Puntos de Referencia Anatómicos

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SUMMARY: To allow students and surgeons to learn the sites for botulinum toxin injection, new types of educational images are needed because MRI, CT, and sectioned images are inadequate. This article describes browsing software that displays face peeled images that allow layers along the curved surface of the face to be peeled gradually in even depths across the surface. Two volume models of the head were reconstructed from sectioned images and segmented images of Visible Korean, respectively. These volume models were peeled serially at a thickness of 0.2 mm along the curved surface of the facial skin to construct the peeled images and peeled segmented images. All of the peeled images were marked with botulinum toxin injection sites, facial creases and wrinkles, and fat compartments. All peeled images and the text information were entered into browsing software. The browsing software shows 12 botulinum toxin injection sites on all peeled images of the anterior and lateral views. Further, the software shows 23 anatomic landmarks, 13 facial creases and wrinkles, and 7 face fat compartments. When a user points at any structure on the peeled images, the name of the structure appears. Our software featuring the peeled images will be particularly effective for helping medical students to quickly and easily learn the accurate facial anatomy for botulinum toxin injection sites. It will also be useful for explaining plastic surgery procedures to patients and studying the anatomic structure of the human face.

KEY WORDS: Face; Anatomy; Plastic surgery; Botulinum toxins; Visible Human Project.

INTRODUCTION

In most books and articles on botulinum toxin injection for plastic surgery, the injection sites for the facial muscles, vessels, nerves, and superficial musculoaponeurotic system (SMAS) are annotated on computed tomography (CT), magnetic resonance imaging (MRI), face dissected photographs, or illustrations (Carruthers *et al*., 2004; Cotofana *et al*., 2015; Khan & Bagheri, 2014; Kim *et al*., 2016; Trévidic *et al*., 2015). To inform botulinum toxin injection, anatomists and practitioners created three-dimensional (3D) models from the sectioned images from Visible Korean that show injection sites for botulinum neurotoxin and dermal filler on facial structures in 3D (Shin *et al*., 2018a,b).

However, it is very difficult to show spatial relationships of the sites and facial anatomy in the layers along the curved surface of the face, from the skin to the cranium, with books, articles, and 3D models. Further, 3D models do not show all of the structures around the injection sites because these models can show the reconstructed structures. With cadaver dissection, it is also very difficult to show the gradual peeling of the facial layers along the curved surface of the face. In addition, facial illustrations are not realistic.

To address these problems, we created peeled images that show the layers of the curved surface of the face, from

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the skin to the cranium (Kwon *et al*., 2016). However, peeled images alone are not sufficient to allow medical students to learn facial anatomy and obtain clinical knowledge. Therefore, to show the facial anatomy for botulinum toxin injection, it is necessary to mark anatomic and clinical information on the peeled images.

The aim of this study was to create browsing software that presents the peeled images to show the facial structures and botulinum toxin injection sites on the curved surface of the face in detail, with the name of each structure displayed. This software will help students to learn facial anatomy for application in plastic surgery. To achieve this goal, we used peeled images of the head (Kwon *et al*., 2016), instead of CT, MRI, or cross-sectional images of a cadaver (Park *et al*., 2009), and marked the anatomic landmarks and botulinum toxin injection sites on the peeled images.

MATERIAL AND METHOD

From horizontal sectioned images of a cadaver head (interval, 0.1 mm; pixel size, 0.1 mm; color depth, 48 bits color) obtained in a previous study (Park *et al*., 2009), a volume model was made with a voxel size of $0.2 \times 0.2 \times 0.2$ mm. The volume model was peeled serially at 0.2-mm thickness along the curved surface of the facial skin, according to Pedro's technique (Felzenszwalb & Huttenlocher, 2012), to make peeled images of the anterior view (0°) from the skin to the cranium. After the volume model was rotated at every 30° interval from 30° to 330°, the volume model of each angle was again peeled serially to make peeled images at 30° to 330° views (interval, 0.2 mm; pixel size, 0.2 mm; Fig. 1) (Kwon *et al*., 2016).

The 63 structures in the horizontal sectioned images were selected (Table I). In the images, the boundaries of each structure were outlined semi-automatically with the Magnetic Lasso tool in Adobe Photoshop CC (Adobe Systems, Inc., San Jose, CA, USA). Outlines of each structure were filled with solid colors and saved in BMP format with Photoshop to make horizontal segmented images (interval, 1.0 mm; pixel size, 0.1 mm; color depth, 8 bits color). As with the peeled images, the volume model of the horizontal segmented images was made and peeled serially to create the peeled segmented images from 30° to 330° views (interval, 1.0 mm; pixel size, 0.2 mm; color depth, 8 bits color). In addition, in the peeled segmented images, the outlines of each segmented structure were extracted automatically using Photoshop. The outlines were merged with the peeled images and saved to produce the peeled outlined images.

For the 0 mm, -3.8 mm, and -8.4 mm peeled images at 0° (anterior view) and 60° (lateral view), 23 anatomic landmarks were marked, and for the 0 mm and -2.8 mm peeled images at 0°, 13 facial creases and wrinkles and 7 face fat compartments were marked, respectively, with PowerPoint 2010, version 14 (Microsoft Corp., Redmond, WA, USA).

For the 0 mm to -6.0 mm peeled images at 0° (31 images, anterior view), 10 botulinum toxin injection sites with an injection unit (U) were marked on PowerPoint slides by anatomists and plastic surgeons, who referred to relevant books and articles (Khan & Bagheri; Cotofana *et al*.; Mohammadi *et al*., 2015; Trévidic *et al*.; Kim *et al*.). In the same manner, for the 0 mm to -6.0 mm peeled outlined images at 0° (31 images), 10 botulinum toxin injection sites were marked on the PowerPoint slide.

Similarly, for the 0 mm to -6.0 mm peeled images at 60° (31 images, lateral view) and the 0 mm to -6.0 mm peeled outlined images at 60° (31 images, lateral view), 12 botulinum toxin injection sites with U were marked on PowerPoint slides.

In the previous study, we used the C++ language for the browsing software to allow images to be displayed serially (Kwon *et al*., 2017). In this study, five group radio buttons were displayed at the bottom of the screen: "Landmarks," "Sectioned (Anterior)," "Outlined (Anterior)," "Sectioned (Lateral)," and "Outlined (Lateral)." The five buttons were connected with five groups of images: peeled images with anatomic landmarks, creases and wrinkles, and fat compartments; peeled images at 0°; peeled outlined images at 0°; peeled images at 60°; and peeled outlined images at 60°.

RESULTS

When the browsing software is initially run, anatomic landmarks are shown on 0 mm peeled images of the anterior view (Fig. 2A). The scroll bar, radio buttons, and up and down arrows on the keyboard on the left side of the screen are used to peel and pile the images serially from 0 mm to -6.0 mm at 0.2-mm intervals. Users can select and observe one of the five groups by clicking the radio buttons and the left and right arrows of the keyboard on the bottom of the screen (Figs. 2 and 3). Pushing or pulling the mouse wheel magnifies or demagnifies the image, respectively (Figs. 3C, F). Further, placing the mouse over an image reveals the names of 63 structures, which appear in pop-up windows. The 12 botulinum toxin injection sites are visible in all of the images (Figs. 2 and 3).

Table I. 63 segmented structures shown on segmented peeled images.

System	Structures
Integumentary (1)	Skin
Skeletal (13)	Parietal bone, frontal bone, occipital bone, sphenoid bone (posterior clinoid process, anterior clinoid process), temporal bone, ethmoid bone, lacrimal bone, nasal bone, maxilla, zygomatic bone, mandible
Muscular (21)	Levator palpebrae superioris, orbicularis oculi, superior tarsal muscle, procerus, nasalis, orbicularis oculi, corrugator supercilii, orbicularis oris, depressor anguli oris, risorius, zygomaticus major, zygomaticus minor, levator labii superioris, depressor labii inferioris, levator anguli oris, buccinator, mentalis, temporal muscle, buccinator muscle, medial pterygoid muscle, lateral pterygoid muscle
Vascular (2)	Angular artery, angular vein
Nervous (14)	Optic nerve, oculomotor nerve, superior branch of the oculomotor nerve, inferior branch of the oculomotor nerve, trochlear nerve, trigeminal nerve, ophthalmic nerve (lacrimal nerve, supraorbital nerve, frontal nerve, nasociliary nerve), maxillary nerve, abducens nerve, facial nerve
Sensory (12)	Sclera, cornea, common tendinous ring, trochlea, medial palpebral ligament, lateral palpebral ligament, superior tarsus, inferior tarsus, lacrimal gland, lacrimal canaliculus, lacrimal sac, nasolacrimal duct

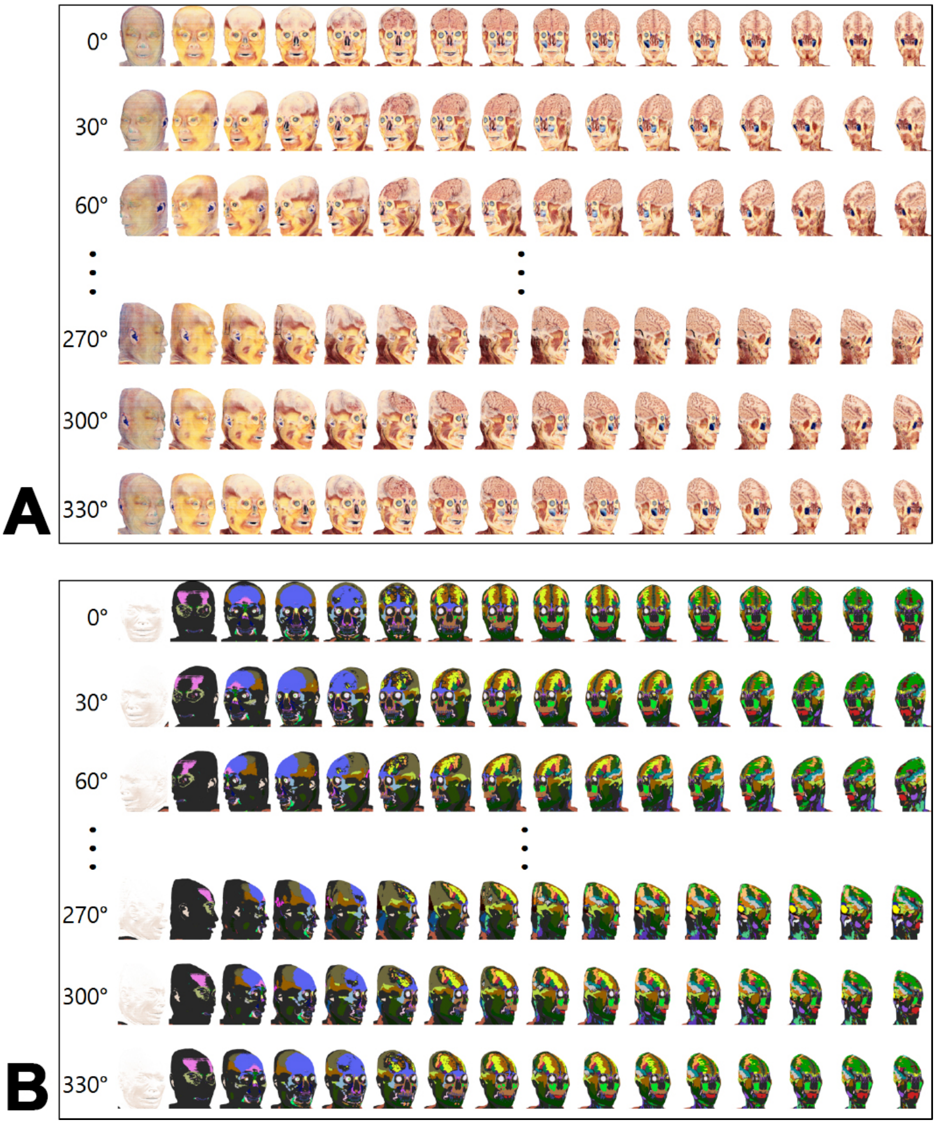
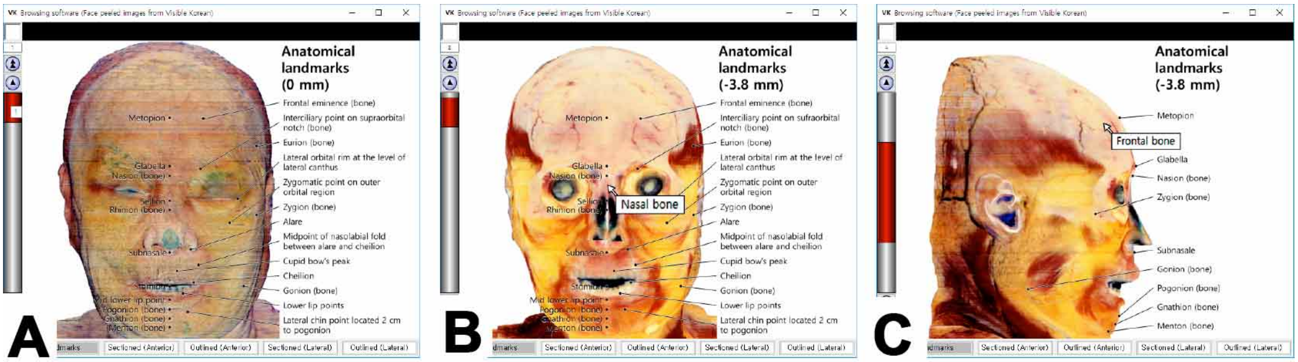


Fig. 1. Face peeled images (A) and peeled segmented images (B) of the full version, from skin to brain, at 0.2-mm intervals (left to right) and rotated peeled images from 0° to 330° obtained every 30° (top to bottom).



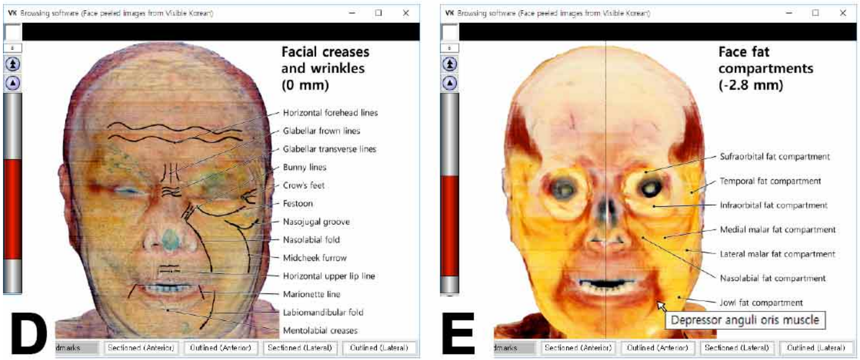


Fig. 2. Peeled images in the "Landmarks" group of the browsing software: 0 mm (A) and -3.8 mm (B) peeled images at the anterior view with an anatomic landmark; -3.8 mm (C) peeled image at the lateral view; 0 mm (D) peeled image with facial creases and wrinkles; and -2.8 (E) mm peeled image with face fat compartments.

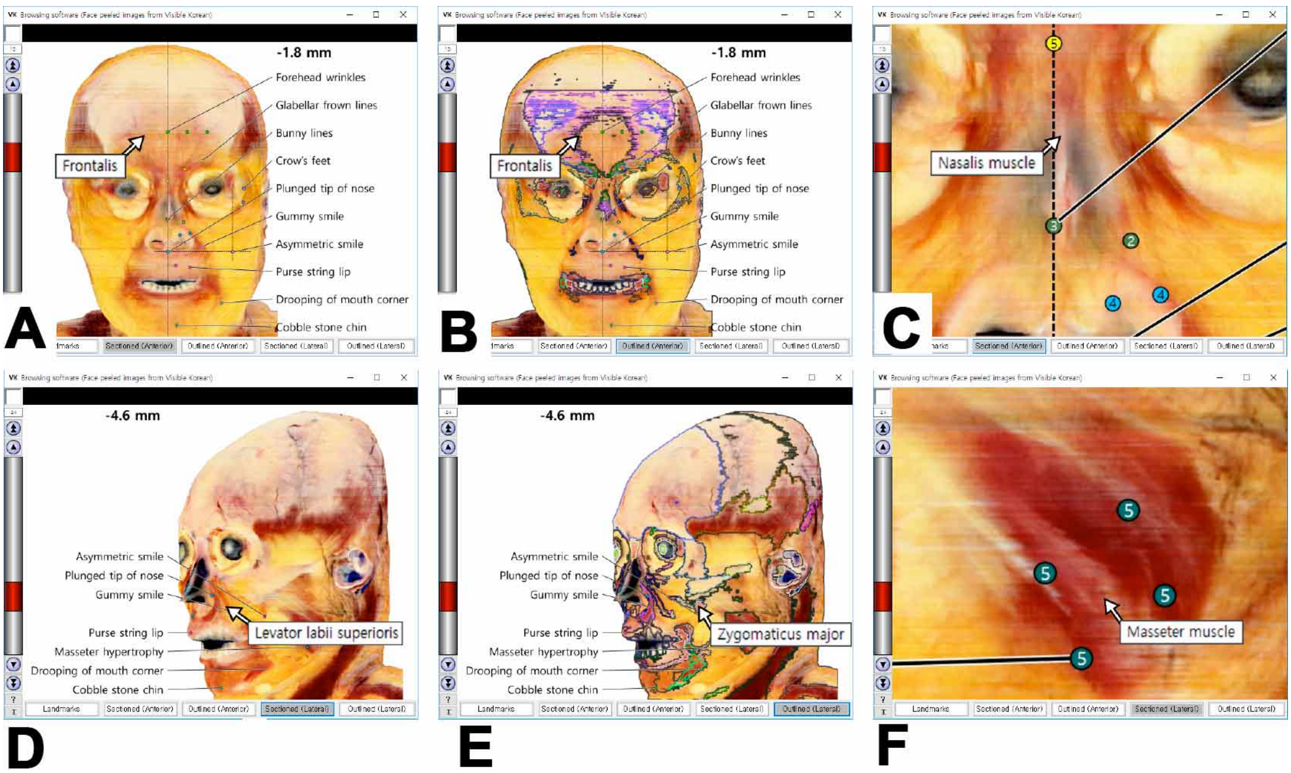


Fig. 3. Peeled images in another group of the browsing software showing peeled images (A, D), peeled outlined images (B, E), and magnified peeled images of the anterior view at -1.8 mm (top) and -4.6 mm (bottom) depth (C, F).

Clicking the "Landmarks" button in the browsing software displays 23 anatomic landmarks on peeled images in the anterior and lateral views. Clicking the "Sectioned (Anterior)" button allows serial browsing of peeled images of the anterior view from 0 mm to -6.0 mm. When the anterior view of the face is peeled continuously with the down scroll bar, down radio button, or down arrow (Fig. 3A), by clicking immediately on "Outlined (Anterior)," the peeled image can be changed to a peeled outlined image at identical depth (Fig. 3B). Clicking "Sectioned (Lateral)" or "Outlined (Lateral)" shows the peeled images in the lateral view. In addition, the images can be magnified and demagnified with the mouse pointed at their center (Figs. 3C, E).

The peeled images in the browsing software show the real shapes of structures on the layers along the curved surface of the face. The use of peeled outlined images shows the injection site of muscle accurately because the outlines of each structure display in the images. The peeled images in the browsing software display the botulinum toxin injection sites along with anatomic landmarks.

As shown in the anterior view of the "Landmarks" group, the metopion is the skin at the midpoint between the bilateral frontal eminences. The glabella is the skin between the eyebrows that is the prominent point in the frontal bone (Fig. 2A). The nasion is the suture between the frontal bone and two nasal bones, and its suture can be shown in the -3.8 mm peeled image (Fig. 2B). In the lateral view, the pogonion is the most anterior point on the mandible (Fig. 2C). The menton is the most inferior point of the chin. The gnathion is the midpoint between the pogonion and the menton. The zygion is the most lateral point on the zygomatic arch (Fig. 2A, B), and the gonion is the angle of the mandible (Fig. 2C). In addition, facial creases and wrinkles (Fig. 2D) and fat compartments (Fig. 2E) are shown in the images of the anterior view (Kim *et al*.; Radlanski & Wesker, 2012).

To smooth forehead wrinkles, botulinum toxin is injected at the medial side of the frontalis muscle to a depth of -2.8 mm and at the lateral side to a depth of -1.8 mm (Fig. 3A). To smooth glabellar frown lines, botulinum toxin is injected at the procerus muscle and the corrugator supercilii muscle, which are located with -2.0 mm peeled images (Fig. 3A). The toxin 2U and 3U are injected at the points on the skin of the corrugator supercilii muscle and the procerus muscle, which are located with 0 mm peeled images (Fig. 3A). A bunny line, which is caused by contraction of the nasalis muscle, is removed by toxin injection at the nasalis muscle to a depth of -1.8 mm (median of the nose) (Fig. 3C) and -2.4 mm (lateral side of the nose). For plunged tip of the nose, the depressor septi nasi muscle and the nasalis muscle are paralyzed by injection at the nose tip and the alar part of the nasalis muscles. To decrease a gummy smile, the levator labii superioris muscle is paralyzed by toxin injection to a depth of -4.6 mm (Fig. 3D). To correct an asymmetric smile, which is caused by abnormal motion of the zygomaticus major muscle, the toxin is injected in the lateral margin of the muscle to a depth of -4.6 mm (Fig. 3E). Although the orbicularis oris muscle is found at a depth of -4.6 mm (Fig. 3D), the toxin is injected shallowly to a depth of -3.0 mm to smooth a purse string lip. To a lift a drooping corner of the mouth, the depressor anguli oris muscle is attenuated with 3U toxin injection (Fig. 2E). To remove a cobblestone chin,

Table II. Thickness of the soft tissue, 12 injection sites, and encountered muscles of the different injection paths on anterior and left views

Region	Botulinum toxin injection site	Thickness of soft tissue for injection*	Muscles encountered
Upper face	Forehead wrinkles	19 cuts	Frontalis
	Glabellar frown lines	18 cuts	Corrugator supercillii, procerus
	Crow's feet	23 cuts	Orbicularis oculi
Middle face	Bunny line	22 cuts	Nasalis (transverse part)
	Plunged tip of the nose	11 cuts	Depressor septi nasi major, leavator labii superioris alaeque nasi
	Gummy smile	21 cuts	Levator labii superioris alaeque nasi, levator labii suprioris
	Asymmetric line	31 or more cuts	Zygomaticus major
	Nasolabial fold	31 or more cuts†	Levator labii superioris alaeque nasi, levator labii suprioris, zygomaticus minor, zygomaticus major
Lower face	Masseter hypertrophy	31 or more cuts	Masseter†
	Purse string lip	23 cuts	Orbicularis oris major
	Drooping of the corner of the mouth	31 or more cuts	Depressor anguli oris
	Cobblestone chin	31 or more cuts	Mentalis

*The thickness of a cut is 1.0 mm. †Only masseter hypertrophy can be shown in the lateral view (60°). All injection sites can be shown on both the anterior view (0°) and the lateral view (60°).

4U toxin is injected at the mentalis muscle. To remove crow's feet, 3U toxin is injected at the orbicularis oculi muscle to a depth of -2.2 mm. To revise a square jaw caused by Masseter hypertrophy, 5U toxin is injected deeply at four points on the masseter muscle (Fig. 3F) (Kim *et al*.; Radlanski & Wesker; Shin *et al*., 2018a,b; Trévidic *et al*.).

Browsing software can be used to learn facial gross anatomy. Five layers of the face (skin, subcutaneous tissue, musculoaponeurotic layer, retaining ligaments and spaces, and periosteum and deep fascia) can be identified. The skin is located at a depth of approximately 0 to -2 mm. In the peeled images, the thinnest subcutaneous tissue is the eyelid, and the thickest tissue is between the risorius and masseter muscles. The peeled images of tissue at a depth of approximately -5 to -6 mm include the musculoaponeurotic layer at each region of the face. In most peeled images, the retaining ligaments and spaces are visible. In particular, the frontal belly of the occipitofrontalis, the platysma of the face, and the zygomaticus major are connected with the SMAS (Table II).

Further, all peeled images and peeled outlined images were added to a PDF file that can be viewed without software installation. However, the PDF file does not display the names of the 63 structures in pop-up windows.

DISCUSSION

Numerous aesthetic practices, such as toxin or filler injections, require students and surgeons to understand the spatial relationships of the facial structures within each curved surface layer of the face (Khan & Bagheri; Cotofana *et al*.; Sykes *et al*., 2015). However, existing educational tools, such as CT, MRI, and color sectioned images, do not adequately illustrate these curved layers of the face because they are plane (flat surface) images. Although the best method for learning the spatial relationships of the curved layers of the face has been classical cadaver dissection (Khan & Bagheri; Trévidic *et al*.; Kim *et al*.), it is very difficult to dissect a cadaver face so that it peels gradually in even depths across its surface. Consequently, students and surgeons had to try to understand the spatial relationships of the curved surface of the face indirectly, based on the insufficient methods that were available.

To increase the understanding of the anatomy of the layers along the curved surface of the face, we produced peeled images showing the curved surface of the face as gradually peeled three-dimensional images in the volume model (Fig. 1) (Kwon *et al*., 2016) and as the layers of the curved surface of the face pictured in books and articles (Radlanski & Wesker; Khan & Bagheri; Cotofana *et al*.; Trévidic *et al*.; Kim *et al*.). The difference between the pictorial layers shown in other studies and the peeled images obtained in this study is that the peeled images show all structures of the face, including the facial muscles, nerves, arteries, and SMAS in true color (24 bits) and high resolution (0.2 mm voxel size) (Figs. 2 and 3). To achieve this, we used the high-quality sectioned images of Visible Korean (Park *et al*., 2009, 2010).

To provide a better understanding of botulinum toxin injection sites on the face, we marked not only the injection sites but also the anatomic landmarks, facial creases and wrinkles, and fat compartments on the peeled images (Fig. 2). Although the location and depth of the injection sites can be measured with MRI, CT, and sectioned images, it is difficult to find the sites on two-dimensional images. With 3D models, other structures around the sites except 3D reconstructed structures cannot be displayed (Shin *et al*., 2018a), and these models do not show the real shapes and real colors of the structures as clearly as peeled images (Figs. 1-3). The peeled images show the real shapes and real colors of the structures because the images were created from real sectioned images (Park *et al*., 2009; Kwon *et al*., 2016).

In this study, the browsing software was chosen as an educational tool for easy user accessibility. The browsing

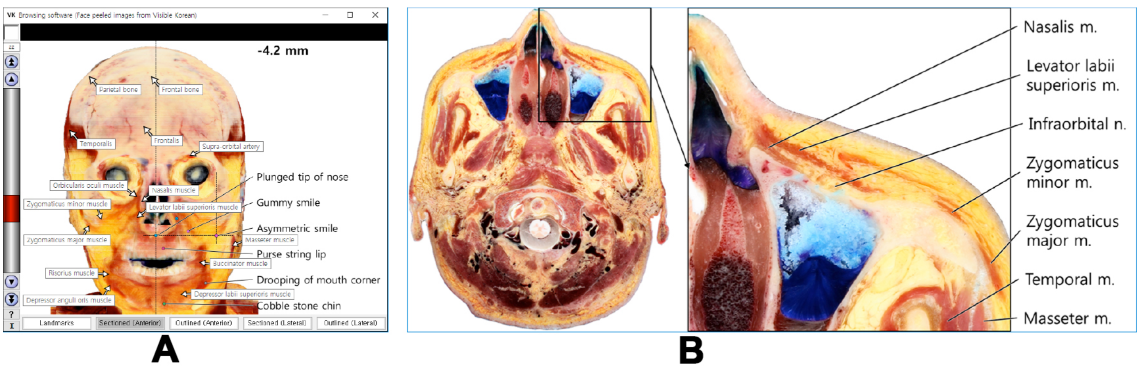


Fig. 4. Comparison of the peeled images (A) in the browsing software and the sectioned images (B) of Visible Korean.

software is particularly effective for students who must learn accurate facial anatomy as well as botulinum toxin injection sites within a short time. Therefore, we suggest the following process for learning the injection sites: Learn facial anatomy by studying whole version peeled images (Fig. 1) (Kwon *et al*., 2016); use the browsing software described in this study to understand the locations and positions of the toxin sites (Figs. 2, 3 and 4A); and finally, use the sectioned images of Visible Korean to learn the facial sectional anatomy, which will increase the learner's knowledge of the sectional shape of the facial structures (Fig. 4B) (Shin *et al*., 2012; Park *et al*., 2017). A comparison of the peeled images and sectioned images will offer the most effective means of learning the facial structures for students and practitioners of plastic surgery. Therefore, we will distribute the software and all image files free of charge at the author's homepage (neuroanatomy.kr).

PARK, J. S.; SHIN, H. K.; SHIN, B. S. & KWON, K. Imágenes de color verdadero de rostros sin piel con puntos de inyección de toxina botulínica y puntos de referencia anatómicos. *Int. J. Morphol., 37(3)*:1016-1022, 2019.

RESUMEN: Para permitir que los estudiantes y cirujanos aprendan los sitios para la inyección de toxina botulínica, se necesitan nuevos tipos de imágenes educativas ya que las imágenes de MRI, CT e imágenes seccionadas son inadecuadas. Este artículo describe el software de navegación que muestra imágenes de cara sin piel que permiten que las capas a lo largo de la superficie curva de la cara se despeguen gradualmente en profundidades uniformes a lo largo de la superficie. Se reconstruyeron dos modelos de volumen de la cabeza a partir de imágenes seccionadas e imágenes segmentadas visibles, respectivamente. En estos modelos de volumen se retiró la piel en serie con un grosor de 0,2 mm a lo largo de la superficie curva de la cara para construir las imágenes sin piel y las imágenes segmentadas sin piel. Todas las imágenes sin piel se marcaron con puntos de inyección de toxina botulínica, arrugas y arrugas faciales y compartimientos de grasa. Todas las imágenes despegadas y la información de texto se ingresaron en el software de navegación. El software de navegación muestra 12 sitios de inyección de toxina botulínica en todas las imágenes de las vistas anterior y lateral. Además, el software muestra 23 puntos de referencia anatómicos, 13 pliegues y arrugas faciales y 7 compartimentos de grasa facial. Cuando un usuario selecciona cualquier estructura en las imágenes sin piel, aparece el nombre de la estructura. Nuestro software con las imágenes sin piel será particularmente efectivo para ayudar a los estudiantes de medicina a aprender rápida y fácilmente la anatomía facial precisa para los sitios de inyección de toxina botulínica. También será útil para explicar los procedimientos de cirugía plástica a pacientes y estudiar la estructura anatómica del rostro humano.

PALABRAS CLAVE: Cara; Anatomía; Cirugía Plástica; Toxinas botulínicas; Proyecto humano visible.

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