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# Three-Dimensional Analysis of Forehead Wrinkles

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**Abstract.** It is important to understand the anatomical characteristics of forehead wrinkles in order to perform a forehead lift. This study aimed to elucidate the mutual relationships among tissues composing the forehead using computer software that enables the stereoscopic observation of the tissues studied in arbitrary directions. The specimens were obtained from five cadavers and prepared in serial sagittal sections. Three-dimensional images were prepared by inputting the forehead wrinkle data obtained from serial sagittal sections. Consequently, the forehead skin was found to be fixed to the superficial galea aponeurotica through fibrous septa, suggesting that movement of the frontalis muscle would be transmitted to the skin, not through the fibrous septa alone, but from the superficial galea aponeurotica closely attached to the frontalis muscle through the fibrous septa. Since the forehead muscles exhibit a stereostructure where the corrugator supercilii muscle supports three superficial forehead muscles, including the frontalis muscle, the orbicularis oculi muscle, and procerus muscle on the periosteal side, it was presumed that a sufficient effect would not be attained unless the corrugator supercilii muscle was operated on concurrently in conjunction with these muscles during a procedure involving the superficial forehead muscles in a forehead lift. Based on the findings from the three-dimensional images obtained, effective tissue treatments could be achieved by performing (1) dissection between the superficial galea aponeurotica and the frontalis muscle, (2) dissection between the deep galea aponeurotica and the periosteum, and (3) a procedure incorporating the forehead muscles in order.

**Key words:** Three-dimensional analysis—Forehead wrinkles—Forehead lift

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It has been reported that forehead wrinkles are caused by the consequent loss of elasticity and tonicity of the skin with aging, by atrophy of the subcutaneous tissues and the facial muscles, and by gradual resorption of the bone, as well as habitual forehead frowning [6,7]. However, many of the reports on wrinkles so far have mainly focused on the epidermis and dermis and few of them have described studies on the mutual relationship among the tissues involved ranging from the epidermis to the muscle layer and periosteum. Montagna et al. [4], and Tsuji et al. [10], reported on histological changes of the epidermis and dermis beneath the wrinkles, while Klingman et al. [1], reported no histological changes in the epidermis and dermis, the results of which have not yet been agreed upon. Like the reports by Klingman et al. [1] and Piérard et al. [5], have described that there were no histological changes of the epidermis or dermis and they have instead indicated changes of the fibrous septa in the subcutaneous tissue. According to their indication, as compared with surrounding tissues, the fibrous septa beneath the wrinkles were broader and shorter and these changes are involved in the origin of the wrinkles. Moreover, Washio et al. [11], have indicated the continuity of the skin and frontalis muscle through the fibrous septa and have described the importance of procedures for the fibrous septa, frontalis muscle, and galea aponeurotica in forehead lift. Nevertheless, they have not mentioned any anatomical relationship between the fibrous septa, frontalis muscle, and galea aponeurotica in detail. Other articles have also not described in detail any anatomical relationship between these tissues. In an anatomical writing, “Anatomy Textbook,” the forehead is largely observed from the anterior surface, which is not satisfactory enough for us to understand the three-dimensional structure of the forehead. In forehead lift, it is important to understand the mutual relationships of the various tissues composing the forehead wrinkles. Therefore, we reconstructed three-dimensional images from serial histological sections using computer graphics in order to study the

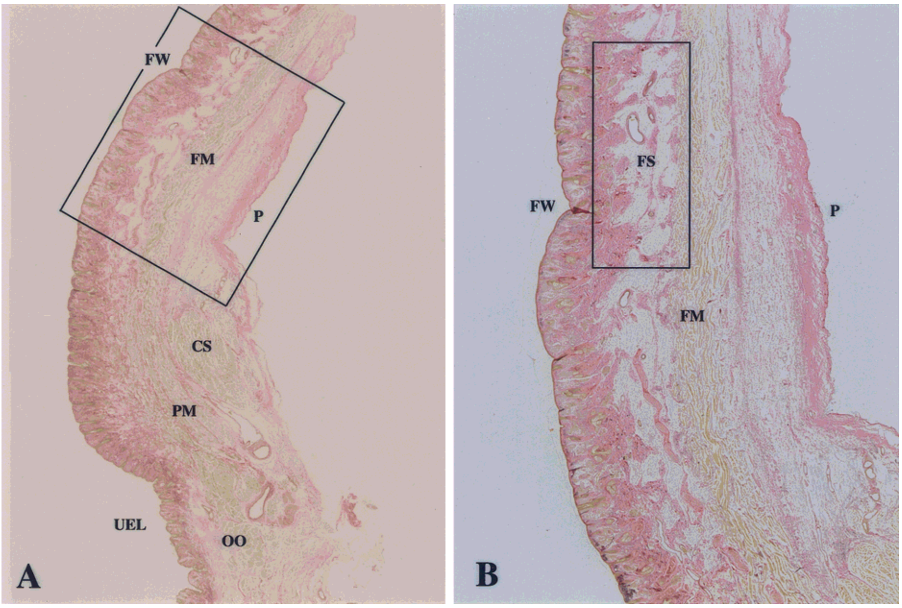



**Fig. 1.** Histological sections were stained by the elastica van Gieson stain. Collagen fibers developed red color, muscle fibers developed a yellow color, and elastic fibers developed a black color. Fat tissue was minimally stained. **(A)** Deep forehead wrinkles (FW), the frontalis muscle (FM), the corrugator supercilii muscle (CS), the procerus muscle (PM), and the orbicularis oculi muscle (OO) were all observed. UEL: Upper eye lid, P: Periosteum (×0.7). **(B)** The fibrous septa (FS) ran from the dermis to the frontalis muscle (FM) (×1.5).

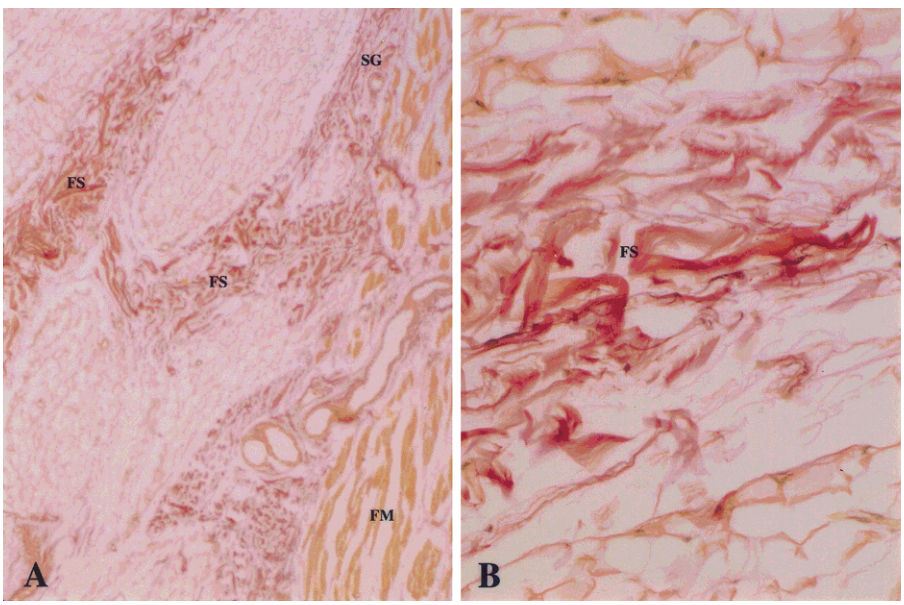
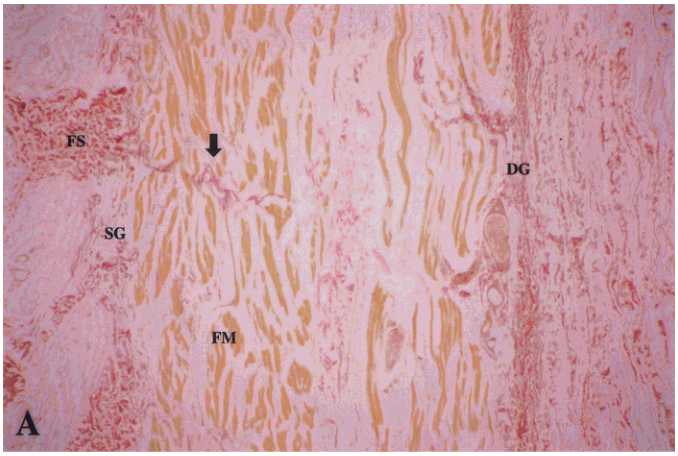



**Fig. 2. (A)** Collagen bundles are fibrous septa (FS) dividing the subcutaneous fat layer. SG: Superficial galea aponeurotica (Elastica van Gieson stain; ×40). **(B)** The fibrous septa contained elastic fibers in addition to collagen fibers (Elastica van Gieson stain; ×100).

three-dimensional mutual relationships of the skin, subcutaneous tissue and forehead muscles. These images enabled us to observe the relationships in arbitrary directions by selecting an arbitrary tissue among those comprising the forehead wrinkles. Three-dimensional images obviously show the mutual relationship of the tissues comprising the forehead wrinkles which have been previously difficult to observe, and are very useful in understanding the three-dimensional structure of forehead wrinkles. Furthermore, we studied effective procedures for tissues in forehead lift based on these three-dimensional images of forehead wrinkles.



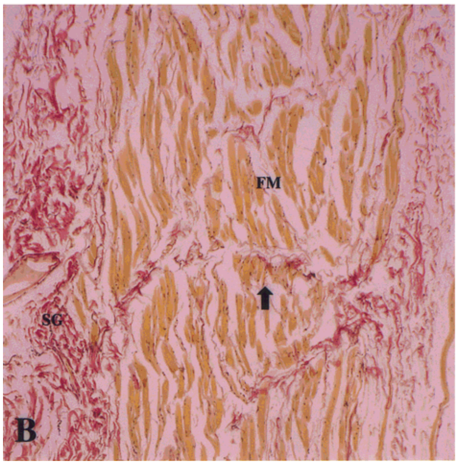




**Fig. 3. (A)** The frontalis muscle was covered by the superficial galea aponeurotica (SG) and the deep galea aponeurotica (DG) (Elastica van Gieson stain; ×20). **(B)** The perimysium (arrowhead) bundling muscle fibers were closely linked with galea aponeurotica (Elastica van Gieson stain; ×40).

## Materials and Methods

The specimens were obtained from five cadavers, consisting of two males and three females with a mean age of 78 years (range, 65–96 years), as small sections of the forehead skin containing the periosteum during routine anatomical training for medical students. Each of the materials was fixed in 10% formalin and embedded with paraffin. It was serially sliced in a sagittal plane to a thickness of 6 μm. Staining of sections at an interval of 60 μm was performed by the elastica van Gieson stain. Stained histological sections were subject to histological study under microscope.

Three-dimensional images were prepared using a three-dimensional model reconstructing computer software program, 3D Surface (Ratoc System Engineering Co., Ltd. Tokyo, Japan). They were obtained from the skin, subcutaneous tissue, galea aponeurotica, facial muscles, and periosteum. The data was digitalized by tracing the tissues studied from the photomicrographs of histological sections at magnifications of 0.7–2.5x and inputting them into the computer. The three-dimensional images were prepared by continuously entering the data from the photomicrographs at an interval of 960 μm. Then three-dimensional mutual relationships and characteristics of the tissues comprising the forehead wrinkles were then studied using the three-dimensional images.

## Results

### *Histological Findings*

The forehead wrinkles did not disappear in the course of collecting the samples and epidermis and dermis in the histological sections were found to have creases consistent with wrinkles (Fig. 1). In the subcutaneous tissue, collagen bundles dividing the subcutaneous fat layer were observed. These collagen bundles were the fibrous septa, which ranged from the dermis to the galea aponeurotica (Figs. 1B and 2A). The galea aponeurotica, mainly consisting of collagen fibers and elastic fibers, consisted of two layers as the superficial and deep galea aponeurotica (Fig. 3). The frontalis muscle was present between these two layers of the galea aponeurotica, and the perimysium of the frontalis muscle and these layers of the galea aponeurotica were closely related (Fig. 3B). The frontalis muscle was inserted into the dermis of the eyebrow together with muscle fibers of the orbicularis oculi muscle. There was loose connective tissue between the deep galea aponeurotica and the periosteum, which formed the subgaleal layer. The deep galea aponeurotica attached to the periosteum of the supraorbital rim in the form of multiple layers through the subgaleal layer.

### *Three-Dimensional Findings*

The forehead wrinkles were conscientiously shown in the three-dimensional images of whole tissues (Fig. 4A). The frontalis muscle contacted with the procerus muscle in the medial eyebrow and with the orbicularis oculi muscle in the area from the central to lateral eyebrow (Fig. 4B). The procerus muscle originated in the periosteum of the nasal bone and contacted with the orbicularis oculi muscle and frontalis muscle in the medial eyebrow. The corrugator supercilii muscle was located deeply in the frontalis muscle, orbicularis oculi muscle, and procerus muscle, and it originated in the periosteum around the junction of procerus muscle and orbicularis oculi muscle, namely, the superomedial orbital rim, and it reached the junction of the frontalis muscle and the orbicularis oculi muscle covering from the medial and central eyebrow (Fig. 5).

The three-dimensional images exhibiting deep forehead wrinkles showed that the fibrous septa closely attached to the superficial galea aponeurotica while partitioning the subcutaneous fat layer. Between the superficial and deep galea aponeurotica, the frontalis muscle was present, as if the muscle had been put between these two sheets (Fig. 6). Inside the frontalis muscle, the perimysium was observed continuing from the superficial and deep galea aponeurotica (Fig. 7). The subgaleal layer was formed between the deep galea aponeurotica and the periosteum of the frontal bone.

## Discussion

The three-dimensional images enable observation in the posterior view, which had been difficult to do previously, and multidirectional observation of the forehead muscles was possible. The three-dimensional images in the posterior view revealed that the corrugator supercilii muscle originated from the superomedial orbital rim and continuously reached the junction of three muscles: the frontalis muscle, the orbicularis oculi muscle, and the procerus muscle. In the three-dimensional images, the frontalis muscle, orbicularis oculi muscle, and procerus muscle were all located in the superficial layer of the forehead, a finding different from that for the corrugator supercilii muscle. These three muscles were therefore named superficial forehead muscles. According to Tarbet et al. [9], the frontalis muscle consists of paired muscles, originating from the galea aponeurotica near coronal suture, interdigitates with the orbicularis oculi muscle in the central and lateral area, and inserts into the skin of the eyebrow across the procerus muscle in the medial area. In addition, they have reported that the corrugator supercilii muscle originates from the superomedial orbital rim and inserts into the skin of the medial eyebrow across the frontalis muscle and orbicularis oculi muscle. The superficial forehead muscles and corrugator supercilii muscle contain many junctions where the muscle fibers completely interdigitate, so that fully understanding the three-dimensional relationships present might be necessary in order to devise and apply procedures to these muscles. The results of the present study suggest that it is important to understand structural characteristics and effects of a stereostructure of the corrugator supercilii muscle which supports the superficial forehead muscles, i.e., the frontalis muscle, orbicularis oculi muscle, and procerus muscle, from the periosteal side. Namely, it was presumed that desirable efficacy could be attained when applying any procedure to the superficial forehead muscles consisting of the frontalis muscle, orbicularis oculi muscle, and procerus muscle as well as the corrugator supercilii muscle near the junction, in forehead lift. So, when choosing the layer to be dissected for procedure of the corrugator supercilii muscle, the adjacent subgaleal layer proved the best choice based on both histological and three-dimensional image findings.

Next, we investigated the three-dimensional mutual relationships of the tissues comprising wrinkles mainly focusing on deep transverse wrinkles, which are characteristic among forehead wrinkles. Beneath the epidermal and dermal creases corresponding to the forehead wrinkles, are the septa ranging from the dermis to the superficial galea aponeurotica (Figs. 3A and 6). Histologically, these septa were mainly composed of collagen fibers exhibiting fibrous septa dividing the subcutaneous fat layer (Fig. 2). Riefkohl [8] described the subcutaneous fat layer ranging from the frontalis muscle to the skin as a firm fibro-fatty layer. The subcutaneous fat layer divided with the fibrous septa is considered to be contained in this layer, whereas there is no detailed description on the structure of the firm fibro-fatty layer. Therefore, a satisfactory understanding of the mutual relationship of the skin, frontalis muscle and galea aponeurotica composing wrinkles could not be gained from this article. On the other hand, Knize [3] described that the forehead skin is fixed closely to the frontalis muscle via the fibrous septa running in the subcutaneous fat layer and superficial galea aponeurotica. Also, in our study, the fibrous septa were clearly observed to closely attach to the superficial galea aponeurotica, as if they were suspended from the forehead skin (Fig. 7). However, the fibrous septa did not directly continue up to the frontalis muscle. In the three-dimensional images, the septa extending from the superficial galea aponeurotica to the muscle layer of the frontalis muscle, extended from the deep galea aponeurotica, too, histologically representing the perimysium (Fig. 4B). These perimysium play a role in bundling the muscle fibers and transmitting movement from the frontalis muscle to the galea aponeurotica. In the three-dimensional images omitting components of the frontalis muscle, the three-dimensional mutual relationship between the perimysium and the two layers of the galea aponeurotica was clearly presented, indicating a close conjunction with the galea aponeurotica in three-

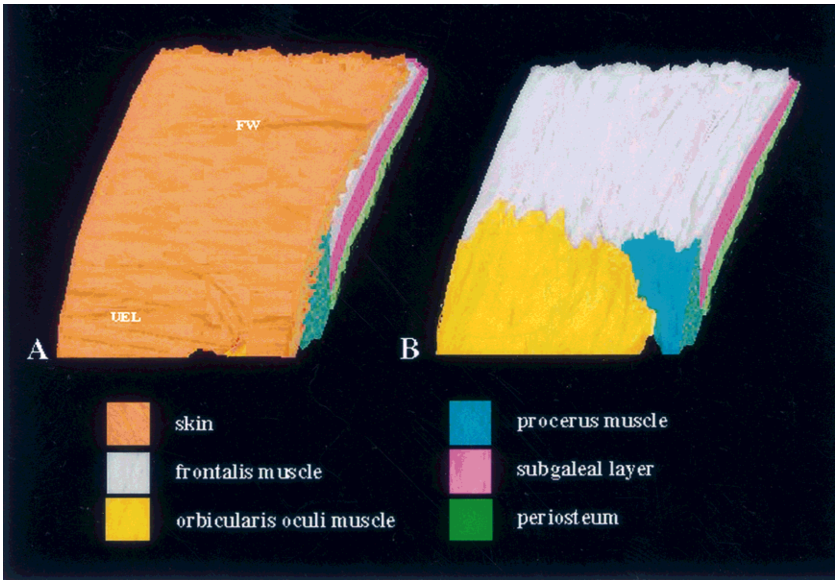



**Fig. 4.** These are three-dimentional images of the right hemi-forehead. **(A)** A left oblique image. **(B)** This is the image excluding components of the skin, the subcutaneous fat layer, and the superficial galea aponeurotica.

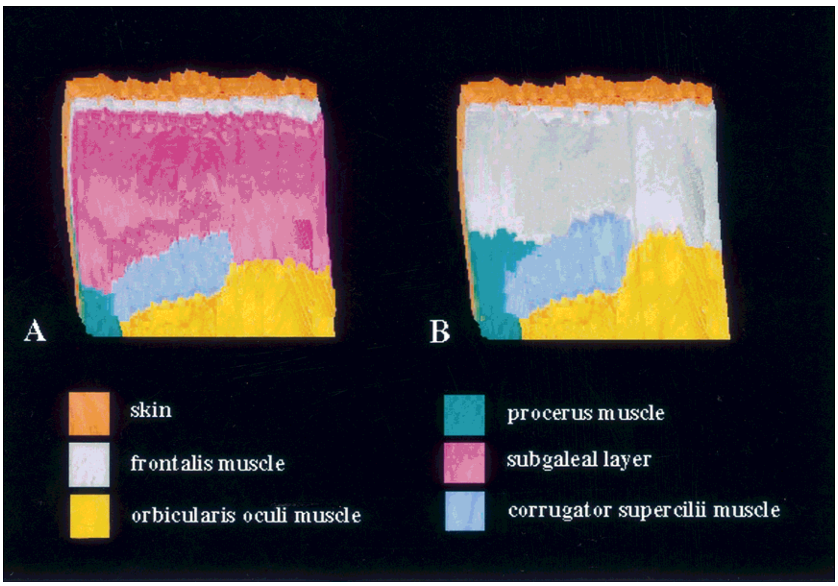



**Fig. 5. (A)** A posterior image excluding the periosteum component. **(B)** A posterior image excluding components of the periosteum, the subgaleal layer, and the deep galea aponeurotica.

dimensions. That is, it was confirmed by the three-dimensional images that the skin was fixed to the superficial galea aponeurotica through the fibrous septa and that movement of the frontalis muscle was transmitted to the skin not only through the fibrous septa, but also through, first, the superficial galea aponeurotica and, then, the fibrous septa.

Then, based on the above results, we studied the dissected layer to which effective procedures are applicable in forehead lift using three-dimensional images. The three-dimensional images demonstrated that the main tissues transmitting movement of the frontalis muscle to the skin were the superficial galea aponeurotica and the fibrous septa, suggesting that manipulating these tissues, as well as the frontalis muscle, might be essential to improving forehead wrinkles. To treat the frontalis muscle and these tissues, identifying the layers to be dissected is important. Generally, the layers to be dissected include three types the subcutaneous layer, the subgaleal layer, and the subperiosteal layer. Subcutaneous dissection causes less sensory disturbance and yields a more effective forehead lift, though the problem of hematogenous disturbance of the flap remains. Subgaleal dissection has a favorable effect in forehead lift but may cause sensory disturbance due to injury of the supraorbital nerve. Subperiosteal dissection has a low incidence

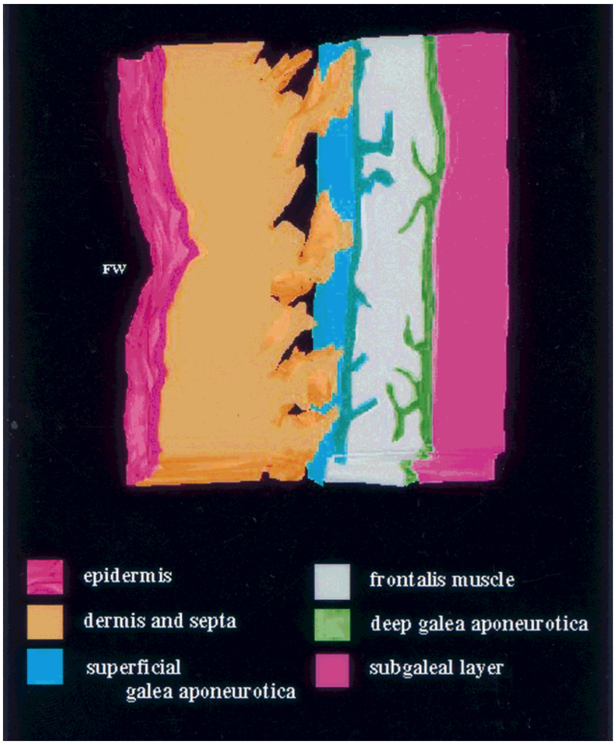



**Fig. 6.** A left oblique image mainly including deep forehead wrinkles. Components of the subcutaneous fat layer and periosteum are excluded. The fibrous septa are closely attached to the superficial galea aponeurotica.

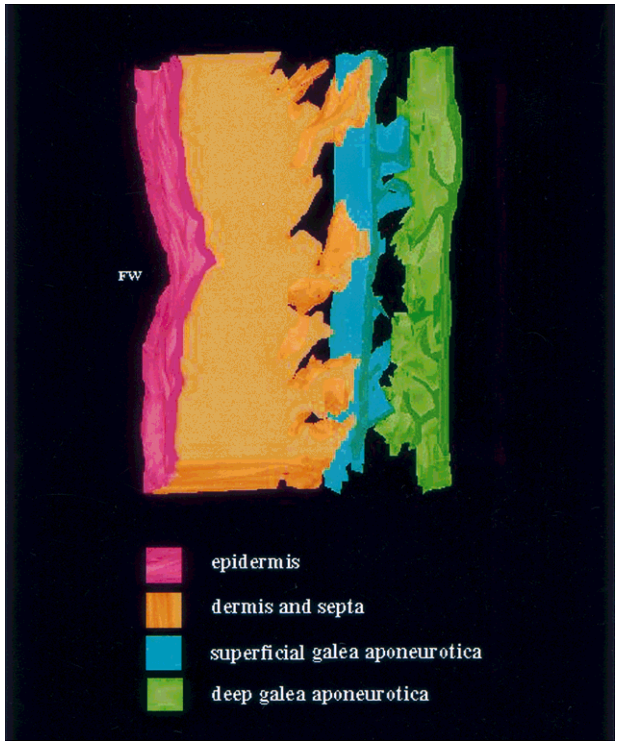



**Fig. 7.** A left oblique image excluding components of the subcutaneous fat layer, the frontalis muscle, the subgaleal layer, and the periosteum. The perimysium extends from the superficial galea aponeurotica and the deep galea aponeurotica. It can be shown by three-dimensional imaging that the two layers of the galea aponeurotica have a close relationship with the frontalis muscle through the perimysium.

of sensory disturbance and stabilizes the hemodynamics of flap but attains a lower efficacy in forehead lift because of periosteal tension. We judged that the dissected layer attaining effective forehead lift in three-dimensional images would be between the superficial galea aponeurotica and frontalis muscle. Dissection of this layer can suppress action of the frontalis muscle on the skin by blocking the continuity of the frontalis muscle and the superficial galea aponeurotica. Furthermore, it enables stretching of the continuous skin through the fibrous septa by stretching the superficial galea aponeurotica, too. Nevertheless, this dissected layer alone is not satisfactory enough to release contracture of the frontalis muscle and thereby the other forehead muscles. To release contracture of the frontalis muscle, the deep galea aponeurotica with close continuity to the frontalis muscle should be treated as well. Therefore, dissection of subgaleal layer is necessary. This is because this layer is best utilized for those procedures involving other forehead muscles. The most effective dissected layers in forehead lift are these two layers, which was determined by three-dimensional image findings. In a dissecting procedure for these two layers, caution to prevent injuries to the supratrochlear and supraorbital nerves, especially injury to the supraorbital nerve should be exercised. According to Knize [2], the supraorbital nerve originates from the supraorbital foramen and separates to the superficial and deep divisions. The superficial division penetrates through the frontalis muscle and passes in the subcutaneous layer toward the cephalad. The deep division passes from the subgaleal layer up to the coronal suture. Thus, injuries to the superficial division of the supraorbital nerve and to the deep division of the supraorbital nerve should be cautioned against, respectively, during dissections between the superficial galea aponeurotica and the frontalis muscle and dissections of the subgaleal layer.

By utilizing three-dimensional reconstructing software we were able to observe the mutual relationship of the tissues, which have been observed only in limited views so far, in arbitrary views. An understanding of the three-dimensional structure of the forehead is important not only for forehead lift but also for other reconstructive surgeries. From now on, we will clinically apply surgical procedures based on the knowledge gained from these three-dimensional images and study the results of the application.

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