Training System Using a Force Feedback Device for Acupuncture Treatment

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Abstract—**Many people who wish to become professional acupuncturists lack practical training in performing actual acupuncture because of anxiety about deep needling, lack of practical training time, and so on. In order to solve this problem, we are developing an acupuncture training system based on a force feedback device, called Acupuncture Trainer (ACT). We added a new automatic camera functionality, in which the camera position automatically adjusts to the target area of the force feedback device. As a result, the user can easily practice an insertion operation at a fixed position, and the convenience of our system has improved.**

Keywords—computer graphics; 3D modeling; force feedback; haptic device; acupuncturist;

I. INTRODUCTION

Acupuncture is a treatment method in which specific points of the body are simulated by piercing or contacting with dedicated acupuncture needles. Suppression of sympathetic nerve activity has been mentioned as the action of acupuncture [1-5]. Stiff muscles relax with acupuncture stimulation, suppression of muscle sympathetic nerve activity is involved in relieving muscle hypertension, and muscle blood volume increases.

The practice of treatment using actual acupuncture needles is indispensable in the training of professional acupuncturists. In this practical training, after considering safety education, training h initially carried out using practice equipment, and then shifts to practical training between students. However, there are many people without sufficient practical training time, and it is difficult for them to become accustomed to performing acupuncture on a real human body [6].

In order to solve the above problem, we have been developing an acupuncture training system called Acupuncture Trainer (ACT)(Fig. 1), which makes use of a personal computer and a force feedback device. It is possible to practice safe and effective training and treatment by using ACT. ACT can display a three-dimensional (3D) model of the human body with meridian points, and the user can study the meridian points interactively. The user can pick out a meridian point and read detailed information on the point. ACT can interactively change the transparency of skin, muscle and bone, updating the display in real time. Through ACT a user can touch the meridian points by using a haptic device, and is able to perform acupuncture on the virtual human body on the screen.

However, in general, the operational space of the haptic device is very narrow in comparison with screen space. A user can obtain a reactive force inside the operational space of the haptic device. Therefore, when a user picks a meridian point outside of the operational space, it becomes difficult to perform accurate insertion. For example, the user has to move the selected meridian point to the center of the screen every time, which is inconvenient.
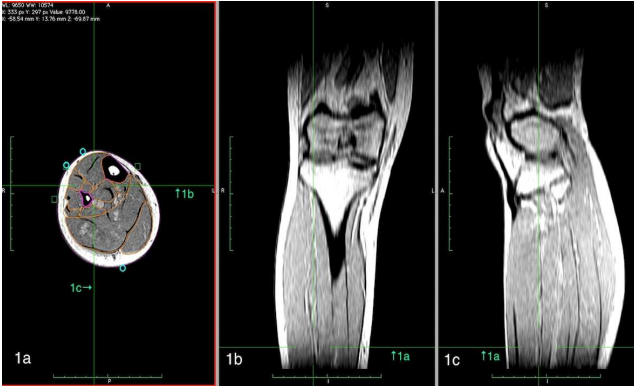
Fig. 1 Acupuncture Trainer (ACT)
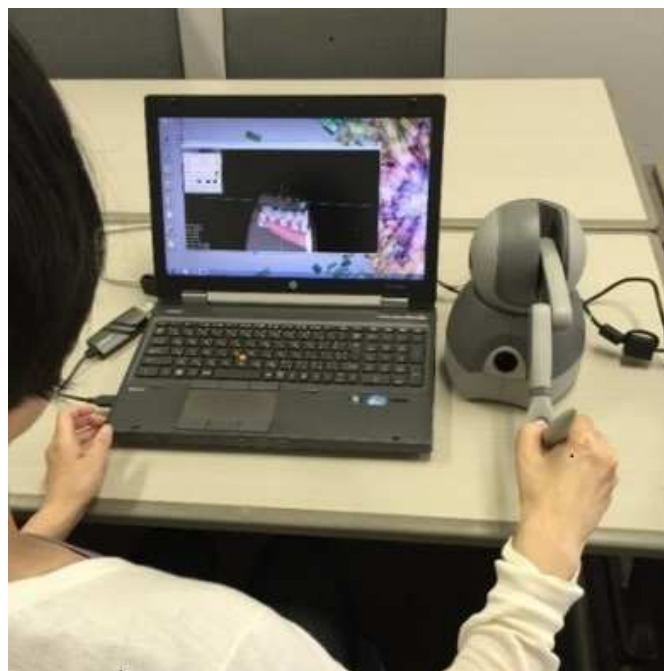
Fig. 2 Segmentation from MRI image (OsiriX)

Fig. 3 Specification of meridian points

Fig. 1 Output of polygonal data (ZBrush)

Fig. 5 3D model of foot (ZBrush)

In order to improve this procedure, we propose an interactive operation mode, in which the camera position changes automatically by taking into consideration the operational space of the haptic device. The user can manipulate the meridian points in the operational space, and this makes it suitable for performing accurate insertion.

II. OVERVIEW OF ACUPUNCTURE TRAINER

A. Development environment

Our ACT has been developed for Microsoft Windows. We have used a professional haptic device (Touch) from 3D Systems Ltd. in order to perform accurate insertion at meridian points. For software development, we have used Visual C++ 2012, the MFC (Microsoft Foundation Class) library, OpenGL, and the OpenHaptics toolkit.

B. Modeling a human body with acupuncture points

First, we segmented the skin, muscle, and bone regions from MRI and CT image scans of the human body. Next, we approximated three-dimensional data of the human body model using a polyhedron from the extracted image regions. We utilized several image processing (IP) and computer graphics

(CG) software tools, including Osirix [8], ZBrush [9], and Volume Extractor [10-11]. Volume Extractor is a 3D visualization system developed at Iwate Prefectural University.

MRI and CT are different methods with completely different principles of measurement. MRI cannot measure at a single time in a wide area of the human body, but it is more suitable for imaging muscles and organs. On the other hand, CT has the problem of X-ray exposure. However, the measurement time is short, and it is easy to segment bone and skin of the human body by using pixel values.

Fig. 2 shows the main screen of OsiriX, which displays a sectional view of an MRI of a foot. Fig. 3 shows the specification of the position of meridian points. ST38, ST40, and BL57 in this figure show the meridian points in the 3D MRI image coordinate space. Since the DICOM image format holds the spatial information of the measured slice image, such as the origin, world coordinates, pixel size, and so on, we can specify the precise position for all slice images. The meridian points are represented by spheres. We set up the meridian points interactively by considering muscle and bone position [11]. We display these points and the meridian information on the skin interactively, and then the user can confirm its position and retrieve additional information.
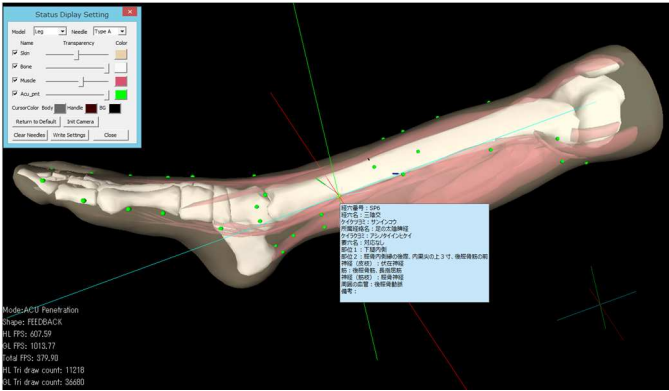
Fig. 6 ACT main screen　　(transparent skin,
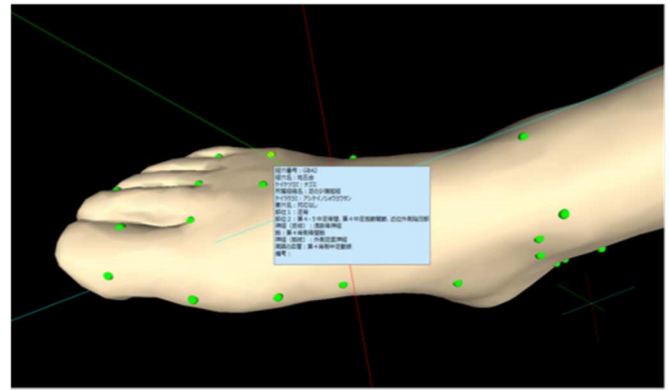display acupuncture information)

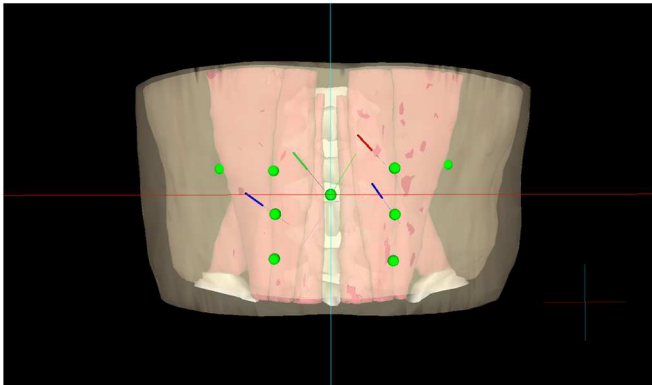Fig. 7 Display of acupuncture information

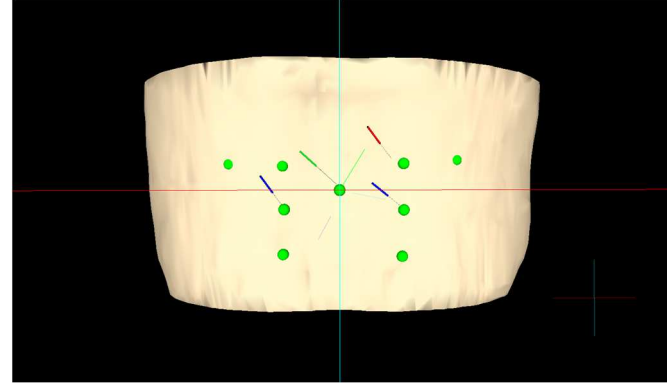Fig. 8 3D model of Torso (translucent skin)

Fig. 9 3D model of Torso (opaque skin)

We created three training models for foot, arm, and torso, and the meridian points were prepared on the skin of the foot, arm, and torso. Figs. 4 and 5 show the main screen of ZBrush, and they display a 3D polygonal model of skin, muscle, and bone. ZBrush has many effective operations for a large polygonal model.

Next, we discuss the general purpose functions of ACT. The user can rotate/enlarge/reduce the model using the mouse. When the mouse cursor is set to the position of the meridian point, ACT can display the detailed information of the meridian point.

Fig. 6 shows the ACT main screen. ACT consists of a main display area and a menu. Fig. 7 shows important acupuncture information related to the selected meridian point on the pop-up dialog. A user can adjust the transparency of the skin and display acupuncture information effectively. The user can learn about many meridian points and the relationship between the meridian points and the human body, while studying the position of the meridian point in three dimensions.

Figs. 8 and 9 show a situation in which acupuncture training is conducted for the torso model. In the ACT system, it is possible to change the training model by changing the polygon model. First, the meridian point is displayed in red, and it changes to green after the meridian point is selected.

C. Interactive operation of Acupuncture Trainer

Acupuncture operations are performed with the stylus attached to the Touch. This device has six degrees of freedom in translation and rotation. The stylus is utilized for camera coordinate movement and for attitude control of ACT.

When the needle is in contact with the skin of the human body model, pressing button 1 of the stylus switches to insertion mode. Depending on where the tip of the needle is located, the stress will change. Strong resistance will be felt on bone, and the needle does not penetrate into bone. In order to judge whether the needle has been inserted in the proper position, if the tip part of the acupuncture needle is very close to the meridian point, the stinger pattern changes to green; otherwise, it changes to orange. When the user presses button 2 of the stylus in insertion mode, the needle remains on the screen, and the needle operated by the user can again move freely. In this way, the user can visually confirm all of the results of his/her insertions after all operations.

Fig. 10 describes the needle's translation, rotation, and insertion due to the user's operation. When the user inserts an acupuncture needle, the user feels different resistance according to the internal state, such as skin, fat, muscle, bone, and the insertion angle. In this figure, x_1, y_1, and z_1 are determined by transforming the coordinates of the tip of the stylus into coordinates in the normal space. Also, θ is determined from the rotation matrix obtained from the rotation angle of the stylus. Although the direction vector of insertion is determined when insertion has started, it is difficult for humans

StartPos
(x_1, y_1, z_1)

force feedback

insertion force

actual direction of insertion

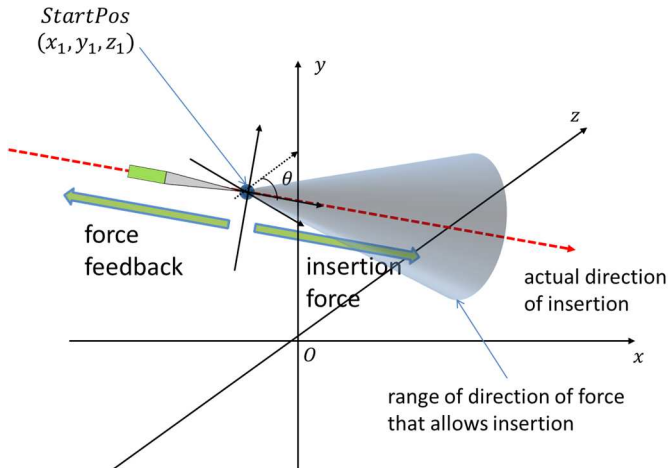range of direction of force that allows insertion

Fig. 10 Needle's translation, rotation, and insertion due to user's operation

to precisely apply force against the device in the direction of the vector. Therefore, ACT allows a certain degree of angular misalignment between the direction vector of insertion and the vector that is given by the user. The cone in Fig.10 represents the range of direction of force in which insertion is allowed.

D. Model display setting

The model display settings are selected in the status display setting window. Here, it is possible to perform model selection, display permission/permeability/color settings of each part of the model, erase an inserted needle, and so on.

By increasing the permeability of the skin, it is possible for users to easily grasp the positional relationship between the meridian points, bones and muscles. Also, by hiding the meridian points, it is possible for practice sessions to more closely mimic actual acupuncture treatment.

III. AUTOMATIC CAMERA MOVEMENT

In acupuncture operations on ACT, when the selected acupuncture point on a human body model exists outside the operating space in the haptic coordinate system, the operations of touching the acupuncture point become difficult, and it is impossible to get suitable force feedback. Even if a touch

operation is possible, it is desirable that the acupuncture target be located as near to the center of the screen as possible in order to bring it closer to the operating space in the haptic coordinate system for an actual insertion operation. In order to solve this, it is necessary to translate the model so that the insertion position comes to the front, but the translation must be conducted by as simple an operation as possible so that the user can concentrate on the insertion operation.

In order to realize this, we implemented automatic camera operation in ACT. Using this operation, users can move models easily to suitable positions in the target space of the force feedback device. When the user moves the mouse cursor over the key point and clicks the left mouse button, the model translates from the center coordinates of the target point to the origin coordinates. We have set meridian points as target points.

This change in camera position is also performed simultaneously in the haptic coordinate system of the force feedback device. Thus, when performing an insertion operation, the user can repeatedly insert needles at almost the same position. In this way, we believe that the convenience of the system has significantly improved.

Fig. 11 shows an automatic camera operation of the force feedback device to target space. When the location of the model is like that shown in the left side of Fig.11, even if the user wishes to insert a needle in the acupuncture point in the red circle, the stylus of the device will be unable to reach that point. In that case, if the user clicks on the acupuncture point, the model translates to the view shown in the right side of Fig.11 and the user can conduct an insertion operation, keeping the stylus near the center of the device.

The expressions shown in Fig.12 describe how to translate and rotate the model. The method of calculation is shown in Fig. 13. Expression (a) is a translation matrix, which is a translation from the center coordinate of the target acupuncture point to the origin. Expression (b) is a camera matrix, which describes rotation from the unit vector along the z-axis to the normalized vector V, whose extension line passes through a point on the normal space computed from coordinates of the mouse cursor. Expression (c) is an expression for computing the rotation angle θ. Expression (d) is an expression for computing the rotational axis vector. Expressions (e), (f), and (g) are expressions for computing the coordinates of vector V.
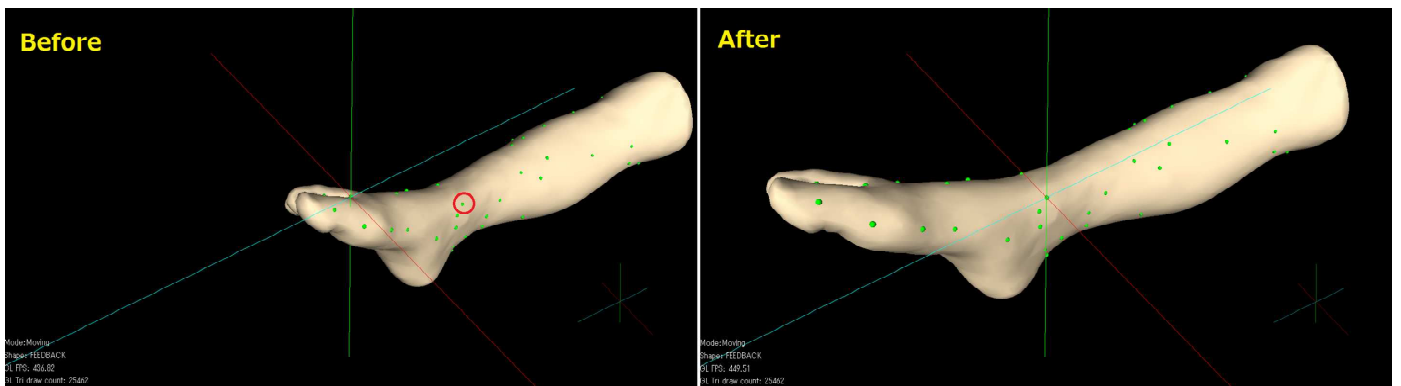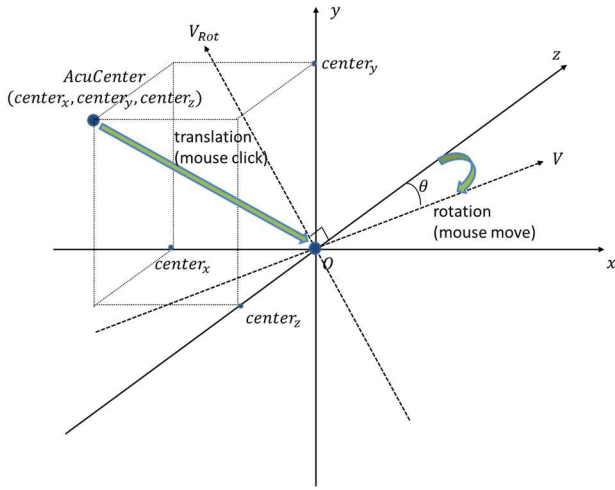

Fig. 11 Automatic camera operation

Fig. 12 Model translation and rotation

$$\begin{bmatrix} x^2(1-cos\theta)+cos\theta & xy(1-cos\theta)-zsin\theta & zx(1-cos\theta)+ysin\theta & 0 \\ xy(1-cos\theta)+zsin\theta & y^2(1-cos\theta)+cos\theta & yz(1-cos\theta)-xsin\theta & 0 \\ zx(1-cos\theta)-ysin\theta & yz(1-cos\theta)+xsin\theta & z^2(1-cos\theta)+cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}\text{(b)}$$

$$\theta = arcsin(\,|\,V_{Rot}\,|\,)\,V_{Rot} \qquad\qquad\qquad\qquad \text{(c)}$$

$$V(p_x, p_y, p_z) \times V_z(0,0,1) \qquad\qquad\qquad\qquad \text{(d)}$$

$$p_x = (mouse_x \times 2 \div windowwidth - 1) \div \\ windowheight\ windowwidth \quad \text{(e)}$$

$$p_y = (windowheight - mouse_y) \times 2 \div windowheight - 1 \qquad \text{(f)}$$

$$p_z = \begin{cases} \sqrt{0.8^2 - \sqrt{p_x{}^2 + p_y{}^2}} & (\sqrt{p_x{}^2 + p_y{}^2} < 0.8 \times \frac{\sqrt{2}}{2}) \\ (0.8 \div \sqrt{2})^2 \div \sqrt{p_x{}^2 + p_y{}^2} & (\sqrt{p_x{}^2 + p_y{}^2} \geq 0.8 \times \frac{\sqrt{2}}{2}) \end{cases} \quad \text{(g)}$$

stable operation can be performed. In the evaluations, experienced acupuncturists pointed out that it is difficult to pierce the skin accurately because the meridian points of our system (green points) are small.

V. CONCLUSION

In this paper, we described ACT, which uses a force feedback device for acupuncture treatment. We also explained (1) 3D modeling of the human body and details of the placement of acupuncture points, and (2) the automatic camera operation that we implemented in ACT.

This function makes it easy to pierce the skin with needles. Since the active ranges of different force feedback devices are different and the user may not know the range beforehand, the automatic camera operation is particularly valuable for use with the several force feedback devices. The 3D model can be confirmed with respect to the actual meridian point that can be confirmed at practicing acupuncture needle. Furthermore, we examined the possible educational benefits of ACT as an educational tool to improve recognition of acupuncture sites. We also plan to make a 3D model of the entire human body and implement it in ACT, which should make the device even more effective.

IV. EVALUATION

We conducted a simple questionnaire to confirm the effectiveness of the automatic camera movement in ACT. Participants operated two versions of our system. In one of them, the automatic camera movement function was not implemented (V1.0), and in another it was implemented (V2.0). After that, participants answered four questions about how the new version of our system changed compared to the old version.

Most of the participants answered "good" or "very good". On the other hand, no one answered "bad" "very bad" or "I don't know" (See Fig. 14). This demonstrates the effectiveness of Ver. 2.0. The operable space of the haptic device is small in comparison with the displayed screen. Therefore, it is important to calculate the position of the camera at which

$$TransMat = \begin{bmatrix} 1 & 0 & 0 & -center_x \\ 0 & 1 & 0 & -center_y \\ 0 & 0 & 1 & -center_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad \text{(a)}$$
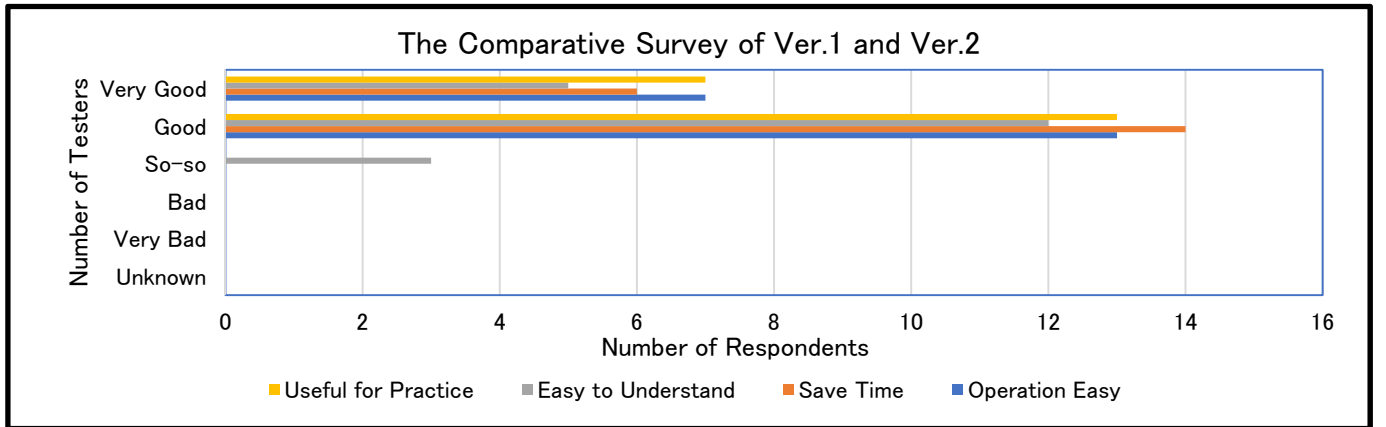
$$CameraMat =$$

Fig. 13   Survey comparing Ver. 1 and Ver. 2

A 3D model of the human body was created from human MRI and CT images using common and inexpensive software such as OsiriX, ZBrush, and Volume Extractor. It is possible to inexpensively create real 3D models using our method. In addition to acupuncture training, it can be applied to various other fields. With the automatic camera operation, users can utilize the force feedback device effectively. As a result, users can easily practice the insertion operation at a fixed position, and this improves the convenience of our system.

3D printing of anatomical structures related to acupuncture points is also an effective approach for education (See Figs. 15 and 16). The models in Figs. 15 and 16 were 3D printed using an Objet500 Connex 3 (3D systems Ltd). The skin surface was transparent, and the bones and streaks were colored. By hollowing the interior of the model in Fig. 16, we made the position of the major psoas easier to understand. Understanding the relation between acupuncture points and the human body is made easy by observing these 3D printed models.

Furthermore, we are currently making plans to include a remote education function in ACT in the near future. We will also collect and analyze data using ACT, and aim to further improve our system.

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