COMPUTER ASSISTED PLANNING USING DEPENDENT TEXTURE MAPPING AND MULTIPLE RENDERING PROJECTIONS IN MEDICAL APPLICATIONS

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Abstract: Direct volume rendering based on 3D-texture mapping has improved recently. [1]. However, simultaneous visualisation by different sources (multi-modality image integration) or, the single source of information from different time intervals, is yet limited [2]. This work presents three options to visualise objects, issued from two or more sources that were previously registered: (1) Multimodal Volume Rendering (MVR); (2) Mixed of Surface Rendering, also called Indirect Volume Rendering with Volume Rendering (VR); and, (3) Multimodality – Multiplanar Reconstruction – MPR, (to our knowledge, this has not been reported). The aim of this work, is to obtain objects from any modality, such as MRI or CT, and visualise a ROI under the control of a Multidimensional Transfer Function (TF) defined by one or more Fuzzy Classifiers (FC). Once a good visualisation is reached, the object is segmented to create a polygonized model of the surface, and this representation can be mixed with any modality from the patient's studies. The results show that, the use of 3D navigation with a probe, multimodality-MPR, 3D texture mapping visualisation, interactive TF, interactive widgets, and medical knowledge, cooperate to improve surgery pre-planning. In conclusion, our proposed multimodal visualisation technique allows and improves the simulation of surgery planning [3].

Introduction

Direct Volume Rendering (DVR) has proven to be an effective and flexible visualisation method, since it does not need a previous segmentation of the object. During many years, 1D Transfer Functions (TF) only based on grey-level, opacity, or colour, were used. However, the computer time for rendering of the original Raycasting-algorithm was too long to visualise the objects in real-time. An exhaustive analysis of the models for the scientific visualisation in the medicine is presented in Montilla et al [4].

Levoy in 1988 [5] introduced two styles of Transfer Function, both 2D and both using gradient magnitude for the second dimension. One Transfer Function was created with the purpose of accentuating the interfaces between materials. The other TF was created to accentuate the regions of the same iso-value. Adjusting a Transfer Function was a tedious task due to: 1) Finding an appropriate Transfer Function is generally accomplished by trial and error. 2) Workstations with high performance graphic cards are needed. 3) Graphic interfaces had not been implemented to select multi-dimensional Transfer Functions.

With the technology now available, the DVR method has improved, owing to the development of three key aspect [6], depicted on the figure 1: 1) New hardware for Volume Rendering, or the low priced high performance graphic cards, such as NVIDIA or ATI, which includes the programming of OpenGL functions and extensions to make the Volume Rendering inside the texture memory of the card; 2) the mathematical development of multi-dimensional Transfer Functions; and, 3) the development of new graphics user interfaces that allows drawing a Transfer Function intuitively and permitting the observance of the final result of the volume rendering interactively.

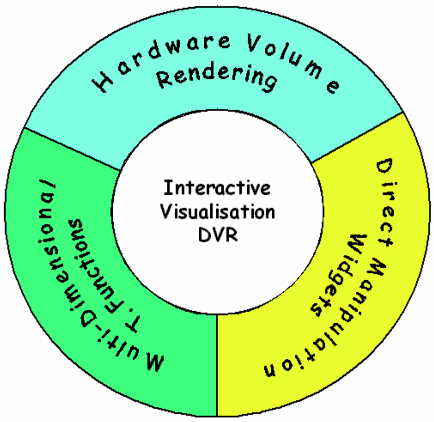

Figure 1. The interactive visualisation is possible due to three key developments: 1) Hardware Volume Rendering; 2) Multi-Dimensional Transfer Functions; and, 3) Direct Manipulation Widgets.

Hardware for Direct Volume Rendering (DVR)

Four techniques exist for the implementation of the DVR method: Raycasting, Splatting, Shear-warp, and 3D texture-mapping hardware-based approaches [7].

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Two of these methods have already been implemented by hardware. The shear-warp method is used by the pricey graphics card Volume Pro PCI. The 3D texture-mapping method (originally by Silicon Graphics) (SGI) [7], is now implemented in the new graphics cards NVIDIA and ATI, at a lower price. We choose NVIDIA graphics cards to carry out this work.

The technique based on 3D texture-mapping solves several problems of the previous methods of 2D texture, due to the development of three key aspects on interactive time: (1) The trilinear interpolation; (2) The programming of OpenGL extensions to implement the diffuse illumination, shading, and classification; and (3) The mathematical technique of preintegration made by hardware to obtain a high-quality rendering even when the sliced number is reduced [8]. Figure 2 depicts the basic mechanism applied in 3D texture-mapping for volume rendering.

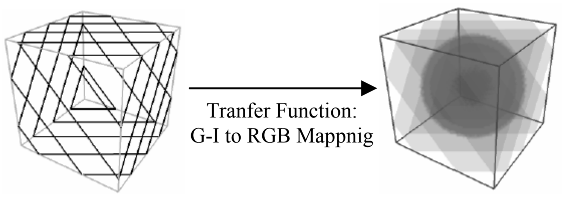

Figure 2. Basic slicing mechanism applied in 3D texture mapping based volume rendering. Also the TF is used as 3D dependent texture-mapping.

Multi-Dimensional Transfer Functions

The adjustment of the Transfer Function interactively is an important task in the volumetric visualisation. The objective of the Transfer Function is to assign the optical properties, such as: the opacity and the colour of the data to visualise.

On the space G-I Gradient-Intensity, we draw the two-dimensional histogram G-I of the three-dimensional image and the "Transfer Function" (TF). The histogram is refreshed when the region of interest changes, which is important for the segmentation.

The TF is built interactively adjusting manually the Fuzzy Classifiers (FC), existing in the space G-I. Any quantity of FC can be added.

The FC separates the materials, or they accentuate the borders of the materials, and define the optical properties; then these properties defined by the TF are transferred to the objects. In our work, four models of FC were used. Figure 3(b) shows two of these classifiers:

1. *Elliptical square*: proposed by SIMIAN Software [9] by the equation:

$$G(x,y)=\left[\frac{(x-x_0)^2}{a^2}+\frac{(y-y_0)^2}{b^2}\right]^2 \qquad (1)$$

Figure 3(b) depicts the use of this FC to define the patient's skin in white colour with transparency. Also, figure 5(b) combines two of this FC.

2. *Trapezoidal*: proposed by Levoy [5], the slope of the ramps is in the direction of the intensity on the G-I space. Figure 3(b) depicts the use of this FC to define the tissue-bone, also in figure 8.

3. *Triangular*: proposed by Levoy [5], it is used to accentuate the interfaces between regions, or the borders. The triangle opens up in the direction of G, the bisector of the triangle in that direction could be inclined at will, as well as the width.

4. *Rainbow*: has a constant opacity and the colour varies in the direction of the intensity. Also, it has global adjustment of opacity, hue, lightness and saturation (HLS). Figure 10 shows an example the use of this FC.

The first three classifiers above listed, have a colour selection one can decide on (hue and saturation), constant on the area defined by the FC. The function assigned to the FC defines the attribute of opacity. Also, all of the FC designed has a global adjustment of opacity and lightness.

The final result will be totally dependent on the Transfer Function that is chosen.

Direct Manipulation Widgets

Direct manipulation widgets are basic geometric objects designed to provide the user with a 3D interface to adjust interactively one Transfer Function. The construction of a widget is often guided by the conditions of the system. Each sub-part of a widget represents some functionality. The user has access to modify their parameters.

Figure 5(b) shows two Widgets used to modify two FC. Each one of them has the hue and saturation controls, level of opacity, size of the covered region for the FC, displacement of the centre of the elliptic function inside the Widget, and concealment of the Widget frame, as depicted in figure 5(d). In figure 3 two Widgets are used to obtain the patient's model with the purpose of planning a surgery.

Methodology
System Specifications

The system has been developed using a new programming structure, which allows modeling the interactive objects, which we have called "Mobiles", known as widgets in the bibliography. However, in the programming model that we use, we make them more versatile, and they have the capacity to interact among them.

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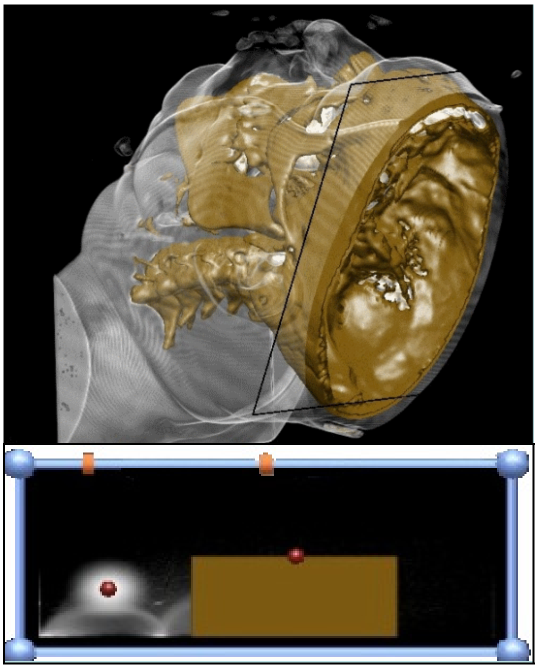

Figure 3. (a) Visualisation of the Visible Human skull (VHP) [10] with the CT images. (b) Widget for the manipulation the Transfer Functions.

Figure 4 shows the developed system, which contains six different classes of mobiles: (1) A mobile to handle the multidimensional Transfer Function, where exists the histogram, set of variables intensity, and gradient. Also, there are mobiles that are Fuzzy Classifiers. (2) Several mobiles which correspond to the models of Fuzzy Classifiers affect the TF. The TF is used as a function for mapping the 3D texture. (3) A mobile to define the ROI. These TF are global functions that modified all the volume and they are affected by the information coming from all the volume. Also, they lack the capacity to differentiate regions. The selection of ROI modifies in real time the multidimensional histogram, thus the user can identify regions of the chosen object without interference from other objects that are retro projection from other regions of the volume in the same space. (4) A mobile that represents a probe in the 3D space; the probe navigates in all the image modalities simultaneously. This probe has three components: an inflatable terminal target, a cylindrical body with which we carried out displacements, and a proximal sphere that commands the rotations. (5) Mobiles to display different cuts coming from Multimodality-MPR. (6) The multiple slices at the right of the figure are also a mobile.

Any quantity of windows with MPR projections can be open simultaneously, and in each one of them, one can select the chosen modality of the image. Thus, it is in fact a model MPR-multimodal, which is not jet of common usage in the bibliography. The 3D probe has clones in each one of the MPR windows which allows moving the probe on the cut plane. The movement of the probe is transmitted to the clones, and the movement of the clones is transmitted to the whole system of the probe and its clones. The MPR windows have its own 3D ROI where exist a cut plane, and they are adjusted in an independently. The displacement and adjustment of the ROI size of the MPR windows allows making displacements, and zooms over the cuts. These MPR windows do not navigate the information of the 3D texture, but the original dataset of the patient's studies. The MPR windows has six views that can be selected, the three habitual: axial, sagital, and coronal, and three orthogonal views, two of them containing the body of the probe. This facility provides the physician, the visualisation of the navigation of the probe, inside the patient's anatomy, when simulating a procedure of surgical planning.

Segmentation

For the segmentation, the target of the probe is located on one or several MPR views. On a chosen point of the object to segment, double click on the target of MPR view. This point becomes a seed to begin the search of the iso-surface of the object. This procedure can be repeated as many times as it is needed, until obtaining a model that represent an optimal view of the object. Afterwards, one can add parts to the object of interest, such as in the cases of complex objects which possess several components, or several scales, by repositioning the ROI again.

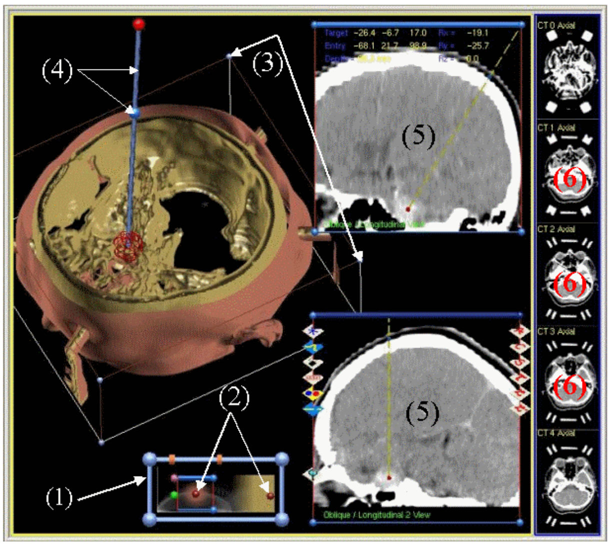

Figure 4. Main window of the Software for surgical planning developed for this project, with eight interactive mobiles.

Results
Medical Applications

Figure 5 shows the visualisation of the brain vessels tissue from a 3D MR angiography study. The original dataset [11] is composed of 256 x 256 x 150 voxels, which is obtained from the subtraction of two acquisitions: one before, and one after the injection of the dye contrast. It is easy to compare the excellent

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quality from our images when using the method of 3D texture-mapping hardware based approach compare with the visualisation obtained in [11].

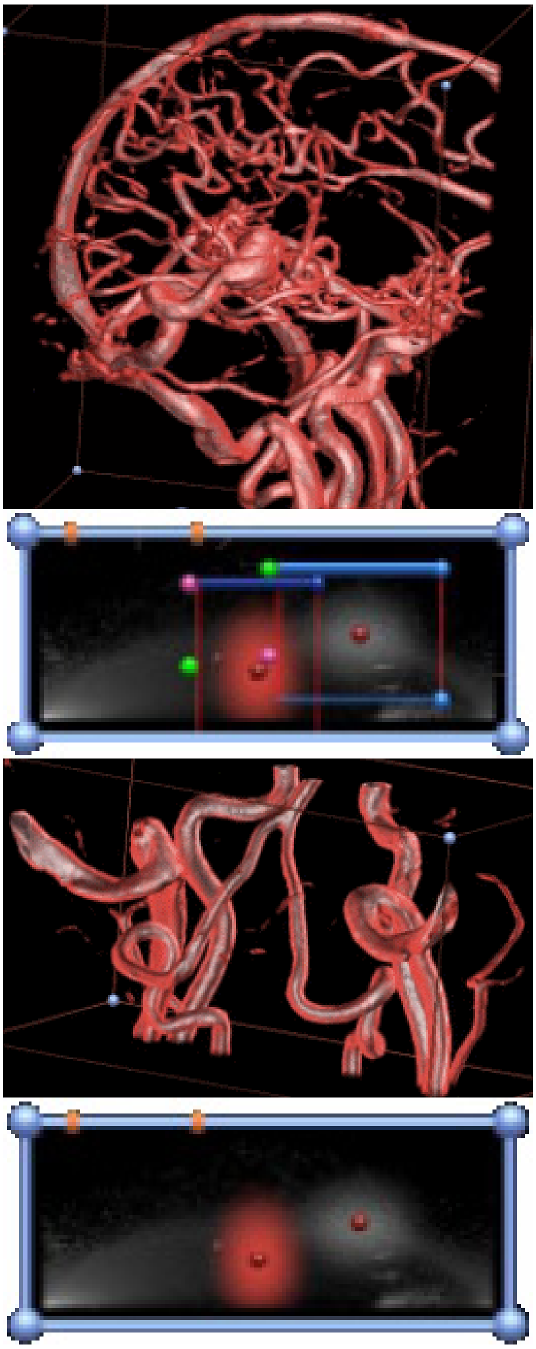

Figure 5. Visualisation of the brain vessels.

Figure 6 shows a clinical case of one patient of the "Hospital Metropolitano del Norte" at Valencia, Venezuela, where the volumes of CT and MRI were rendered independently, using the method of 3D texture-mapping. The volumes of the CT and MRI images were fused, to obtain a single projection. The tissue-bone is visualised parting from the images of CT and the meningioma is visualised from the images of MRI. That is possible since the MRI images have a rich amount of information meant for the soft tissue. Our method of visualisation using 3D texture-mapping hardware-based does not consider the multi-texture process. However, for the surgical planning we obtain an approximate view of the two interested volumes, as it is shown in figure 6. An equivalent result could be obtained segmenting the meningioma issued from the MRI study and fusing it with the image of 3D texture issued from the CT.

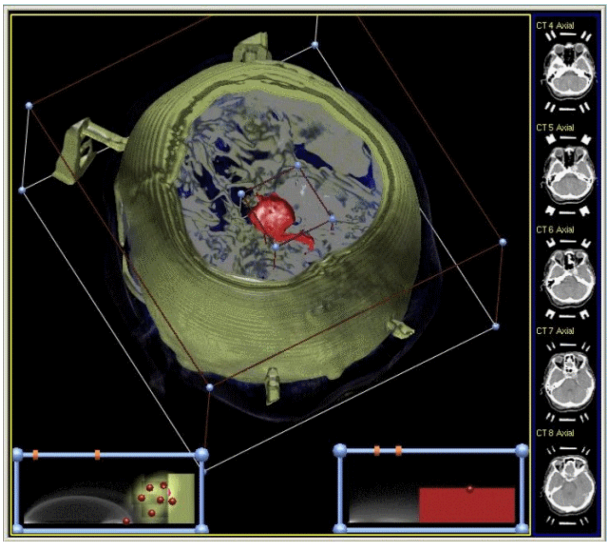

Figure 6. Clinical case of a patient with a meningioma.

Multimodality-MPR

To use the MPR Multimodal, consider that, previously two or more studies issued from several modalities have been registered in space. In our case, this procedure is supported by the use of stereotactic frame. Afterwards, it is important that the specialist can analyse the patient using both modalities of vision: the three-dimensional and the two-dimensional. For this reason in the developed software is considered important the interaction among both modalities. We are interested in the simultaneous visualisation of 3D projections plus the visualisation of two-dimensional cuts. The movement and the visualisation are interconnected interactively through a probe that indicates the access position inside the brain. This novel visualisation promises to be an indispensable tool for the surgical planning.

Figure 7 shows two types of multimodal visualisation, in the superior part a tomography cut is observed with the superposition of the magnetic resonance image. In the inferior part of the figure the equivalent is shown in 3D with different colours for the 3D multimodal visualisation of half of the head with resonance and the other half with tomography.

Figure 8 shows a tomography and resonance study, previously registered. The user can interact in both

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studies, mixing the images of CT and MRI in the window of surgery planning. The superior image shows the target positioned in a specific anatomy with the purpose of verifying the quality of the registration. The novel part corresponds to the interconnection of all graphic elements in 2D and 3D that are observed in the figure, and they allow knowing at all moment the position of the probe inside of the anatomy of the brain, in multiples modalities.

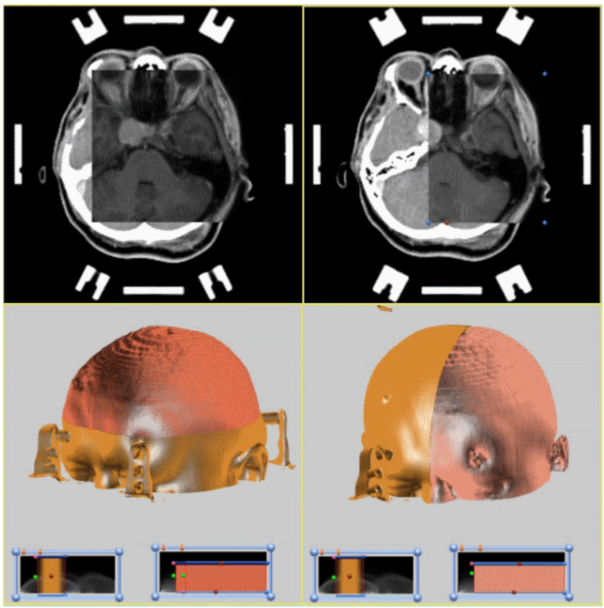

Figure 7. Images fusion after Registration with a stereotactic frame of Leibinger. Original studies of CT and MRI obtained by Praezis.

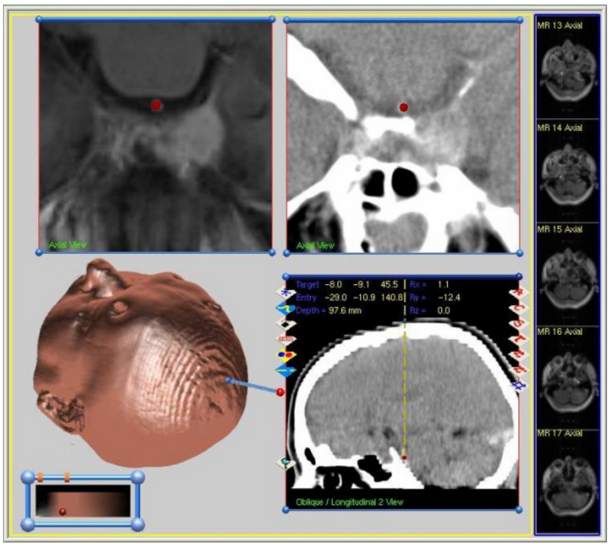

Figure 8. Surgical planning using MPR multimodal visualisation.

Computer Assisted Planning of Surgeries

For the evaluation of this methodology presented in this work, a human skull mounted on a stereotactic frame (Micromar) with an Emotion scanner (Siemens) was scanned; as observed in the figure 9. The captured images of the tomograph have 512 x 512 pixeles.

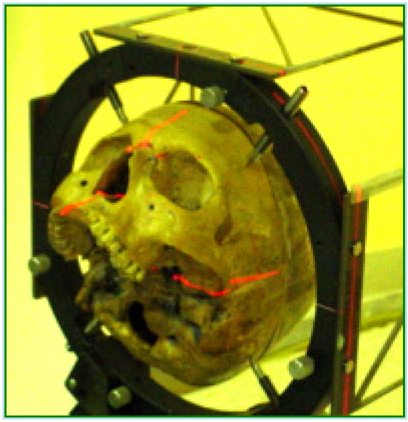

Figure 9. Skull to prove the precision of the method.

Figure 10 shows the surgical planning and it uses a volume transform with 12 degrees of freedom for the frame register. The user can interact with the probe in 2D and 3D spaces. We may open up any number of windows. As figure 10 depicts, the axial view and two orthogonal views containing the probe are shown. Our software gives the stereotactic coordinates of the simulated tumour and then this result is verified on the skull of the figure 9.

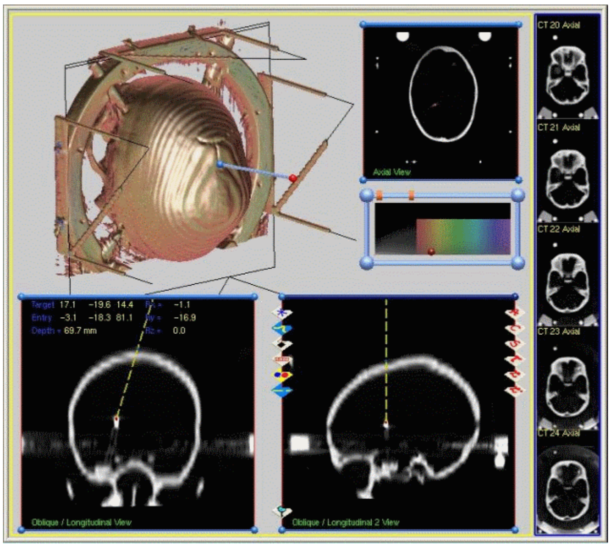

Figure 10. Simulation of the surgical planning with a stereotactic frame Leksell.

Discussion

The present work demonstrates the value of the Direct Volume Rendering using multi-dimentional Transfer Functions and the feasibility of using these sets of images in the pre-operative planning. This approach can be applied in the clinical practice with minor effort by the surgeon. The main advantage is the easiness of manipulation of the Transfer Functions by the widgets

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and the excellent visualisation, plus the correct visualisation of the structures near to the target. On the other hand, all the tests were conducted on standard PCs equipped with consumer high-performance graphic cards such as NVIDIA; thus, sophisticated workstations for a surgical planning are not required.

Conclusions

This system allows combining the 3D navigation with a probe, a novel proposal for the MPR-multimodal vision, visualisation using 3D texture-mapping, interactive Fuzzy Classification, and medical knowledge to obtain interested objects to visualise them with studies of different modalities. Our new technique presented allows simulating and planning of surgeries, visualising the navigation of the probe through the patient's anatomy, and obtaining more knowledge of the particular anatomy of each patient.

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