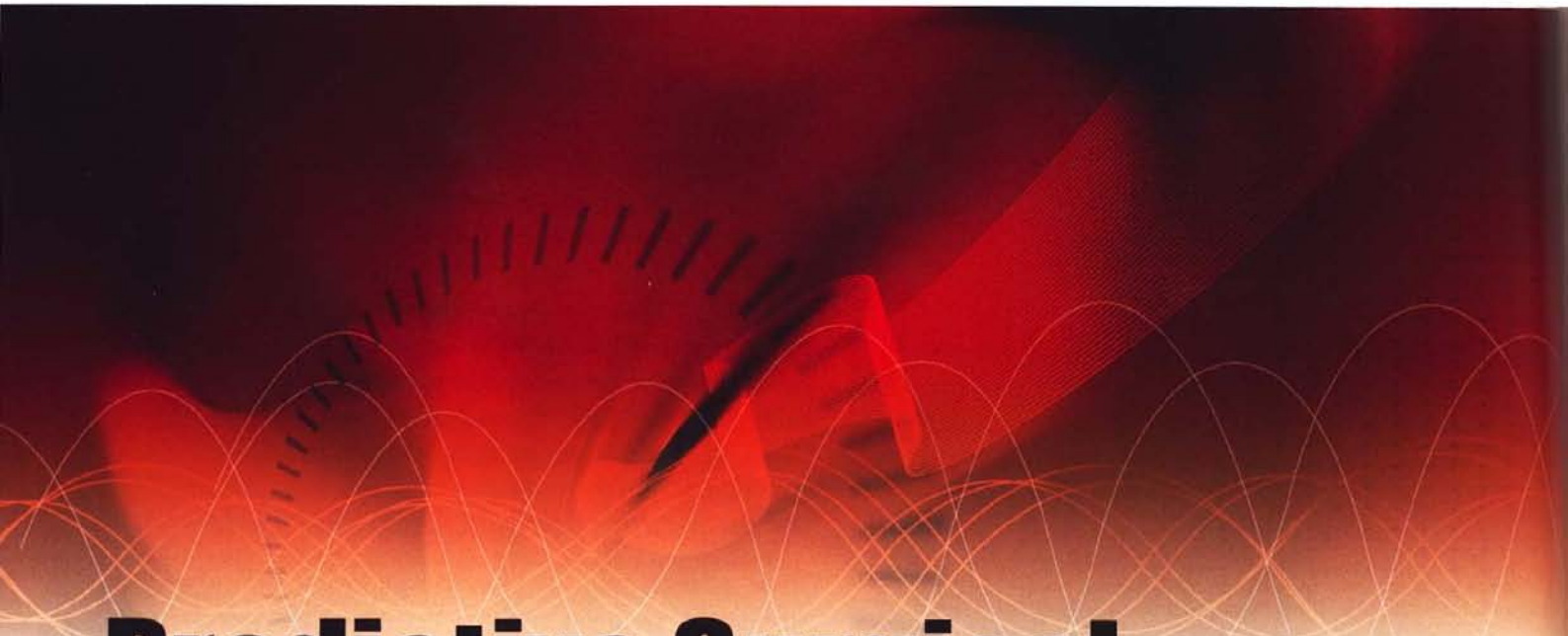


Predictive Surgical Simulation for Planning Cardiac Surgeries

The next wave in the planning of complex cardiac surgeries will empower cardiac surgeons with the ability to see the results before the operations.

by Hao LI and Wee Kheng LEOW

Most cardiac surgeries are complex procedures because of the complexity of human heart and various heart diseases. Special care and a delicate surgical plan are required for complex cardiac surgeries. Moreover, the anatomical structures of different patients differ significantly, including the pattern, size, orientation and spatial relationships of the blood vessels. Precise surgical planning is needed to tailor the surgical procedure to different patients. At present, no convenient computer tool is available for the surgeons to perform pre-operative planning and simulation. They often rely on manual drawing to visualize the surgical procedure and the expected results. This approach is not precise and is impossible to provide detailed information about the possible outcome of the surgical procedure.

To improve the precision and effectiveness of cardiac surgical planning, novel computer simulation systems that perform planning and simulation of cardiac surgeries are in demand. These systems should be able to help the surgeons to easily explore various surgical options, predict the surgical outcomes of different

options, accurately evaluate the surgical outcomes and determine the best surgical options.

Over the last decades, many surgical simulation systems have been developed. Most of them are reactive systems that simulate real-time behaviour of the body tissues in response to user inputs that emulate real surgical operations such as cutting and suturing. These reactive systems are very useful for medical training and preoperative planning of simple operations. However, they are not suitable for predicting the results of complex surgical procedures because the user will need to go through all the detailed surgical steps, which is very tedious and time-consuming.

In contrast, our research goal is to develop a predictive simulation system for cardiac surgery. This system visualizes 3D models reconstructed from patient's CT/MR images for the surgeon's reference. Given a small number of user inputs, the system can predict complex surgical results that involve soft tissues such as the heart and the blood vessels. With this kind of system, the surgeon does not have to go through all the surgical steps to see the expected surgical results. They can easily and efficiently explore various surgical options to develop a comprehensive surgical plan.

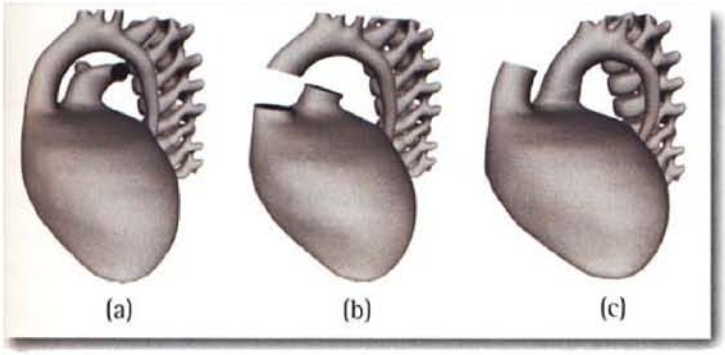


Figure 1: Demonstration of surgical simulation of aorta reconstruction. (a) Reconstructed 3D model from a patient's CT images. (b) Arterial transection results. Some parts of the blood vessels are removed for visual clarity. (c) Reconstructed aorta. The reconstructed aorta bends more than its original configuration.

Our target application, in collaboration with Professor Chiu Ing-Sh from National Taiwan University Hospital, is complex cardiac surgery, such as Arterial Switch Operation, Bidirectional Glenn procedure, etc. Our current prototype system can simulate several crucial surgical operations including artery transection (cross-sectional cut) and incision, blood vessel joining and aorta reconstruction etc. Figure 1 illustrates an example of artery transection and aorta reconstruction.

In addition, our system can measure important properties of the blood vessels, including stretching, bending and torsion results of the surgical operation. It visualizes these properties in an intuitive manner (Figure 2). The surgeon can then easily determine whether the predicted surgical results are acceptable

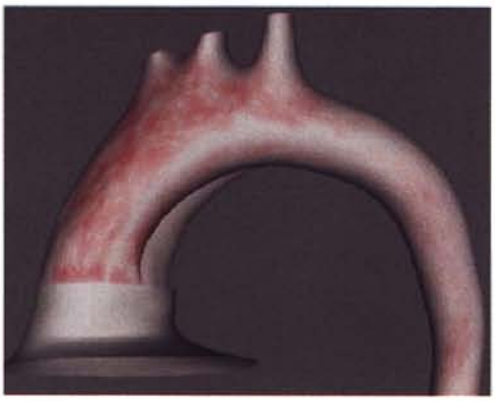
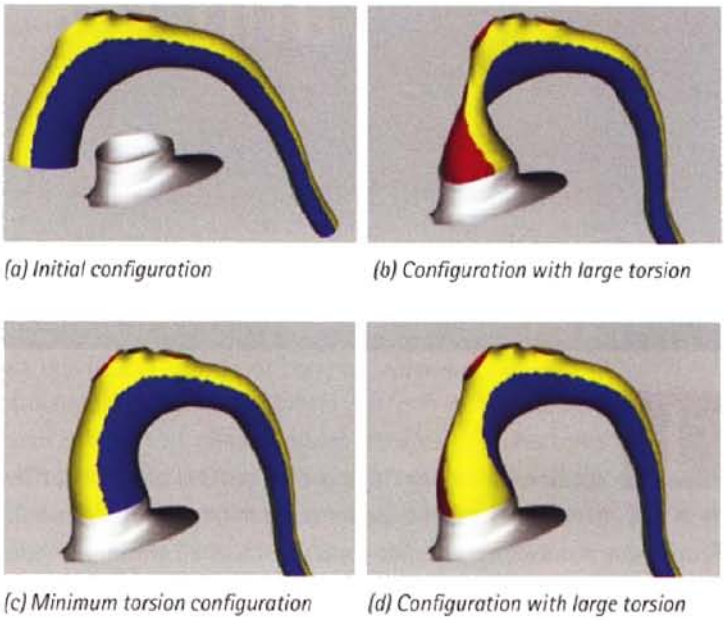


Figure 2: Stretching of blood vessel is indicated by red colour.

or not. If the result is not acceptable, the surgeon can quickly try another surgical option. The system can also compute the configuration of the blood vessel that satisfies certain properties, such as minimum torsion (Figure 3).



(a) Initial configuration *(b) Configuration with large torsion*

(c) Minimum torsion configuration *(d) Configuration with large torsion*

Figure 3: Joining of aorta to neo-aortic root. Aorta is shaded in colour to visualize torsion. The system can automatically find the joining configuration with minimum blood vessel torsion (c).

Our simulation system does not require the surgeon to carefully emulate the whole surgical operation. Instead, it acquires only several points picked by the user to indicate the surgical option. After that, it can intelligently predict the desired surgical results. With this system, the surgeons can easily and efficiently explore various surgical options to determine the best options.

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