The Computer-assisted Port Placement Planning System for Minimal Invasive Cardiac Surgery

Zhe Luo, XuBo Yang, Lixu Gu *, Junfeng Cai, Rong Xu and Qiang Zhao

***Abstract*—Minimal invasive cardiac surgery has many advantages such as minimal wound, fast recovery. However the inappropriate port placement will result in serious problems, for example, the view of thoracoscope can not cover the target, the surgery instruments can not reach the target and so on, which not only affect the effect, but also even may lead to the surgery failure in worst case. So it is crucial to make a scientific and accurate port placement planning for minimal invasive cardiac surgery. This paper presents a computer-assisted port placement planning system based on four criterions to achieve the planning. The system was used to do the port placement planning on five atrial septal repair (ASR) patients and five coronary artery bypass grafting (CABG) patients. The results were compared to the results using traditional method to justify its validity and superiority.**

I. Introduction

MINIMALLY-INVASIVE cardiac procedures can potentially reduce complications arising from surgical interventions by minimizing the size of the incision required to access the heart, while employing medical imaging to visualize intracardiac targets without direct vision [1]. In recent years, there has been a progress trend to use the minimal invasive surgical techniques on the cardiac surgery to reduce the side effects of the surgical procedures [2].

The minimal invasive cardiac surgery is done with the thoracoscope and two surgical instruments which are inserted into the patient's chest through three ports that were opened on the patient. However it arises a problem on the location of the ports. Incorrect port placement will result in problems such as the view of thoracoscope can't cover the target and the instruments cann't reach the surgical region, which not only affect the efficiency, but also even lead to the surgery failure in worst cases.

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The traditional port placement planning is done by the surgeons according to the experience associated with the bony landmarks after they read the images of patient. This kind of port placement planning method is still used wildly in most minimal invasive cardiac surgery at present. The traditional method has the disadvantages of big differences between the patients, largely dependence on experience and lack of measurable standard. TM.Peters first tried to do the port placement planning research using the 3D image [3]. He used the 3D model reconstructed from the patient's chest image of CT and MRI to rebuild the surgery environment model and simulate the surgery in it according to the special request of coronary surgery to find the best approach. This original method has not specific measure criterion which makes it stop at the point based on the satisfaction of the surgeon. Moreover the method didn't take all the information obtained before the surgery into account. However it opened the way using the 3D image to do the preoperative planning of minimal cardiac surgery. After that many researchers used the 3D images to do the preoperative planning. But the researches of preoperative planning still stay on the way using 2D image which can not show the anatomical structure. It still has a long way to the preoperative port placement planning which is safe, surgeon comfortable and optimum.

The system presented in this paper uses the visualization technology to gain the 3D models of the heart and skeleton from the CT image of patient, and achieves the port placement planning with an algorithm based on four optimum criterions.

II. Methed

A. The definition of parameter

First of all, we need to define three parameters: α , β and d as shown in the figure 1 where

α : The angle between the normal of the target and the direction of the line segment connecting the port and the target.

β : The angle between the normal of the port position on the chest wall and the direction of the line segment connecting the port and the target.

d : The distance between the port and the target.

B. The criterions of optimum

We proposed 4 optimum criterions as follow according to the relative references and the surgery experience of surgeon of the Zhongshan Hospital Fudan University.

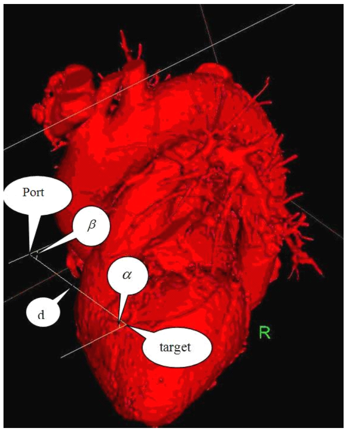

Fig. 1. The definition of parameter

1) The reachability criterion

This criterion judges whether the surgery instrument is long enough to reach the target.

2) The view of thoracoscope criterion

For the port of thoracoscope which is zero degree, the smaller the α is, the better view the surgeon can get. Therefore the α should be as small as possible with it is less than 90 degree [4][5].

3) The flexibility of the instrument criterion

The β angle showing the flexibility of the surgery instrument actually. The larger the β is, the larger motion range and the better flexibility the surgery instrument has. However if the β is too large, it will give the surrounding tissue extra pressure which may cause the unnecessary injuries [4][5][6][7]. Thus the β angle should be as big as possible less than 60 degree [5] in ASR and 90 degree in the CABG according to the surgeon's experience.

4) The optimum triangle criterion

In the minimal invasive cardiac surgery, one thoracoscope and two surgery instruments are used. So there are three ports for them forming a triangle. Take the line segment between the two ports of surgery instruments as hemline, its length showing the possibility of the collision between the two instruments [5][7]. The quotient of the other two sides which is the shorter one dividing the other one expresses the symmetry of the triangle. So the hemline is supposed to as large as possible, and the quotient as big as possible.

C. The process of the preoperative port placement planning

After the model of heart and skeleton constructed, the port placement planning can be done on them. There are three steps to finish the port placement planning. All the three steps are process in the system.

1) We need the target position and should compute the normal of target. However, the surface of the target is not flat. Thus the normal of the target's surface can not be confirmed directly. Here we propose a method to solute this problem. We can put a lot of points on the target's surface (Fig 2). Then these points can be used to fit a plane with least square method. The normal of the plane can be considered as the normal of target and the geometric center of the points can be considered as the target position(Fig 3).

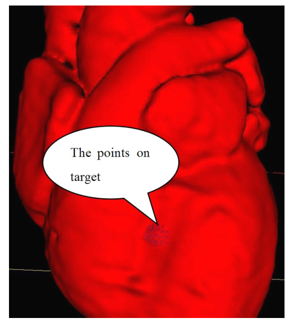

Fig. 2. The points on target

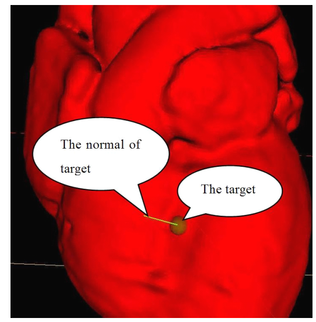

Fig. 3. The target and its normal

2) Compute the candidate positions for ports and their normals. For the ports are put in the intercostal, the candidate positions should also be put in the space between two adjacent ribs. The edge of rib could be considered as a curve. Thus we can calculate a curve between two ribs which fits the surface of chest wall between the two ribs well, and obtain the candidate positions along the curve. The system uses the cardinal spline to create the curve as the Fig 4 showing.

Then compute the normal of each candidate point. The normal of the candidate point should be the same as the normal at the position of the candidate point on the chest wall's surface. We can get the normal plane at a point of cardinal spline. The normal needed is in the plane. The plane confirmed by the control points can be used to find the normal from the plane (Fig 5).

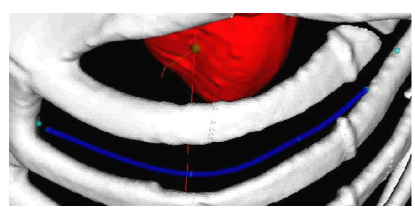
Fig 4. The curve of candidate points

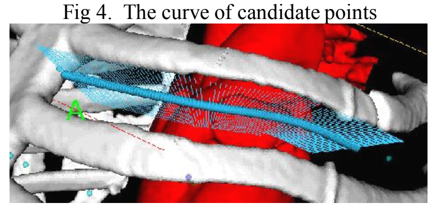
Fig 5. The normals of candidate points

3) The last step is to select ports from candidate points. After creation of the candidate points on the intercostals around the target, the ports for thoracoscope and instruments

will be selected from the candidate points first. We calculate the α , β angle and the distance to the target of each candidate point. Remove the candidate point whose distance to the target is longer than the length of instruments from the candidate points according to the first criterion above. Then the candidate point which has the smallest α angle is selected as the port for thoracoscope according to the second criterion above and it also is removed from the candidate points. The next step is to choose the ports for surgery instruments. We get the every possible two points from the candidate points and make them construct a triangle with the thoracoscope port. Take the line segment between the two ports of surgery instruments as hemline and calculate its length and the lengths of the other two sides. An evaluation value is proposed according to the criterion 3 and 4 and given to every triangle. The triangle which has the biggest value will be selected and two points of it will be used as the ports for surgery instruments. The evaluation value which considers four factors is expressed as follow.

$$f_1 * \bar{\beta} + f_2 * \beta_e + f_3 * h + f_4 * s_e \quad (1)$$

$\bar{\beta}$: The average of the β angles of the two candidate points of a triangle.

β_e : In case of the excessive difference between the two β angles, β_e which is the quotient of the smaller β angle dividing the other one is considered.

h : The length of the hemline.

s_e : According to the criterion 4, the length of two sides which are not hemline should be as equivalent as possible. Thus, s_e which is the quotient of the shorter side dividing the other one is considered.

f_i : The weight of each factor.

The Fig 6 is a result of the port placement planning done by the system.

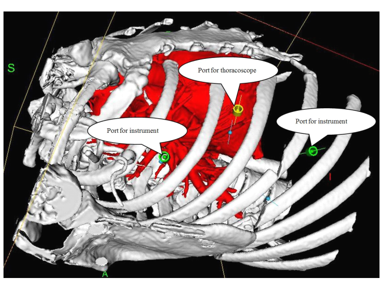

Fig. 6. A result of port placement planning

III. EXPERIMENT

According to the reference, the experience positions of the ports of the CABG[8][9][10][11] and ASR[12][13][14] are shown in the table1.

We used the system to do the port placement planning on five CABG patients and five ASR patients. The Fig 7 and 8 show an example for CABG and ASR respectively. The yellow triangle is the optimum positions and the blue triangle is the experience positions.

And the results were compared to the results using experience positions as the table 2 and table 3 showing respectively.

IV. DISCUSSION

The table 2 and table 3 are the statistics of CABG and ASR respectively. The $\bar{x}$ is the mean. From the data statistics, we can see that the optimum ports of thoracoscope for these two kinds surgeries are smaller than the experience ones, which will take much better view according to the criterion 2. The ports for the surgery instruments are bigger than the experiences, so the optimum ports for instruments will more flexible according to the criterion 3. And the results of optimum ports are more stable than experience ports. The eighth and ninth rows of these tables are the values according to the criterion 4 using expression (1).We can see the traditional way and the optimum way have little difference in this aspect. It reveals that traditional way and the optimum way have good correlation in this aspect, and both values were close to the maximum 0.5. Both the traditional way and optimum positioning method can provide comfortable operation and have low possibility of collision between the surgery instruments. However, the optimum ports have better view and flexibility benefit from the balance of the optimal criterions, which is considered superior to the traditional way.

V.DISCUSSION

This paper depicts and implements a new developed system to achieve the port placement planning in the minimal invasivecardiac surgery. This system overcomes the disadvantages of traditional way and supplies the surgeon a generally applicable, scientific and effective computer-assisted system to finish the port placement planning correctly.

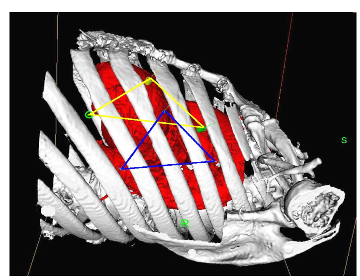

Fig 7. A result of CABG

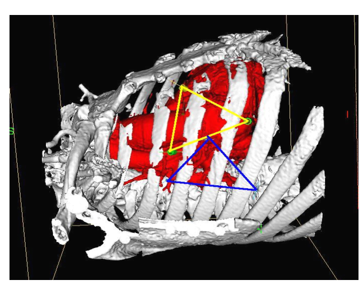

Fig 8. A result of ASR

TABLE I
EXPERIENCE POSITIONS FOR CABG AND ASR

Port type	CABG	ASR
Thoracoscope port	midclavicular line at the fourth intercostal	midclavicular line at the fourth intercostal
Left instrument port	midaxillary line at the sixth intercostal	midaxillary line at the sixth intercostal
Right instrument port	midaxillary line at the third intercostal	midaxillary line at the third intercostal

TABLE II
THE RESULT OF CABG

Patient number	Experience port for thoracoscope	Optimum port for thoracoscope	Experience port for left instrument	Optimum port for left instrument	Experience port for right instrument	Optimum port for right instrument	The value of criterion 4 for experience port	The value of criterion 4 for optimum port
1	67.56	21.12	42.23	43.23	30.23	41.29	0.42	0.38
2	52.23	24.50	35.96	46.76	49.25	43.52	0.40	0.42
3	57.93	22.06	44.52	60.23	45.88	59.36	0.40	0.41
4	39.03	24.02	33.52	66.36	50.27	63.58	0.42	0.40
5	30.65	20.96	46.38	61.51	41.05	60.12	0.41	0.40
$\bar{x}$	49.48	22.532	40.522	55.618	43.336	53.574	0.41	0.402

TABLE III
THE RESULT OFASR

Patient number	Experience port for thoracoscope	Optimum port for thoracoscope	Experience port for left instrument	Optimum port for left instrument	Experience port for right instrument	Optimum port for right instrument	The value of criterion 4 for experience port	The value of criterion 4 for optimum port
1	57.04	23.21	45.36	48.70	28.96.	44.35	0.41	0.39
2	71.17	21.36	50.53	42.63	47.36	42.47	0.42	0.41
3	35.58	22.33	42.38	49.63	39.25	48.66	0.40	0.39
4	43.75	25.27	35.77	50.02	37.73	42.98	0.41	0.41
5	40.23	28.79	46.59	48.76	40.24	45.22	0.42	0.40
$\bar{x}$	49.554	24.192	44.126	47.948	38.708	44.736	0.412	0.40

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