

A Development of Navigation System for Mosaic Plasty using Electromagnetic Sensor

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Abstract—Mosaic plasty is a surgery that transplant osteochondral grafts for osteochondritis dissecans. In mosaic plasty, cylindrical osteochondral grafts are harvested from normal area, and transplanted to injured area. The one of the most important thing of this surgery is that the graft should be perpendicular to the surface of the cartilage. The navigation system that aims improvement of precision is already studied, however cannot be applied to use an endoscope. In addition, it is a problem to have bad precision of the transplant in the freehand. Therefore, we thought that the system would widely used if we develop the mosaic plasty navigation system under an endoscope. This study proposes a navigation system to determine a proper position and pose for harvesting. In the experiments, a femoral imitation bone is used as a profile of the femoral joint surface. The experiment consists of the following three procedures: Trace and display of the femoral joint surface profile and a harvester. Display of a normal vector for the femoral joint surface. Measurement of the deviation of the normal vector. In the results, the developed system could display the femoral joint surface and the normal vector for the femoral joint surface virtually. Also, the deviation of the normal vector was an average of 7.27 degrees. As future works, there are to decrease the deviation of the normal vector by improving the precision to acquire the femoral joint surface profile, and to visualize the normal vector for the generated surface.

Keywords—component; mosaic plasty; electromagnetic sensor; 3D image processing; navigation system

I. INTRODUCTION

One of the treatment of the cartilage damages of the knee is mosaic plasty. The self cartilage transplantation method such as mosaic plasty requires precision in 3D. The navigation system that aims improvement of precision is already studied, however cannot be applied to use an endoscope. In addition, it is a problem to have bad precision of the transplant in the freehand. Therefore, we thought that the system would widely used if we develop the mosaic plasty navigation system under an endoscope. We propose a system to navigate a perpendicular transplantation with a three-dimensional electromagnetic sensor under an endoscope. The system requires to navigate with precision same as freehand. The matter evaluated with precision is the angle which a normal for the joint surface and the axis of articular cartilage which is harvested and a

transplanted. In the precedent study, freehand was 10.7 degrees[1].

A. ARTICULAR CARTILAGE

The articular cartilage is covering joint surfaces, and has a role to smooth the joint move. When this articular cartilage suffers the damage, a pain occurs to the joint. For a cure for articular cartilage, drillings for the subchondral bone had been performed in 1957 by Pridie. However, that drilling restores not the hyaline cartilage but the fibro cartilage. Then, Matsue et al. [2] and Brittberg et al. [3] reported a reproduction of the articular cartilage with the hyaline cartilage.

B. MOSAIC PLASTY

A method of transplantation grafts to the femoral condyles in autologous osteochondral transplantation is named as “mosaic plasty” by Dr. Hangony, and an original surgical instrument was developed and spread out rapidly[4]. It is a transplantation surgery that a graft is harvested from a non-load part of the bone surface, and inserted to the cartilage defect as shown in Fig. 1.

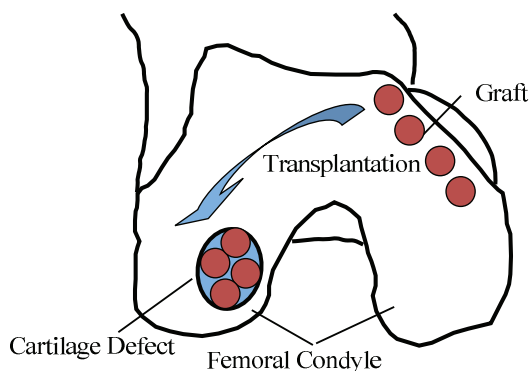


Figure 1. MOSAIC PLASTY

C. SURGERY PROCEDURE

For the procedure of this surgery, It consist of the four following procedures as shown in Fig. 2.

- Loose body of the cartilage defect is removed.
- The place of the cartilage defect is drilled to making a hole.
- A cartilage graft is harvested with a harvester.
- The harvested graft is inserted to the defect.

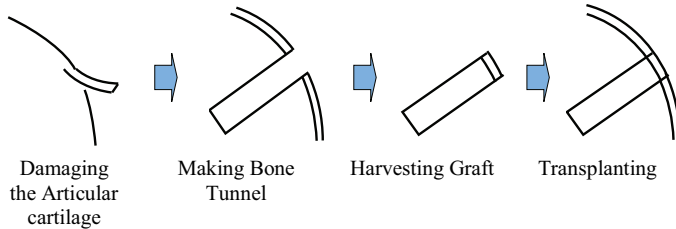


Figure 2. Surgery Procedure

D. THE PROBLEMS OF THE SURGERY

When a discontinuous surface is made after transplantation, there is a problem that it is easy to separate an articular cartilage from the bone surface. With a movement of the knee joint. It results in regenerating the cartilage defect. Therefore, it is important to harvest and transplant the cartilage graft vertically to the joint surface, so that the surface should be continuously.

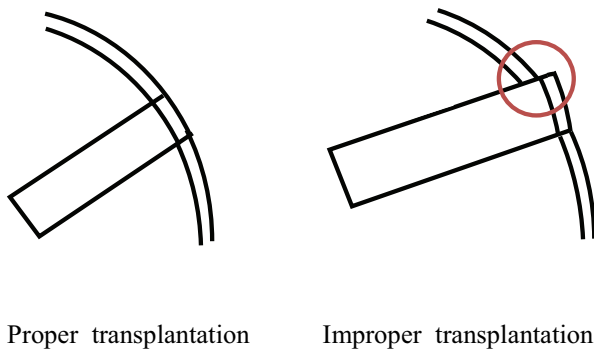


Figure 3. A proper and improper example of the transplant

II. MATERIALS AND METHODS

A. Electromagnetic Sensor

In this study, we perform the three-dimensional position and pose that we used electromagnetic sensor (Polhemus Inc., PATRIOT) as shown in Fig. 4 [5]. An electromagnetic sensor enables us to acquire data without being influenced by a physical obstacle. It is six degree of freedom measurements device consists of one transmitter, two receivers and a control unit. The precision of this device is 1.52 mm about the position

0.4 degree about the pose. This precision is guaranteed in 30 inches between a transmitter and receiver.

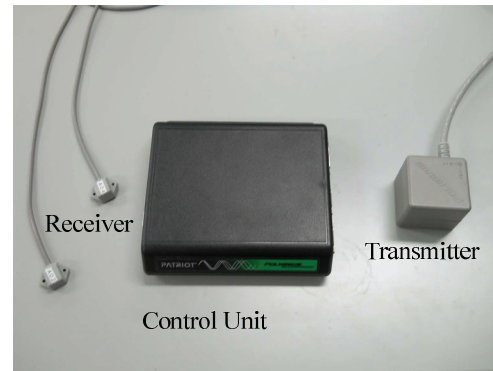


Figure 4. Electromagnetic sensor (PATRIOT)

B. Proposal Method

In this study, we use an electromagnetic sensor and propose a method to navigate the harvester which is perpendicular to the knee joint surface. The proposal method consists of three steps. The steps are A) Acquisition of the joint surface profile, B) Display of the joint surface profile and the harvester. C) Navigation of harvester.

1) Acquisition of the joint surface profile

A tracer whose tip has a force sensor is used to acquire a profit of the femoral joint surface. The receiver is attached to the tracer to obtain three-dimensional information. The joint surface is obtained by tracing the profile of the joint surface as shown in Fig. 5.

Here, to obtain information of the tip of the tracer , it is necessary to calibrate the position and pose of the sensor. Information of L_1 and L_2 , that is relative position from the sensor to the tip of the tracer is known beforehand as shown in Fig. 6. In addition, Fig. 7 shows a relationship between the center of the sensor and the tip of the tracer which is determined by pose parameters of ψ , θ , and ϕ . And positional informations of the sensor in it self are x , y , z .

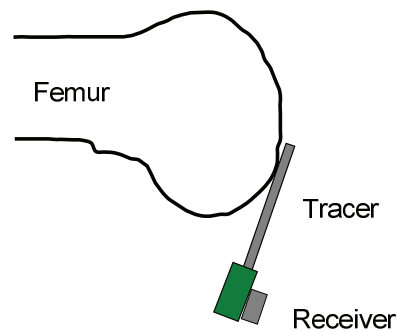


Figure 5. Tracer

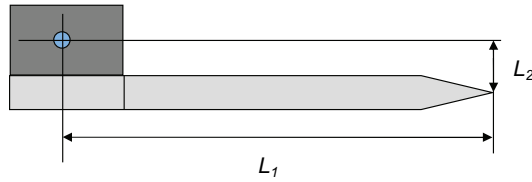


Figure 6. The distance between center of the sensor to the tip of the tracer

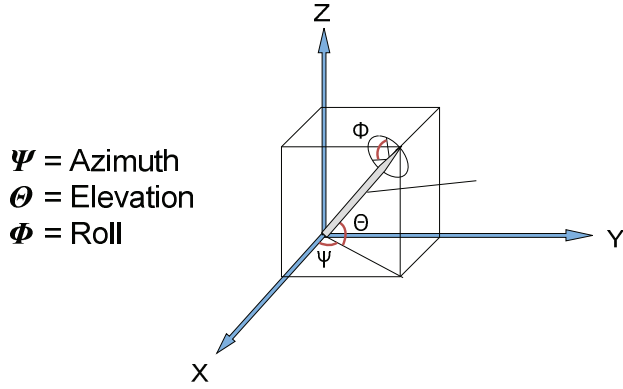


Figure 7. The pose between the center of the sensor to the tip of the tracer

The calibration is performed with the following equation,

$$x = L_1 \cos \psi \cos \theta + L_2 (\sin \psi \sin \phi + \cos \phi \sin \theta \cos \phi)$$

$$y = L_1 \sin \psi \cos \theta + L_2 (-\cos \psi \sin \phi + \sin \phi \sin \theta \cos \phi)$$

$$z = -L_1 \sin \theta + L_2 \cos \theta \cos \phi$$

2) Display of joint surface profile and harvester

The electromagnetic sensor is attached to the harvester which is a surgical instrument during the graft harvesting. The profile of the acquired femoral joint surface and the developed harvester are virtually visualized in a three-dimensional space on the computer.

a) Creation of virtual a joint surface profile

The information acquired using the tracer is displayed as points. Therefore a joint surface profile should be virtually created from the points. The reasons to create surface are the following things. It is easy to understand the femur profile rather than points. It shows a proper position and pose which is perpendicular to the knee joint surface. In this study, the marching cube method[6] was used to create the joint surface from the points. In the method, a data set should be three-dimensional volume data. Therefore, the collected points are approximated to the nearest points as vertexes of cube lattice of a size set beforehand as shown in Fig. 8. Vertexes i, j, k are set on axes x, y, z respectively. When a point is less than the midpoint of a distance between two vertexes, the point is set to be i, j , or k . In otherwise, the point is set to be $i+1, j+1$ or $k+1$ as shown in Fig. 9. In that process, when a point exists, it is set to be one. When no point exists, it is set to be zero. This time,

to be used Marching cube method[6] as a way to create surface from point.

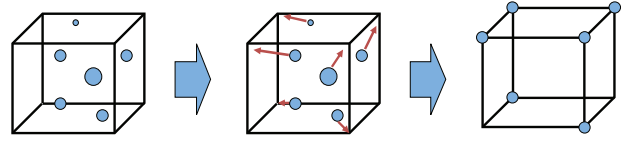


Figure 8. Similar to the vertex of the cube lattice

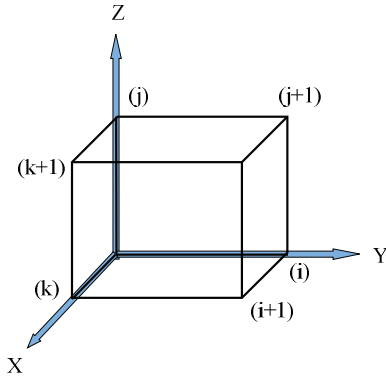


Figure 9. Approximate method to the vertex of the cube lattice

3) Navigation of harvester

The computer navigates a surgeon to hold the harvester at a proper position and pose in real-time the harvester is perpendicular to the bone surface as shown in Fig. 10.

The algorithm to display the normal vector devises the following. On real femoral joint surface, pointing the place that wants to let you display the normal vector in harvester. Existing points on a spherical surface of a radius of 10 mm around the tip of the tracer are selected as shown in Fig. 11 and Fig. 12. A spherical surface is shown as a brown line. Then points on the surface are shown as red points. Next, three points are extracted from the red points so that the three points close to be an equilateral triangle as shown in Fig. 13. Last, a normal vector could be calculated from the extracted three points, and the normal vector and the femoral joint surface are displayed simultaneously.

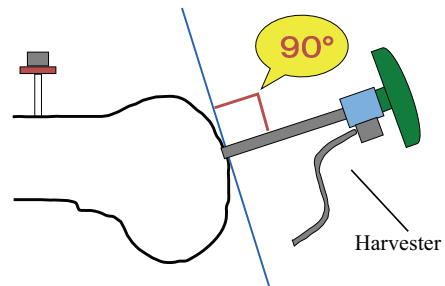


Figure 10. Navigation of harvester

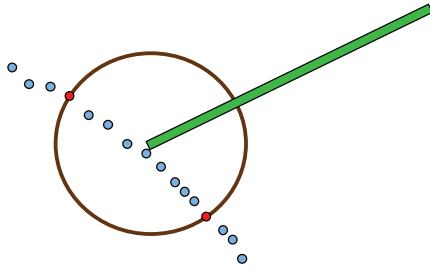


Figure 11. Normal vector indication algorithm (lateral viewpoint)

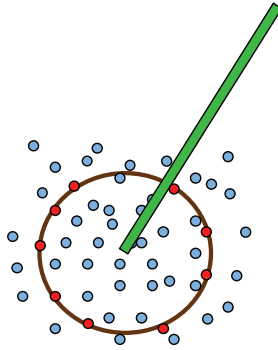


Figure 12. Normal vector indication algorithm (anterioris viewpoint)

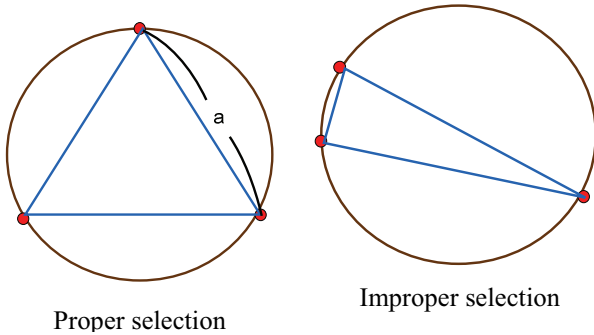


Figure 13. Three points of how to get to choose among the point

C. EXPERIMENTS

1) Display of the joint surface profile

In this experiment, the femoral sawbone is used as the shape of joint surface as shown in Fig. 14. As position and pose information is also required for sawbone, the titanium pins are inserted to the femoral sawbone approximately 80 mm in the proximal from the knee joint line, then the sensor is fixed to the pins with an attachment. Actual measurement scene is shown in Fig. 15.

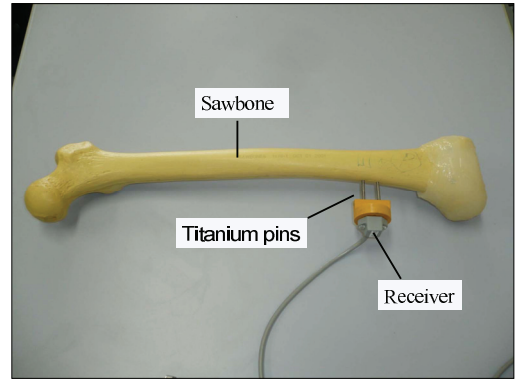


Figure 14. Femoral sawbone

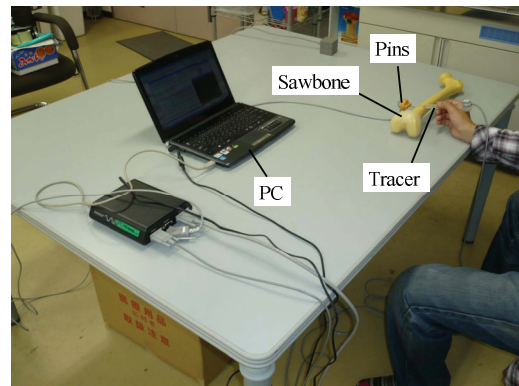


Figure 15. Measurement scene

2) Display of the normal vector for the knee surface

A place where the tip of the tracer is indicated is calculated on the computer. A normal vector which is located at the calculated position, and is perpendicular to the bone surface is analysed. The normal vector is displayed on the three-dimensional space as shown in Fig.16.

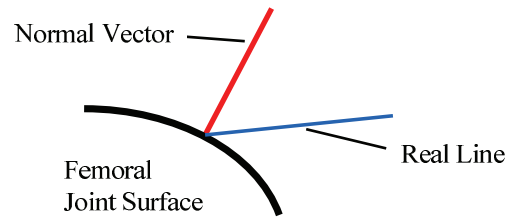


Figure 16. Normal vector

3) Measurement of deviation of the normal vector

In this experiment, we measure deviation of the normal vector. The deviation is calculated as the maximum angle between two poses of the normal vector when we keep pointing for 5 seconds to arbitrary point on the joint surface in same pose as shown in Fig. 17. The number of the measurement places is ten points at arbitrary position on the joint surface in same pose. To investigate the cause of the normal vector swing, we examine the position error of the tip of the tracer at the same time.

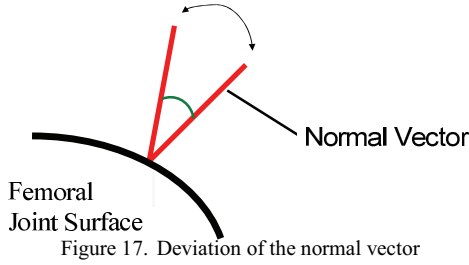


Figure 17. Deviation of the normal vector

III. RESULTS

A. Display of the joint surface profile

The obtained profile of joint surface is shown in Fig. 18. The figure is a result in the viewpoint from the frontal of the femur. Virtual display was realized by the proposal method.

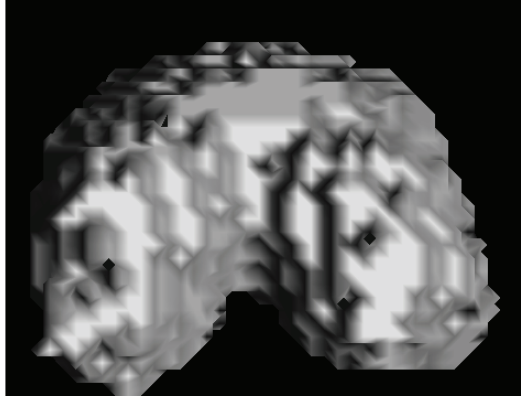


Figure 18. The acquisition of the joint surface profile

B. Display of the normal vector for the knee surface

A result of display of the normal vector is shown in Fig. 19. The figure is a viewpoint from the outside of the femur. In this figure, two lines show the normal vector for the joint surface and the real harvester. The harvester could be navigated as perpendicular to the bone surface by adjusting the pose of the harvester so that they overlap these two lines as shown in Fig. 20.

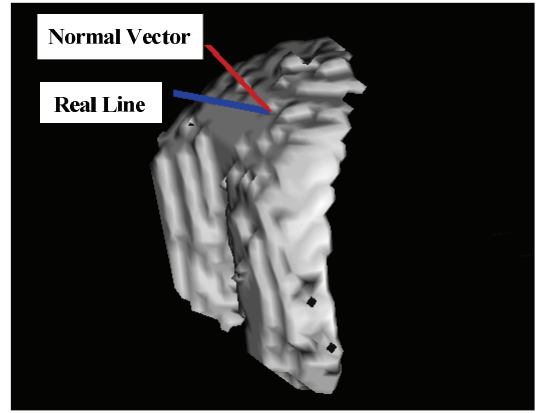


Figure 19. Display of the normal vector and the harvester

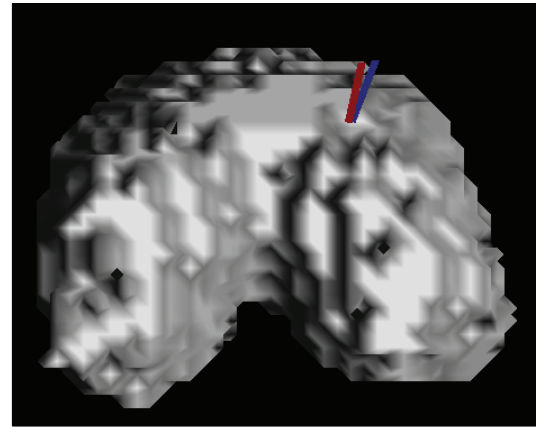


Figure 20. An example of overlap

C. Measurement of deviation of the normal vector

The result of deviation measurement of the normal vector is shown in TABLE I. From the results, the average of pose deviation of the normal vector was 7.27 degrees. The standard deviation was 3.29 degrees. The average of the position error was 0.0031 mm, the standard error was 0.001 mm. From the above, they have no association to deviation measurement of the normal vector and measurement of the position error.

TABLE I. MEASUREMENT OF THE POSITION ERROR AND MEASUREMENT POSE DEVIATION OF THE NORMAL VECTOR.

<i>Place</i>	<i>Position (mm)</i>	<i>Pose (degree)</i>
1	0.00305	1.7819
2	0.00247	8.269
3	0.00352	12.9373
4	0.00531	10.8232
5	0.00236	6.0446
6	0.00328	4.4925
7	0.00234	4.7907
8	0.00211	6.1175
9	0.00216	9.38
10	0.00425	8.0687
mean	0.0031	7.27

IV. DISCUSSION

Firstly, we developed the mosaic plasty navigation. In the experiment, we installed a sensor to a tracer and a femoral sawbone. We were able to display the normal vector in this time, it was developed that there was some deviation on the normal vector. It might be influence of the position error to make a deviation. However it is difficult to be decrease the error of the position, because the current value 0.0031 mm is too small to improve. However, the pose error is too large, then it showed be improved before applying a clinical situation.

In this study, the problem of this proposal method is that the extracted three points are affected by the position error of a sensor. To solve this problem, we should examine the changing algorithm to calculate a normal vector. One of the solution is to

calculate the normal vector from the surface of the profile. By doing so, we reduce the deviation of the position and pose error.

V. CONCLUSION

In this study, we developed the mosaic plasty navigation system that we used an electromagnetic sensor. We traced the femoral sawbone and tried the acquisition of the femoral joint surface and the display of the normal vector. As a result, we were able to display the femoral sawbone joint surface and the normal vector, and the deviation of the normal vector was an average of 7.27 degrees.

Future works are to depress the deviation of the normal vector, to enable automatic acquisition of the femoral joint surface by the tracer with a force sensor, and to improve the position and pose precisions of the system.

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