Investigating Effective Parameters in Tactile Determination of Artery included in Soft Tissue by FEM

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ABSTRACT

One of the newest ways of surgery is known as Minimally Invasive Surgery (MIS), which in spite of its benefits, because of surgeon's tactile sensing omission, causes some problems with detection of arteries and their exact positions in tissue during a surgery. In this study, tactile detection of an artery in tissue has been modeled by finite element method. In this modeling, three 2D models of tissue have been created: tissue, tissue including a tumor, and tissue including an artery. After solving the three models with similar boundary conditions and loadings, the 2D tactile mappings and stress graphs for upper nodes of models, which have the role of transferring tactile data, have been explored. Comparing these results showed that stress graphs of upper nodes of tissue including an artery is time-dependent. However, for two other models it is constant. Then, the effect of variation of different parameters of the model on artery detection such as tissue thickness, artery diameter, and elastic module of artery wall has been studied.

KEYWORDS

Soft tissue, artery, tactile detection, physical properties, finite element method (FEM)

1. INTRODUCTION

Nowadays, the advances of engineering sciences have caused the development of different surgical methods. Minimally invasive surgery (MIS) against open surgery is a kind of new surgical method in which two or three incisions with nearly 1 cm diameter or so are being created on external surface of the body. Then, tiny long surgery tools are entered through these incisions into the body and the surgeon does the operation by these tools. Because of the numerous advantages of MIS, comparing with traditional open surgery, the researchers are putting a great deal of effort on optimizing the design and capabilities of its related tools. Some of these advantages are: reducing damage to healthy tissue, decreasing trauma, patients heal more quickly, reducing recovery times, etc. MIS suffers from one major drawback: it decreases the sensory perception of the surgeon and the surgeon might accidentally cut or incur damage to some of the tissues [1].

One of the main difficulties which surgeons encountered in this area is inability in determining the physical and mechanical properties such as detecting the arteries embedded in tissues through the long and rigid surgical tools [2]. Different methods such as pre-operative CT scan exist for detecting an artery and tracking it. This method uses 3D data taken from magnetic imaging to determine the location of artery pre-operation. Because of the change of the anatomical location of the artery during surgery, this method is not effective. The other method is using ultrasound techniques. Beside their advantages, they also have some limitations such as calcification that occurs as a result of atherosclerosis may obstruct the ultrasound beam [3]. Therefore, a practical method which could eliminate these limitations during the surgery process sounds quite necessary. Artificial tactile sensing is a new technique for

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detecting of arteries in soft tissues by palpation. Therefore, in laparoscopic surgeries like bringing the gall bladder out of body, the location of cutting is burnt for bloodshed prevention or some grippers are placed in each side of the cutting location.

A novel method which recently developed for minimally invasive surgery is providing the contact area of surgical tools with artificial tactile sensing [4]. Unlike tumor detection, a very rare number of studies could be found in literature on detecting of an artery and the location of its stenosis by tactile method [5], [6]-[8]. In one of studies related to tactile detection of arteries, a sensorized finger was constructed which was capable of detecting pulse rate and waveform at wrist artery and sensing bard nodules in a mock breast [9]. It is noticeable that in this study, numerical solution was not performed. In another study, a long 10 mm diameter probe was constructed with an array of tactile sensor set in the end of it [10]. This sensor was pressed against the tissue of interest and pressure distribution was read out as electrical signal across contact area. Then this information was processed and the presence of an artery in tissue was concluded. In this study, just like the pervious works, numerical solutions were not employed. The last study on artery detection is related to construction of a tactile sensor that can track a vessel with various curves in artificial tissue with silicon type by a programmable robot [11]. Similar to pervious works, in this study numerical solution were not performed again.

In the present study; we have investigated the detection of an artery in a tissue by using 2D modeling and finite element method. Also, distinction of an artery inside of a tissue from a tumor inside of a tissue was investigated. In addition, the effect of geometrical and mechanical parameters of the tissue and the artery was investigated artery detection. Also, an optimized geometry for the tip of probe was proposed

2. NUMERICAL SOLUTION

In every application of tactile sensing method, the physical contact between tactile sensor and object or tissue is of special importance. In this physical contact, according to the design of sensor, a parameter of touch was used as a criterion for measuring or an operative for stimulating a sensor. This criterion can be force, pressure (stress), displacement (strain), temperature, humidity, roughness, stiffness, and softness that is appeared on the surface of the touched object in which tactile data was transferred between it and the sensor. Otherwise, they cannot be a suitable criterion [6]. In the present study, the palpation process which is the method of determining physical and mechanical properties of an object through the touch of surgeon's fingers or surgical tools equipped with artificial tactile sensing with tissue was modeled.

A. *Definition of Problems*

Most of the problems related to the omission of surgeon's tactile and sight sensing MIS is disability of surgeon in distinction of tissue itself, tissue including a tumor, and tissue including an artery.

During an open surgery, the surgeon puts his/her fingers on different location of the tissue, with applying a force between 0.1 to 10 N and finding different properties can explore different embedded objects such as an artery or a tumor. In this modeling, we considered a long and rigid surgical tool equipped with artificial tactile sensing which play the role of a surgeon's finger. We simulated the palpation of model by this simulated finger. A schematic of the palpation and its simplified model is presented in Fig. 1.

B. *Modeling, Simplifying, and Assumptions*

In this study, we considered thee models with similar geometry and the real data of brachial artery. The schematic of this model with the simulated finger is presented in Fig. 2 in which the diameter of the tumor and the inner diameter of the artery are 10 and 4.5 mm, respectively. The thickness of the artery is 0.63 mm. We considered only one pulse of the artery for simulating.

In all of models, the tissue, the tumor, and the artery were assumed elastic and isotropic material. The modulus of elasticity of the tissue and the artery are 50 [14] and 400 [8] kPa, respectively. The Poisson's ratio of the tissue, artery, and tumor were considered 0.45 [14], 0.49 [13], and 0.3 [10], respectively. Also, the modulus of elasticity of tumor has been assumed 20 times larger than tissue [8].

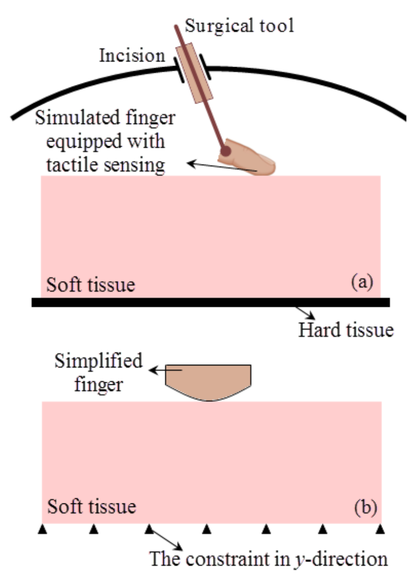

Figure 1: (a) The contact of the artificial finger with the soft tissue in MIS and (b) The simplified model of part (a) for using in finite element solution.

C. Finite Element Model and Boundary Conditions

We defined a contact between the bottom side of the simulated finger and the top side of the tissue in every three models. These models have been solved by finite element method through ABAQUS software (release 6.6.1). The length of each model has been considered 80 mm so that the left and the right side of the tissues be far from the artery and the tumor and do not effect the stress distribution of the artery, the tumor and their environments. Bottom side of the tissue in each model has been fixed in the y-direction, that is, the direction of loading on top side of the model. With prevention of rigid body motion, each model was solved.

For having continuous strain in touch site of the artery and the tumor with tissue, they were glued to tissue by gluing same nodes together. The model has been meshed by a 4-node bilinear plane stress quadrilateral element.

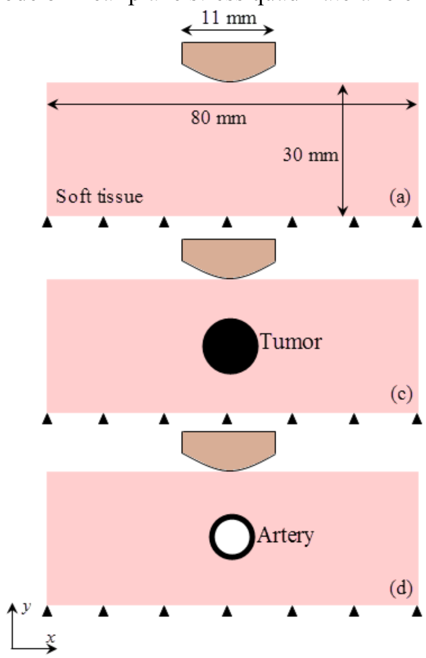

Figure 2: (a) Soft tissue model, (b) Tissue including tumor, and (c) Tissue including artery with geometrical dimension of each model.

D. The Method of Results Extraction

For results extraction, we applied displacement -1.5 mm on the top side of the tissue through the simulated finger. Then, we extracted the stress graph for all nodes on the top side of every three models at an arbitrary time and a specific finger location. We repeated this manner for different finger location on top side of the tissue. At the end, for every model, we generated a graph consisting of the maximum stress of extracted graph. In Fig. 3, the tactile image of three models; tissue itself, tissue including a tumor, tissue including an artery are presented at an arbitrary time.

3. Numerical Results

The solution time of this study was considered 2 seconds. For the first 1 second, the finger reached on maximum indentation and, for the next 1 second, the pressure data was applied to inner side of the artery. We extracted the stress graphs for a limit of 30 mm around the artery and the tumor. The results are as follows. For results derived of Section *B* to *E*, we consider base model with indentation 3.8 mm.

A. Appearance of the Symptoms of Existence of an Artery or a Tumor on Top Side of Models

In Figs. 4, 5, and 6, the stress graphs (consisting of maximum stresses) of three models at three arbitrary times 1.1 (systolic), 1.3, and 1.4 (diastolic) second. The existence of a time-independent stress peak in these graphs indicated an embedded object with the modulus elasticity more than its surrounding tissue. The existence of a time-dependent stress peak in the graphs indicated an artery in the tissue. As we expected, the positions of the stress peaks of Figs. 5 and 6 were located just at the artery and the tumor location. By comparing the graph of Figs. 5 and 6 with Figs. 7 and 8, it is obvious that our results were validated by other study results.

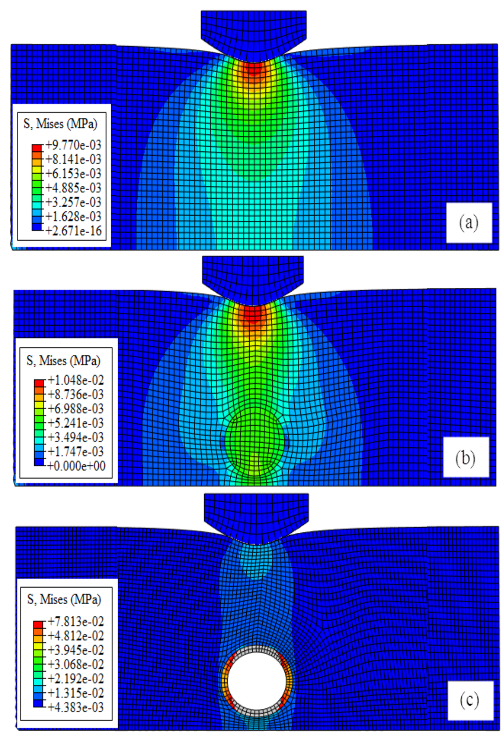

Figure 3: 2D tactile images a) the tissue itself, b) tissue including a tumor, c) tissue including an artery (tactile image c is related to time 0.425 second).

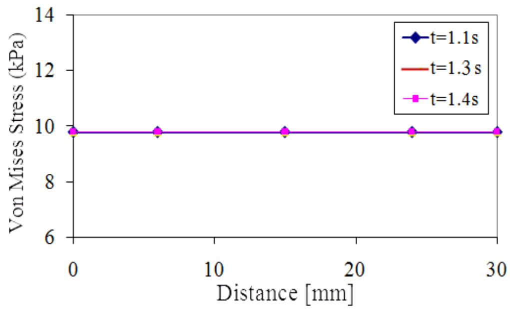

Figure 4: Von Mises stress graph for nodes on top side of model tissue itself.

B. The Effect of Artery Diameter

The difference of Von Mises stress of top side of the tissue including an artery between two arbitrary times 1.1 and 1.4 second and the variation of artery diameter from 3 to 9.5 mm is derived and presented in Fig. 9. As it is clear, increasing the artery diameter causes increasing the value of the graph peak.

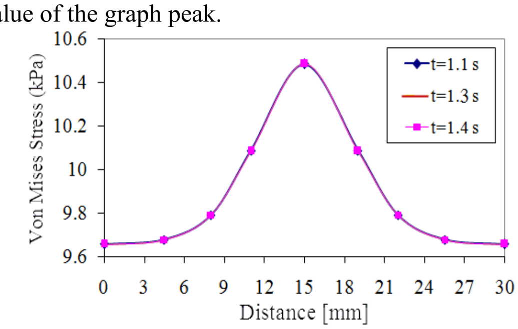

Figure 5: Von Mises stress graph for nodes on top side of model tissue including a tumor.

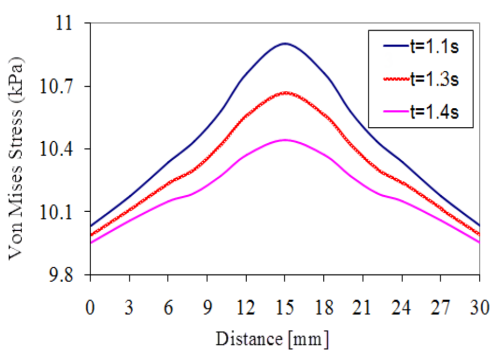

Figure 6: Von Mises stress graph for nodes on top side of model tissue including an artery.

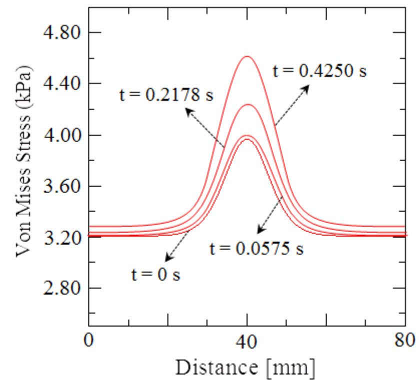

Figure 7: Von Mises stress graph for nodes on top side of model tissue including an artery at four times [1].

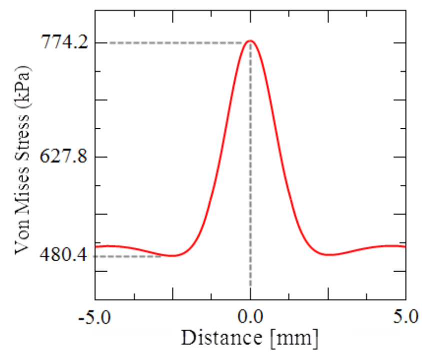

Figure 8: Von Mises stress graph for nodes on top side of model tissue including a tumor [7], [8].

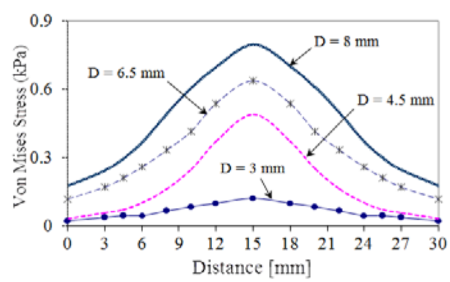

Figure 9: The graph of Von Mises stress difference for nodes on top side of model tissue including an artery versus the different values of modulus elasticity of the artery.

C. The Effect of Modulus Elasticity

The difference of Von Mises stress of top side of the tissue including an artery between two arbitrary times 1.1 and 1.4 second and the variation of modulus elasticity of the artery from 0.4 to 4.4 MPa is derived and presented in Fig. 10. As it is seen, hardening the artery causes reducing the value of the graph peak.

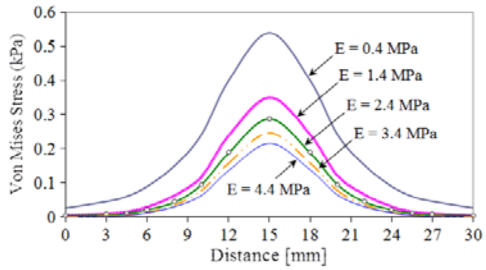

Figure 10: The graph of Von Mises stress difference for nodes on top side of model tissue including an artery versus the different values of artery diameter.

D. The Effect of Tissue Indentation

The difference of Von Mises stress of top side of the tissue including an artery between two arbitrary times 1.1 and 1.4 second and the variation of the indentation from 2.5 to 4.1 mm is derived and presented in Fig. 11. As it is clear, increasing the indentation in tissue until 3.8 mm causes increasing the value of the graph peak and after that it reduces because of artery collapsing.

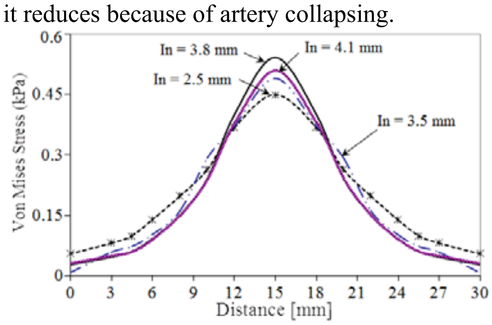

Figure 11: The graph of Von Mises stress difference for nodes on top side of model tissue including an artery versus the different values of the indentation in tissue.

E. The Effect of Tissue Thickness

We defined the distance between the top side of the artery and the top side of the tissue. The difference of Von Mises stress of top side of the tissue including an artery between two arbitrary times 1.1 and 1.4 second and the variation of the indentation from 10.5 to 20.5 mm is derived and presented in Fig. 11. It is seen that increasing the tissue thickness causes degreasing the value of the stress graph peak.

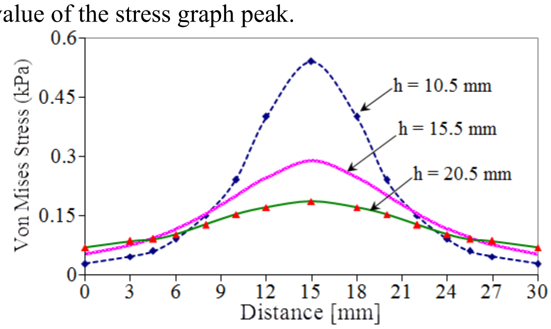

Figure 12: The graph of Von Mises stress difference for nodes on top side of model tissue including an artery versus the different values of tissue thickness.

F. The Effect of Tip Geometry of Finger

Four fingers with different geometry were presented in Fig. 13 and the stress distribution in the models for constant indentation 3 mm are shown in Fig. 14. The stress concentration made in the model by fingers 13-*a* and *b* were caused the overshoot in stress graphs. In modeling the fingers of 13-c and d, we patterned the geometry of human finger. In stress graph related to these two fingers, we cannot suddenly see any overshoot.

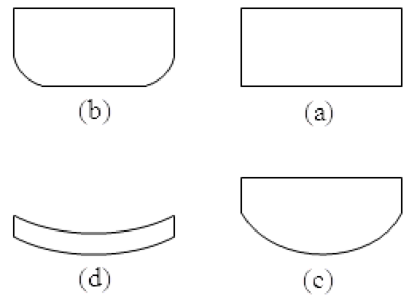

Figure 13: Schematic of four geometries for the finger: (a) rectangular, (b) fillet rectangular, (c) circular, and (c) elliptical.

4. Discussion

In this study, the palpation of physician was modeled and simulated by finite element method. This modeling has been performed for three 2D tissue models: tissue itself, tissue including a tumor, and tissue including an artery.

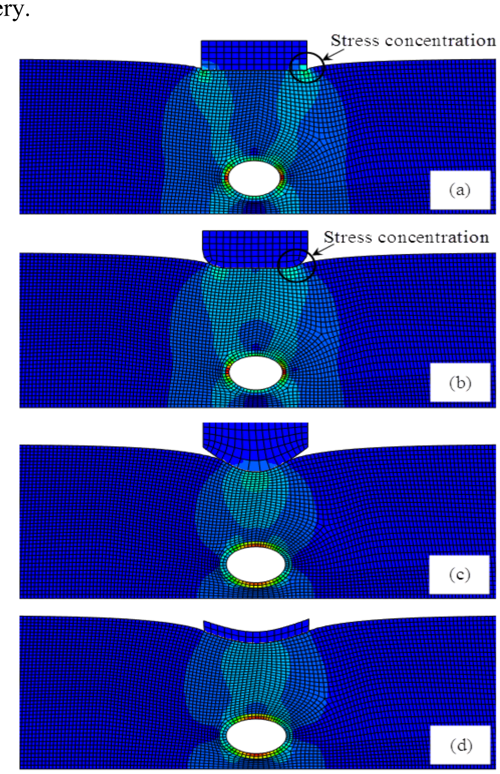

Figure 14: The stress distribution in models for different geometries of finger at indentation 3 mm.

With comparing Von Mises stress graphs shown in Figs. 4, 5, and 6, we can conclude that with applying same loading on top side of each model shown in Fig. 2, if 1) the stress values versus top nodes and time be constant there exists the tissue itself, 2) if the stress graph consists a peak, the tissue includes other material with different mechanical properties of soft tissue like tumor or artery, 3) if the value of the stress peak versus time be constant, the tissue includes tumor, and 4) if the value of the stress peak be time-dependent, the tissue includes artery. Therefore, the cases which can be explored from these stress graphs include: the existence of a hard embedded object in soft tissue, distinguishing between the artery and the tumor inside the soft tissue, and determination of the exact location of the artery and the tissue inside the soft tissue.

By referring to the results shown in Figs. 9, 10, 11, and 12, we can conclude that the increasing in artery diameter and reducing the tissue thickness cause the increasing in transfer of arterial pressure to the top side of the tissue. Increasing the modulus elasticity of artery brings about the degreasing in transfer of arterial pressure. Increasing the indentation in tissue to 3.8 mm, it causes increasing the stress peak.

According to Fig. 14, we can claim that using the finger *d* can be explored embedded objects such as the artery better than finger *c*. Other geometries, because of generating the stress concentration, cannot be used for detecting of embedded objects.

5. CONCLUSION

In this study, by creating three tactile models and exploring 2D tactile image and stress graphs for each one and comparing them together, we could detect the existence of a tumor or an artery in tissue. According to our results, we were able to distinguish the tissue itself from tissue including a tumor, and tissue including an artery. This distinction is useful for surgeons during minimally invasive surgery. Also, we investigated the effect of different parameters on artery detection. The increasing the artery diameter and reducing the tissue thickness increases the sensing of arterial pulse.

6. ACKNOWLEDGMENT

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7. REFERENCES

[1] A. Abouei Mehrizi, S. Najarian and M. Moini, "Modeling of tactile detection of an artery in a soft tissue by finite element analysis," Amirkabir Journal of Science and technology, to be published.

[2] W. J. Peine, "Remote palpation instruments for minimally invasive surgery," Ph.D. dissertation, Div. of Eng. and Appl. Sci., Harvard University, 1998.

[3] J. Dargahi and S. Najarian, "Human tactile perception as a standard for artificial tactile sensing- a review", Inter. J. of Med. Rob. Comp. Ass. Surg., vol. 1, pp. 23-35, 2004.

[4] M. E. H. Eltaib and J. R. Hewit, "Tactile sensing technology for minimal access surgery-a review", Mechatronics, vol. 13, p.p. 1163-1177, 2003.

[5] J. Dargahi and S. Najarian, "A Supported membrane type sensor for medical tactile mapping", Sensor Review, vol. 24, pp. 284-297, 2004.

[6] S. M. Hosseini, S. Najarian, S. Motaghinasab, and J. Dargahi, "Detection of tumors using computational tactile sensing approach", Inter. J. of Med. Rob. Comp. Ass. Surg., vol. 2, no. 4, p.p. 333-340, 2006.

[7] S. M. Hosseini, S. Najarian, S. Motaghinasab, "Analysis of effects of tumors in tissue using of artificial tactile modeling", Amirkabir Journal, to be published.

[8] S. M. Hosseini, S. Najarian, S. Motaghinasab, and S. Torabi, "Experimental and numerical verification of artificial tactile sensing approach for predicting tumor existence in virtual soft tissue", Proc. of the 15th Annual-International Conf. of Mechanical Engineering, 2007.

[9] P. Dario, M. Bergamasco, "An advanced robot system for automated diagnostic tasks through palpation" IEEE Trans. on Biomed. Eng., vol. 35, no. 2, p.p. 118-26, 1988.

[10] W. J. Peine, S. Son, and R. D. Howe, "A palpation system for artery localization in laparoscopic surgery", First Inter. Symp. on Medical Robotics and Computer-Assisted Surgery, Pittsburgh, 1994.

[11] R. A. Beasley and R. D. Howe, "Tactile tracking of arteries in robotic surgery", Proc. of IEEE, International Conf. on Robotics & Automation, Washington, DC, 2002.

[12] M. H. Lee and H. R. Nicholls, "Review article tactile sensing for mechatronics-a state of the art survey", Mechatronics, vol. 9, pp. 1-31, 1999.

[13] D. J. Mozersky, D. Sumnfer, D.E. Hokanson, and D.E. Strandness, "Transcutaneous measurement of the elastic properties of the human femoral artery", Circulation AHA Journal, v. XLVI, 1972.

[14] A. E. Kerdoke, S. M. Cotin, M. P. Ottensmeyer, A. M. Galea, R. D. Howe, and S. L. Dawson, "Truth cube: establishing physical standard for soft tissue simulation", Med. Imag. Anal., vol. 7, pp. 283-291, 2003.