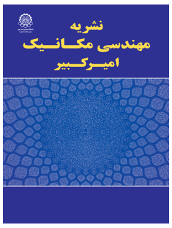

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Investigation of the Effect of Different Friction Models On Experimental Extraction of 3D Nanomanipulation Force and Critical Time of Colon Cancer Tissue

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ABSTRACT: Nano-dimensional particle displacement, property improvement, and studies on cellular tissues are some of the applications of the nanomanipulation process using atomic force microscopy. In general, the manipulation process begins with the contact of the needle and the desired cell tissue and with the application of force on the beam. The increase in force will continue until the resistance forces such as friction are overcome. At this time, the critical force and time are recorded. In this article, colon cancer tissue has been studied. The important parameter evaluated in this study is the critical force and time according to different friction models in order to reduce damage to cancerous tissue. Experimental experiments on colorectal cancer tissue have been performed using atomic force microscopy. LuGre, Coulomb, and HK friction models are used in the simulations. Finally, by comparing the force outcome diagrams and considering different friction models, in 3D manipulation, the maximum amount of force and critical time for the Coulomb friction model and the lowest value for the LuGre friction model are recorded. Considering the apparent contact surface at the Nano-dimensions in the Coulomb model and the actual contact surface in the LuGre friction model, these results are justifiable.

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1- Introduction

Studies on healthy and cancerous cell tissues are performed by the nanomanipulation process using atomic force microscopy. Investigation of various factors in the first phase, such as the effect of cantilever geometric parameters, environmental conditions, cell geometric parameters, as well as resistive forces, leads to the extraction of more accurate information in cellular studies. Also, one of the important parameters in three-dimensional manipulation is the extraction of force and critical time without damaging the cell tissue and considering the resistive forces such as friction. As a result, extracting useful information during this process will have a beneficial effect on the treatment and diagnosis of cancer.

Hou et al. [1] used Atomic Force Microscopy (AFM) to measure cell shear bond strength. After imaging the cell, measurements of cell shear adhesion were made based on different cell positions at the nanoscale. Finally, they realized the difference in adhesion force in different parts of the cell. Two types of colon cancer cells have been studied in this study. Qu et al. [2] studied colon cancer cells using atomic force microscopy to penetrate the target cell membrane. According to the desired results, they have found that this tool can be used to study the properties of cells and be used in the treatment of cancer. Paul et al. [3] compared atomic force microscopy instruments and high-resolution spectroscopy to compare colon cancer cells with healthy cells. They used the density of extracellular vesicles as a criterion for diagnosing cancerous and healthy cells. Finally, they found that these vesicles were denser in cancer cells than in healthy cells. Zarei et al. [4] investigated two-dimensional manipulation in the second phase by considering the contact models of HK, Columbus, and LuGre in the second phase. The results showed the highest amount of displacement and velocity in the LuGre friction model and the lowest value in the Coulomb friction model.

The study of research in the field of manipulation shows the failure to calculate the force and critical time for colon cancer tissue, considering frictional models. For this purpose, in a leading study, an attempt has been made to calculate the critical force and time for colon cancer tissue by considering the friction resistance force in different contact models. Taking this into account in future research will lead to more accurate results and no damage to the cell.

2- Modeling

In the modeling section of this paper, the equations of force governing three-dimensional manipulation are presented.

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Then, the equations of Coulomb, LuGre, and HK contact models are explained. Finally, the experimental work process used in research on intestinal cancer tissue is described. Refer to the reference [4] to examine the equations.

3- Results and Discussion

In all the diagrams in Fig. 1, the forces in the *x*, *y*, and *z* directions are defined as the parameters *Fx*, *Fy*, and *Fz*. Also, the result of all these forces is specified by the *FT* parameter. In the resulting graphs, the points where the force is fixed represent the critical points and indicate the critical time and force in the three-dimensional manipulation of the cancerous cell tissue of the large intestine. Coulomb, HK, and LuGre friction models have been used in this research. As can be seen, in all forms the force in the *z*-direction is constant due to the constant vertical force of the surface, and the other forces are variable. By comparing the graphs, it can be seen that the critical force of the resultant force of the Coulomb friction model has the maximum value and the LuGre model has the lowest value. The same is true of the critical force. The Coulomb friction model is inaccurate due to the apparent surface area of the nanoscale contact, and therefore shows the maximum amount of force and critical time. The LuGre contact model also displays more accurate force and critical time due to the actual contact surface.

4- Conclusion

In this study, considering previous studies on other cancers, the manipulation method based on AFM has been used. The study of cellular tissues is done with special attention due to the importance of not damaging the tissue during the study. One of the resistant factors during the manipulation process is the friction force. The critical force is recorded when overcoming this force and the critical time when starting the movement. In this research, the friction models of Coulomb, LuGre, and HK have been used in the simulations. The force diagrams in the mentioned friction models are drawn in different directions and their results are plotted with a graph called *FT*. As the process of changing the resultant force is fixed, the values of force and time are recorded and considered as critical force and time. The comparisons showed the highest amount of force and critical time in the Coulomb friction model and the lowest value in the LuGre friction model. Considering the apparent contact surface in the Coulomb friction model equations and the actual nanoscale contact surface in the LuGre friction model equations, the difference in values is well justified.

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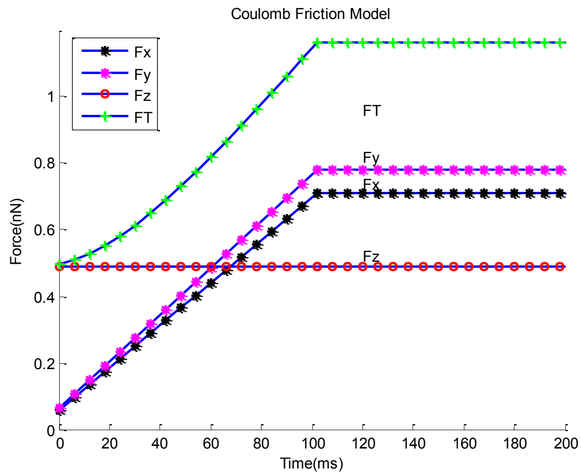
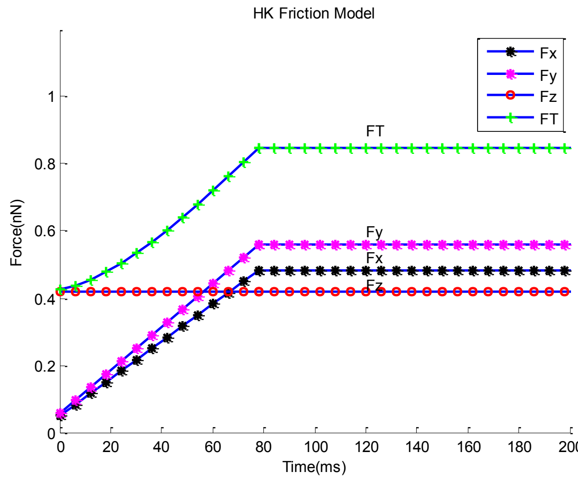
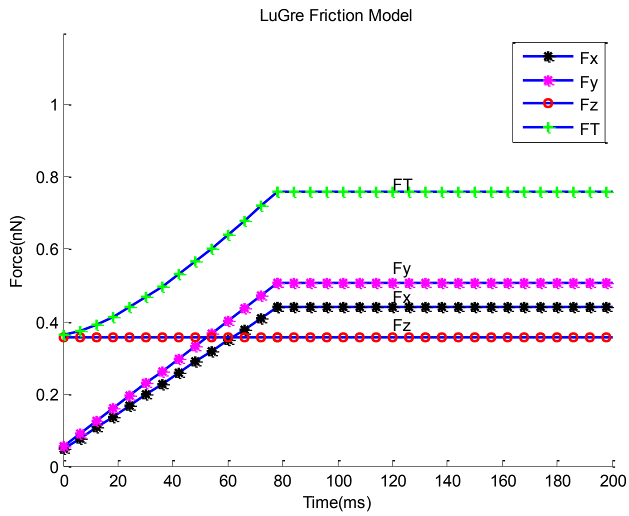


a: Coulomb friction model



b: HK friction model



c: LuGre friction model

Fig. 1. Comparison of force and critical time of manipulation using different friction models

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