Mechanical Modeling with Particle Swarm Optimization Algorithm for Braided Bicomponent Ureteral Stent

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ABSTRACT

This paper focuses on using particle swarm optimization (PSO) algorithm to estimate and find the optimal parameters of the compression model of bicomponent stents composed of poly(lactic-co-glycolic acid) (PGLA) and poly(glycolic acid) (PGA). Generalization model was get through five cross-validation of the experimental data obtained from tests. The experimental data and simulated data fit well, proving that the model could closely reflect the processing of compression mechanical properties of the ureteral stents. Based on the generalization model, numerical simulation method was used to analysis the influence between braiding angle and mechanical properties of the bicomponent stents qualitatively.

Keywords

Bicomponent ureteral stent; compression model; PSO algorithm

1. INTRODUCTION

Ureters are a pair of narrow thick-walled tubes that carry urine from kidneys to urinary bladders. Ureteral obstruction can be caused by some reasons, like trauma, congenital malformation, tumor, calculi and so on. Ureteral stent is a type of tubular medical devices used for repairing the obstructed or impaired ureters. Most of the ureteral stents used in clinic are currently non-biodegradable, which may have adverse effects, e.g. ureteral infection, sedimentation of calculi, waist and abdominal discomfort, blood urine, breakage of stent, urine return and even asecond surgery for stent removal. Recently, the biodegradable ureteral stents, which can be completely degraded in body, and then be discharged*in vitro* with urine after recovery of the impaired ureter to avoid reoperation, have gained more and more attention. The biodegradable materials used for ureteral stent should be biocompatible, mechanically robust, and controllably biodegradable with non-toxic degradation products[1-4].Wang et al. fabricated biodegradable ureteral stents using both poly(glycolic acid) (PGA) and poly(lactic-co-glycolic acid) (PGLA) components for the first time and conducted a series of research on mechanical properties,especiallythe axial tensile and radial compression[5-7].There is an urgent need for systematic study because correlating the braiding parameters and performance properties of stents by experiments alone is not necessary. It is difficult to complete the optimization experiments in laboratory as the process is time consuming, expensive and labor intensive while computational simulation could compensate it by saving cost, time and labor. When using modeling and mechanical properties of stents with different structuresprepared under different conditions,the model could be predicted readilywith the least utilization of labor and time.

Moreover, mechanical properties of stents could also be affected readily by weaving parameters, such as braiding angles, and components of materials. However,these factors were usually ignored in modeling. Till now, there has been no specific model for the mechanical properties of bicomponent ureteral stent yet.

To solve the above problems in modeling of ureteral stents, mechanism model of bi-component ureteral stent is constructed in this paper.Several braiding parameters, including fabric structure, mechanical properties of fibers, braiding angles, etc., were included in the models to check their effects on mechanical properties of the bi-component ureteral stents.

2. BICOMPONENT URETERAL MODELING

To investigate the influence of composing ratio of warp yarns and weft yarns and braiding angle on the mechanical properties of tubes, the area of the tubes was divided into microareas as shown in Figure 1.

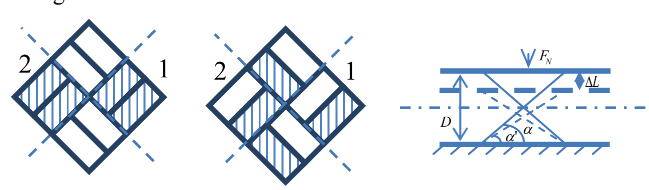

Figure 1. Area element structure and mathematical symbols

The kinetic equation could be written as Equations (1), (2) and (3).

$$F_N = F_{N,1} + F_{N,2} \tag{1}$$

$$\dot{F}_{N,1} = -\lambda F_{N,1} + (m_1 k_a + n_1 k_b)\Delta l \sin\alpha' \tag{2}$$

$$\dot{F}_{N,2} = -\lambda F_{N,2} + (m_2 k_a + n_2 k_b)\Delta l \cos\alpha' \tag{3}$$

where, m_1, n_1, m_2 and n_2 represents the number of *a*and *b* fibers at direction 1 and 2 in Figure 1(a)and Figure 1(b), respectively. k_a

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and $k_b$is the elastic modulus of a and b fibers, respectively. ΔL is replaced by x as deformation of fibers.

3. PARAMETER OPTIMIZATION BY THE PSO ALGORITHMS

To enhance the precision of the model, correction factors were added into Equations (2) and (3) to make it still in form in line withEquation (3).

$$\hat{\hat{F}}_{N,1} = -\lambda_N \hat{F}_{N,1} + \eta_N (m_1 k_a + n_1 k_b)\Delta l \sin\alpha' \quad (4)$$

$$\hat{\hat{F}}_{N,2} = -\lambda_N \hat{F}_{N,2} + \eta_N (m_1 k_a + n_1 k_b)\Delta l \cos\alpha' \quad (5)$$

$\hat{F}_p$ is used to represent the stent stress according to the formula above. F_p represents the actual measurement of the pressure. We hope to find a set of parameters $A_N = [\lambda_N, \eta_N, c_N]$ to get the minimum root-mean-square (RMS) of the error between all the sampling points $\hat{F}_p$ and the output of model F_p. Therefore solving parameters of the compression process model can be converted to the following optimization problem:

$$J_p = \arg\min_{A_N \in \Lambda_N} \sqrt{\frac{1}{N}\sum (F_p - \hat{F}_p)^2} \quad (6)$$

$$s.t. \begin{cases} \lambda_N > 0 \\ \eta_N > 0 \\ C_N \geq 2\sqrt{\eta_N (mk_a + nk_b)} \end{cases} \quad (7)$$

where, N is the number of sampling points, Λ_N is the collection of all the parameters satisfying the condition (7).

As the model of compression process is complicated and nonlinear, it is difficult to get the analytical solution of the optimal parameters. The intelligent PSO algorithm is useful to obtain the numerical solution of the parameters.The parameters of the PSO algorithm to be determined, η_N , c_N and η_s can be regarded as the state of particles, therefore, the optimization problem (6) can be transformed into a function optimization problem of two-dimensional particles. According to the definition of fitness function, we choose the performance index as the fitness function and the tensile performance index is similar.

$$f_p(X_i) = J_p = \sqrt{\frac{1}{N}\sum_{j=1}^{N}[F_p(L_j) - F_p(L_j \mid X_i)]^2} \quad (8)$$

4. SIMLLATION RESULTS

Output data of the model was compared with the actual experimental data, as shown in Figure 2. Figure 3 shows the RMS of the models

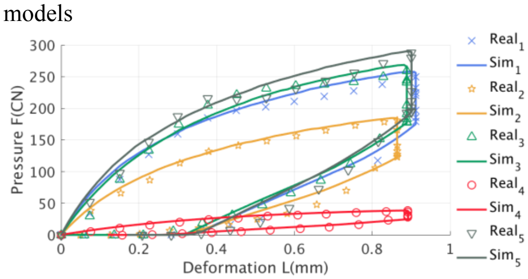

Figure 2. Comparison of experimental data and model output.

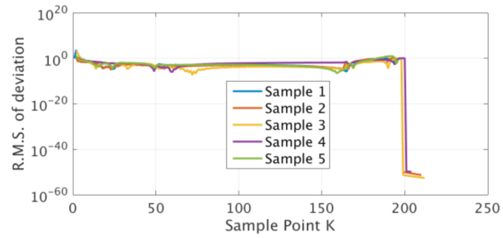

Figure 3. RMS of differences between model output and measured data.

In order to improve the generalization ability of the model, cross-validation of the measured data was used to adjust related parameters of the process model.

5. CONCLUTIONS

In this paper, the compression mechanical model of bicomponent stents composed ofPGLA and PGA is constructed. The PSO algorithm is used to obtain the optimal parameters for the model. The general model is obtained through five cross-validations of the experimental data. The results from modeling could closely reflect the change of compression properties of the ureteral stents during the compression.

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REFERENCES

[1] Chew, B.H., Seitz,C. 2016.Impact of ureteral stenting in ureteroscopy. *J. Current Opinion in Urology*, 26(1), 76-80.

[2] Lingeman, J.E., Preminger,G.M., Berger, Y.et al. 2003.Use of a temporary ureteral drainage stent after uncomplicated ureteroscopy results from a phase II clinical trial. *J. Journal of Urology,* 169(5),1682-1688.

[3] Beiko, D. T., Knudsen, B. E., Watterson, J. D., Cadieux, P. A., Reid, G., &Denstedt, J. D. 2004. Urinary tract biomaterials. *J. Journal of Urology*,171(6), 2438-2444.

[4] Guggenbichler, J. P., Assadian, O., Boeswald, M., & Kramer, A. 2011. Incidence and clinical implication of nosocomial infections associated with implantable biomaterials—catheters, ventilator-associated pneumonia, urinary tract infections.*J. GmsKrankenhaushygieneInterdisziplinär*, 6(1), Doc18.

[5] Wang, L., Chen, F.,Wang, W.Z., Shang, Y.F.,Zou, T.,Wang, F.J.,Zhou, J.M.,Xie, H., Guan, G.P.,Huang, Y.C., et al. 2014. A braided gradually degradable ureteral stent and its preparation. Patent application201110241408.4, China.

[6] Zou, T., Lu, W., Li, W., Wang, W., Fang, C., & King, M. W. 2014. A resorbablebicomponent braided ureteral stent with improved mechanical performance. *J. Journal of the Mechanical Behavior of Biomedical Materials*, 38(C), 17-25.

[7] Zhang, M. Q., Zou, T., Huang, Y. C., Shang, Y. F., Yang, G. G., Wang, W. Z., Zhou, J. M., Wang, L., Chen, F. and Xie, H. 2014. Braided thin-walled biodegradable ureteral stent: Preliminary evaluation in a canine model. J. International Journal of Urology, 21(4), 401–407.