Finite element analysis of mechanical performance of nitinol biliary stent: effect of material properties

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Stent implantation has been regarded as a major strategy to solve gastrointestinal diseases such as biliary obstruction during the last decade. The application of nitinol superelastic stents has been recently considered for minimising such problems as restenosis after stent implantation, the ability to low stent twist, unsuitable dynamic behaviour and inadequate strength radial of stent. In the present article, the effects of material properties on mechanical performance of Z shaped nitinol wire stent under crushing test for clinical applications are studied by finite element modelling. Nitinol stent shows better mechanical and clinical performance after applying 90% crushing, less chronic outward force, high radial resistive strength, appropriate superelastic behaviour and A_f temperature of 24°C.

Keywords: Stent, Biliary duct, Nitinol, Finite element analysis, Mechanical performance

Introduction

Gastrointestinal disease is a main cause of death around the world.[1] Biliary obstruction is the most famous gastrointestinal ailment.[2] Stent placement has been used as a major solution to this hitch during the last decade.[3–6] Stents are used for two chief objectives: preventing short term effects of intimal dissection and elastic recoil and preventing long term effects such as restenosis due to the neointimal hyperplasia. Successful use of stent is bound to the following conditions:

(i) good controllability to achieve an adequate fixation to the duct wall
(ii) satisfactory resistance against the elastic recoil
(iii) resistance to fatigue owing to the pulsatile flow on body kinematics
(iv) size minimisation of the device for easier percutaneous procedure
(v) low thrombogenicity
(vi) high biocompatibility
(vii) long term palliation of patients from malignant obstructive jaundice.

Previous reports show that stent placement palliates the malignant obstructive jaundice and improves the life quality of the patients.[4] Nitinol as a functional biliary endoprosthesis is applied because of its long patency results.[3] Parameters affecting stent performance of nitinol include superelasticity, mechanical hysteresis, chronic outward force (COF), radial resistive force (RRF), stress distribution, plateau stress, strain distribution and martensite percentage.[5–8] Desirable nitinol stents require the lowest COF, the highest RRF, wide stress plateau, full hysteresis loop, small localised stress concentrations and large deformation superelastic strains.[5–12] Long fatigue life and safe failure domains are also needed.[6,13–15] Different geometries such as coil, helical spring, woven (braided and knitted), ring (individual and sequential) and cell (closed and open) have been already used for stents.[5] Z shape stent is a newer design for use in biliary duct.[6] Because of good retrievability and flexibility, Z shape wire stents are most extensively used in stent designs.[5] They can be used to fabricate custom stents of preselected values exerting radial forces of clinical need. Z shape models are also desirable due to their easy manufacturing even in laboratory by hand. Z shape models also allow various designs with different amounts of radial forces described based on Castigliano's second theorem.[17] Important parameters of Z shape stent like stent length, diameter of wire, number of bends, segments angle, stent inner diameter and radial contraction should be determined by analytical equations associated with geometry of the stent.[5,6,16,17] Based on numerical studies performed in the past, increasing inner diameter, segment angles and stent radial contractions improve the performance of the superelastic nitinol stents.[8,11,16,18–21] Increasing length and number of bends of the stents have adverse effects owing to poor superelasticity. Martensite/austenite transformation temperatures (especially A_f) have great effects on suitable performance of superelastic nitinol stents. A_f temperature of the applied nitinol should be lower than the normal body temperature so that the nitinol stent preserves its superelastic behaviour.[6,11,13,22–31] The amount of A_f is chosen on the basis of stiffness and obstruction level of the duct. An A_f close to the body temperature is not desirable for

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