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REVIEW

A novel sax-stent method in treatment of ascending aorta and aortic arch aneurysms evaluated by finite element simulations

Conception d'une méthode de traitement endovasculaire des anévrysmes de l'aorte ascendante et de l'arche aortique

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Aortic aneurysm;
Dissection;
Sax-stent;
Finite element analysis;
Wall stress

Summary
Objectives. — A novel stent method to simplify treatment of proximal ascending aorta and aortic arch aneurysms was developed and investigated by finite element analysis. Therapy of ascending aortic and aortic arch aneurysms is difficult and challenging and is associated with various complications.
Methods. — A 55 mm wide × 120 mm long stent was designed without the stent graft and the stent was deployed by an endovascular method in a virtual patient-specific aneurysm model. The stress-strain analysis and deployment characteristics were performed in a finite element analysis using the Abaqus software.
Results. — The stent, when embedded in the aortic wall, significantly reduced aortic wall stresses, while preserving the side coronary ostia and side branches in the aortic arch. When tissue growth was modeled computationally over the stent struts the wall stresses in aorta was reduced. This effect became more pronounced when increasing the thickness of the tissue growth. There were no abnormal stresses in the aorta, coronary ostium and at the origin of aortic branches. The stent reduced aneurysm expansion cause by hypertensive condition from 2 mm without stenting to 1.3 mm after stenting and embedding.

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Conclusion. — In summary, we uncovered a simple treatment method using a bare nitinol stent without stent graft in the treatment of the proximal aorta and aortic arch aneurysms, which could eventually replace the complex treatment methods for this disease.

MOTS CLÉS
Anévrysme aortique ;
Dissection artérielle ;
Stent ;
Analyse par éléments finis ;
Contrainte pariétale

Résumé
Objectifs. — Le traitement conventionnel chirurgical des anévrismes de l'aorte ascendante et de l'arche aortique est complexe et associé à un risque important de morbi-mortalité. Afin de simplifier la prise en charge de cette pathologie, une méthode de traitement endovasculaire a été développée et étudiée avec l'analyse par éléments finis.
Méthodes. — Un stent de 55 mm de largeur × 120 mm de long a été conçu et déployé par méthode endovasculaire dans un modèle virtuel d'anévrisme chez l'homme. L'analyse des contraintes-déformations pariétales et les caractéristiques de déploiement du stent ont été étudiées par la méthode des éléments finis à l'aide du logiciel Abaqus.
Résultats. — Le stent, ancré dans la paroi aortique, a réduit significativement les contraintes appliquées à la paroi aortique, tout en préservant l'origine des artères coronaires et les troncs supra-aortiques. Lorsque la ré-endothélialisation a été prise en compte par la modélisation, les contraintes exercées sur la paroi de l'aorte ont été réduites, et cet effet est apparu plus prononcé avec l'importance de l'épaisseur de la croissance tissulaire. Il n'y avait pas de contrainte anormale appliquée à la paroi de l'aorte, à l'origine des coronaires ou à l'origine des troncs supra-aortiques. Dans un modèle d'hypertension artérielle, le stent a permis de réduire la croissance anévrysmale (croissance de 2 mm et 1,3 mm, sans et après ancrage du stent, respectivement).
Conclusion. — En résumé, nous proposons une nouvelle méthode de prise en charge des anévrysmes de l'aorte ascendante et de l'arche aortique par voie endovasculaire à l'aide d'un stent nu en nitinol. Cette prise en charge endovasculaire pourrait à terme remplacer les méthodes complexes de traitement chirurgical de cette pathologie.

Introduction

An aortic aneurysm is a common disease in clinical practice. Ascending aorta aneurysm is very common, and serious complications are associated with this condition. Aortic aneurysm disease is the 13th leading cause of mortality in the United States [1—3]. Aortic ruptures and dissections are often associated with serious complications. The most-common etiology of this condition is degenerative, and aortic aneurysms are frequent in patients with Marfan's syndrome, which has an incidence of 1 in 10,000 patients [2]. The treatment option is primarily surgical or beta-blockers in early stages [4]. The ascending aortic aneurysms are treated by Bentall's surgery [5—8], which is a resection anastomosis of the conduit with coronary re-implantation and aortic valve replacement. The treatment of aortic arch aneurysms is even more complex which require supra-aortic rerouting anastomotic or hybrid surgeries with endovascular grafts and de-branching bypasses [9—18]. These surgical techniques, though successful, are associated with high morbidity and mortality rates [19—23].

The mortality rates for Bentall's surgery ranges from 4.5 to 5.5%, with stroke and paraplegia rates of about 2 to 4.5%, acute renal failure rates of 9% and respiratory tract complications rates of 9%. Late mortality rate of Bentall's surgery in follow-up is about 19% and the late neurological complications rate is 4.1% [19,20]. The hybrid surgeries involving aortic arch are associated with a mortality rate of 8.7 to 19%, and stroke and paraplegia rates range from 4.5 to 6% each and acute renal failure is observed in 9 to 11% of patients. Proximal aortic dissections are seen in about 8 to 10%, and retrograde graft leakages are seen in about 9 to 10% of cases [21,22]. The overall re-intervention rates for these procedures range from 6% for Bentall's and up to 27% in hybrid surgeries. Elephant trunk surgeries are associated with 5 to 14% mortality rates and 5-year survival rates of 71 to 82% for complete repair and 35 to 50% for incomplete repairs. Apart from these complications, significant blood transfusions are required for these surgeries [23]. Endovascular stent grafts have early mortality rates of 6.5% and are associated with spinal complications and peripheral vascular problems [24].

The stent grafts are associated with endo-leaks and graft migrations and they require a high degree of precision in deployment to avoid side branch occlusions [25]. These procedures are complicated by cerebrovascular events and peripheral neurological events as well. We investigated a simple Nitinol-based aortic stent as a method to treat ascending aortic and aortic arch aneurysms and to preserve the aortic arch branches. In a previous study, we have proven