Development of Computational Models for Evaluation of Mechanical and Hemodynamic Behavior of an Intravascular Stent

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Objectives

- Develop and integrate parametric stent design, FEA, and CFD analysis to shorten stent development cycle

- Create modified stent drawings in seconds and quickly screen out inappropriate designs by FEA and CFD analysis without going into lengthy testing process
Atherosclerosis is a condition in which an artery wall narrows due to accumulation of fatty materials.

A stent is a wire-mesh tube that can be deployed into an artery to open a narrowed or blocked artery.
Stent Analysis System

Parametric Design

CFD  FEA

Analysis

Optimized Design
Parametric Design

- Linking parameters to geometry in a mathematical way, once the mathematical relation has been established, as the parameters change, the drawing changes
Stent is Composed of Periodic Units
Define Parameters in Stent Unit Cell

- **Connector Width**
- **Strut Width**
- **Crown**
- **V Crown Radius**
- **Y Crown Radius**
- **W Crown Radius**
- **Connector Length**
- **Strut Length**
Link Parameters to Designed Spreadsheet in CAD Software
After Introducing Parametric Design…

Auto-redraw

In Seconds!

Similar Design
Stent Analysis System

Parametric Design

CFD FEA

Analysis

Optimized Design
Key Clinical Attributes

in aspect of hemodynamics
In Aspect of hemodynamics…

- **Wall Shear Stress (WSS)**

  - Low shear area (Area exposed to WSS<5 dyne/cm²) is at high risk of cell proliferation. → Restenosis

Over time, plaque can re-form around the stent.

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Low Shear Area & Recirculation
WSS Variation with Pulsatile Flow
Effect of Skewed Design

Normal

Skewed
CFD -> WSS Distribution

better
Low Shear Area around the Crown

12% better

Skewed one is less ideal in terms of hemodynamics
Key Clinical Attributes

in aspect of mechanics
In Aspect of Mechanics...

- Radial Force
  - Whether or not the force exerted by artery wall could crush the stent
- Plastic Strain
  - Whether the stent tends to fracture
- Fatigue Safety Factor
  - Whether the stent can survive 10 years under cardiac pulsatile pressure
- Recoil Rate after Expansion
  - Achieve desirable stent expansion
4 Steps of Stent Deployment
Step 1: Stent Crimping onto Balloon Catheter
Step 2: Stent Recoil after Crimping
Step 3: Stent Expansion
Step 4: Stent Recoil after Expansion
Stent Radial Force Tester Simulation

Max. Radial Force
Fatigue Test (Goodman method)

Goodman Diagram → Fatigue Safety Factor
Stent Analysis System

Parametric Design

CFD  FEA

Analysis

Optimized Design
Parametric Analysis

- Investigate effects of several geometrical parameters on key clinical attributes
3 Parameters Included

-30%~-15%~Standard~+15%~+30%

- Strut width
- Crown Radius
- Strut thickness
Low shear Area (WSS<5 dyne/cm²)

Strut Thickness → Low Shear Area → Restenosis Rate

Area (mm²)

Strut Width

Crown Radius

Strut Thickness

-30%  15%  0%  15%  30%
Equivalent Plastic Strain

Strut Width
Crown Radius

Plastic Strain

Crown Radius
Strut Thickness
Strut Width

Equivalent Plastic Strain %

-30% 15% 0 +15% +30%

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Expansion Recoil Rate

Crown Radius

Expansion Recoil %

-30%  15%  0  +15%  +30%

Strut Thickness

Crown Radius
Fatigue Safety Factor

- Strut Thickness
- Crown Radius

Safety Factor

Fatigue Safety Factor

Crown Radius

Strut Width

Strut Thickness

-30%
-15%
0
+15%
+30%
Conclusions

- Integrated 3-D parametric stent design with FEA and CFD models was developed.

- The developed computational scheme is able to reduce the development cycle time significantly and helps achieve rapid prototyping.

- The developed CFD method helps improve understanding of restenosis, and FEA method helps investigate the mechanical behavior of a stent.
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