

## Computational Study of the Effect of Torsional Loading on the Behavior of Nitinol Stents in the Femoropopliteal Artery

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### Abstract

Smart stents made from Nitinol shape-memory alloy are gaining attention in the medical field due to their unique properties, including temperature-dependent shape change and superelasticity. Predicting their behavior before fabrication can reduce surgical and therapeutic risks. This study investigates the behavior of three stents (Smart Flex, Tigris, and Viabahn) using finite element analysis under torsional loading and at appropriate temperatures to examine superelastic behavior. The results showed that the Smart Flex stent outperformed others in terms of strain (0.05889), displacement (0.04943 m), stress (528.4 Pa), low force (266.9 N), and martensite fraction (0.8001). It also exhibited the highest twist (4.652 Nm) and torsional moment. In the comparison with experimental data, the Tigris stent had the closest agreement (23.22% difference), while Smart Flex and Viabahn showed differences of 34.78% and 57.71%, respectively. These findings suggest that Smart Flex is the most suitable option for complex medical conditions.

**Keywords:** Stent, smart material, finite element method, vascular, femuropopital.

### Introduction

Stenting is recognized as an effective method for treating various vascular disorders, including arterial occlusions; however, most existing stents are made from non-memory alloys, which can cause issues such as restenosis and reduced flexibility. Nitinol stents, due to their shape-memory and superelastic properties, have been introduced as a suitable option, especially for complex conditions like the femoropopliteal artery. Recent studies have shown that using numerical and analytical models can significantly improve the prediction of the mechanical behavior of Nitinol stents, particularly under torsional and multiaxial loading conditions (Wang et al., 2019; Liu et al., 2018). In this study, three types of Nitinol stents (Smart Flex, Tigris, and Viabahn) were simulated using the Finite Element Method (FEM) in Abaqus under torsional loading and at different temperatures to investigate their superelastic behavior. The stent geometries were designed in SolidWorks and material behavior was modeled using the Arrhenius model, capable of simulating superelasticity and shape-memory effects. The simulation results, including stress distribution, strain, displacement, applied force, and torsional moment, were analyzed and validated against

experimental data using percentage difference methods. The results indicate that the Smart Flex stent outperforms the others under torsional and superelastic conditions, suggesting it is the most suitable option for complex medical applications.

### Discussion and Results

The use of nitinol stents has attracted increasing attention in recent years due to their unique characteristics, such as superelastic behavior and shape memory capability, as an effective approach in the treatment of vascular diseases. Previous studies have shown that numerical analysis can serve as a powerful tool for predicting the mechanical behavior of these stents under various loading conditions, thereby contributing to improved design and enhanced durability (Feng et al., 2019; Tian et al., 2020). However, a thorough evaluation of stent performance, particularly under torsional loading—which is highly significant in highly mobile regions of the body such as the femoropopliteal artery—still requires more comprehensive analyses.

### Examination and comparison of stress-strain under torsional loading:

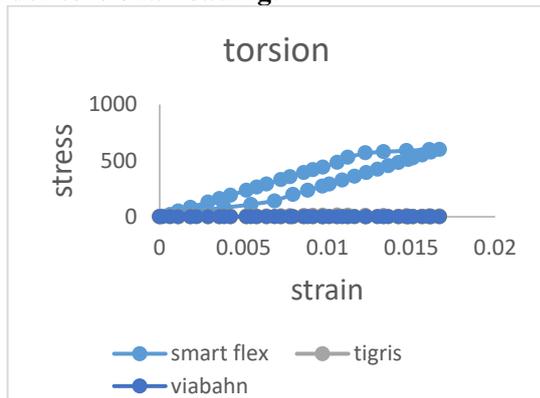


Figure 1: The stress-strain curve obtained for the Smart Flex, Viabahn, and Tigris stents under tensile loading in femoral arteries

The stress-strain simulation results for the Smart Flex, Viabahn, and Tigris stents under torsional loading show significant differences in their mechanical behavior. The Smart Flex stent exhibits the highest strain (0.05889) and stress (529.4 Pa), which, due to its superelastic properties and high flexibility, makes it suitable for complex medical conditions. This stent reduces the risk of arterial wall damage because of its high shape-change capability without failure. In contrast, the Viabahn and Tigris stents, with lower stress and strain, have greater strength and are more suitable for conditions that require less flexibility.

### Examination and comparison of force-displacement under torsional loading:

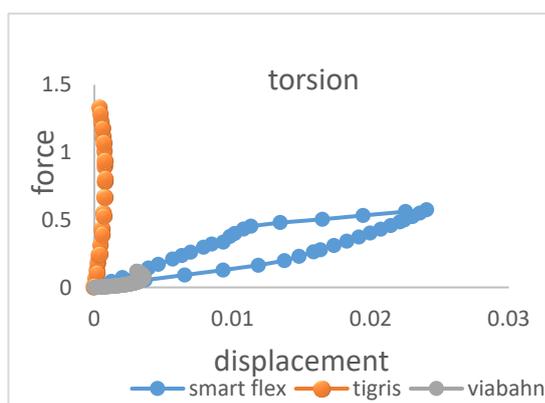


Figure 2: The force-displacement curve obtained for the Smart Flex, Viabahn, and Tigris stents under tensile loading in femoral arteries.

The Smart Flex, Viabahn, and Tigris stents show significant differences in their force-displacement behavior under torsional loading. The Smart Flex stent, with the highest displacement (0.04943 meters) and the lowest applied force (0.02669 Newtons), demonstrates high flexibility, making it suitable for complex medical conditions. In contrast, the Tigris stent, with greater

force and higher axial stiffness, has more strength and is better suited for maintaining arterial patency under high stress conditions. The Viabahn stent provides a balance between flexibility and strength, but with less flexibility compared to the Smart Flex. The choice of the appropriate stent depends on the specific clinical conditions, such as the mobility of the artery and the severity of the occlusion.

### Examination and comparison of martensite strain under torsional loading:

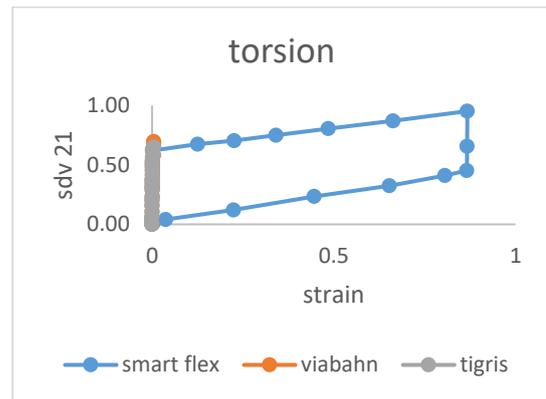


Figure 3: The curve of martensite phase percentage obtained under tensile loading for the Smart Flex, Viabahn, and Tigris stents in femoral arteries.

In nitinol alloy, the reversible phase transformation between austenite and martensite under mechanical loading plays a crucial role in the performance of femoral artery stents. This phase transformation, at temperatures above the  $A_f$  point, leads to recoverable superelastic strains, allowing the stents to adapt to the curvature of the vessels and the torsional torques caused by movements of the lower limbs without permanent deformation. Under torsional loading conditions, the stents must undergo a phase transformation to prevent stress concentration and damage to the vascular tissue. The martensite percentage in these processes is significant; for example, the martensite percentage in Smart Flex stents is 0.8001, reflecting their superelastic characteristics. In numerical simulations, accurate modeling of the austenite-martensite phase transformation and its hysteresis is essential for correctly predicting stress distribution, strain, and torque.

### Examination and comparison of torsional torque and torsional angle under torsional loading:

The investigation of the three stents—Smart Flex, Viabahn, and Tigris—shows that Smart Flex, due to the superelastic property of nitinol, exhibits the highest torsional torque (4.652 N·m) and torsional angle (8.001 rad/m), making it suitable for arteries with high dynamic

movement. In contrast, Viabahn and Tigris have lower values, making them more appropriate for maintaining arterial structure under high-stress conditions. Both simulation and experimental results confirm that stent selection should be based on clinical needs and individual patient characteristics; Smart Flex is suitable for high flexibility and complex medical conditions, while Viabahn and Tigris are better options for mechanical strength and structural stability.

### Conclusions

Numerical investigation of the nitinol stents Smart Flex, Viabahn, and Tigris under torsional and force-displacement loading shows that Smart Flex demonstrates superior performance due to its high torsional flexibility, martensite formation, and superelastic properties. This stent exhibits a strain of 0.05889, displacement of 0.04943 m, stress of 528.4 Pa, low force of 266.9 N, martensite percentage of 0.8001, torsional torque of 4.652 N·m, and the highest torsion, making it suitable for clinical applications involving severe arterial movement. In contrast, Viabahn and Tigris, with higher mechanical resistance and greater displacement, are better options for conditions requiring structural strength and stability under high stress,

although they provide lower torsional flexibility. The results of finite element analyses and numerical simulations emphasize that stent selection should be based on mechanical properties, clinical requirements, and arterial conditions, and that the combination of precise simulations with experimental data is key to enhancing the performance and safety of stents in medical applications.

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