Chapter 1
Creep Experimentation of the Porcine Aorta under Combined Normal and Torsional Loadings

Kris Bayeh†, Luc Nguyen, Nick Baron, Lauren Chamberlain, Torie Pensado, Cade Montes, Krystal Bayeh, and Chandler C. Benjamin

Abstract The viscoelastic properties of aortic tissue such as creep and stress relaxation need to be further studied to better understand the causation of various aortic diseases. In this study, we utilized an Anton Paar MCR-302 rheometer in a parallel plate configuration to investigate the viscoelastic properties of porcine aortas. We applied compressive and torsional loads to circular porcine aorta samples of 0.5 inches in diameter. The top plate of the rheometer initially compressed the samples by either 5, 10, 15, 20, or 25% strain over a span of 10 seconds, and then applied a torsional load of 0.5, 1.0, 1.5, or 2.0 mN-m over a span of 1 second. The combination of compression and torsion was then held for 1000 seconds while the rheometer measured the shear strain response of the aorta. From preliminary testing, samples demonstrated a power law behavior in their shear strain response. The behavior of the creep response appears noticeably different from the stress relaxation response of tests previously conducted in our lab. We also observed that samples performed at higher torque inputs demonstrated internal microstructural tearing at 500% shear strain in which layers of the aortic tissue would visibly separate.

Keywords Creep · aorta · rheology

Introduction

Characterizing the viscoelastic properties of aortic tissue can help facilitate advancements for health conditions associated with the aorta such as aneurysms and grafts [1]. These properties have yet to be thoroughly investigated and it remains unclear how variations in viscoelastic behavior influence aortic function and disease progression[11]. It has been shown that purely elastic models are insufficient in properly capturing the mechanical behavior of arterial tissue [5, 10]. As such, we aim to further explore viscoelastic properties of the porcine aorta through systematic experimentation. In our previous studies,

Kris Bayeh
Biomedical Sciences, Texas A&M University, College Station, TX, 77843.
e-mail: kris-bayeh@tamu.edu

Luc Nguyen · Lauren Chamberlain · Chandler C. Benjamin
Department of Mechanical Engineering, Texas A&M University, College Station, TX, 77843.
e-mail: laurenmchambe@tamu.edu; lucnguyen314@tamu.edu; ccbenjamin@tamu.edu

Nick Baron · Torie Pensado · Cade Montes
Department of Biomedical Engineering, Texas A&M University, College Station, TX, 77843.
e-mail: ni.baron37@gmail.com; toriep@tamu.edu; cademontes@tamu.edu

Krystal Bayeh
College of Medicine, Texas A&M University, Bryan, TX, 77807.
e-mail: krystalbayeh@gmail.com

Chandler C. Benjamin
School of Engineering Medicine, Texas A&M University, Houston, TX, 77030.
e-mail: ccbenjamin@tamu.edu

†Presenting author

© The Author(s), under exclusive license to River Publishers 2026

Jonathan B. Estrada et al. (eds.), *Mechanics of Biological Systems and Materials, Volume 3, 2026*, Conference Proceedings of the Society for Experimental Mechanics Series, https://doi.org/10.13052/rp-9788743816263

we discovered that the shear response is significantly impacted by changes in the normal compressive strain[7]. We also studied the stress relaxation behavior of the porcine aorta under combined compression and shear strain. From this research, it was found that the behavior of stress relaxation is different among normal and torsional shear directions, and that neither of these behaviors are greatly impacted by the intensity of shear or compressive strain[8]. Stress relaxation is an important mechanism to recognize when discussing the viscoelastic properties of aortas as previous research has found that it provides better comprehension of the directional and spatial variations in aortic mechanical behavior[4]. This enables a more accurate understanding of how aortic wall tissue responds over time and across different regions under physiological loading conditions. In addition to relaxation data, it is equally important to analyze creep behavior as the two are complementary to each other and the characteristics that contribute to the differences between them are not thoroughly explored[13]. Creep analysis in itself is essential to developing mathematical models capable of predicting the time-dependent viscoelastic behavior of certain biological tissues, such as that of the aorta[14]. Previous experimental studies have investigated the creep response of arterial tissue, but primarily focus on uniaxial or biaxial modalities [2, 9]. The creep behavior of arterial tissue in the shear direction remains less explored. The present study investigates how porcine aortas react under constant shear stress and normal compressive loads to analyze how the aorta is impacted by sustained mechanical forces over time including creep and structural deformation. This aims to improve our understanding on how mechanical loading can contribute to changes in aortic integrity, which could provide us insight on how to create more durable vascular grafts and help us enhance clinical approaches for managing aortic disease[6].

Experimental Methods

Porcine aortas were harvested and collected from the Texas A&M Rosenthal Meat Center. The aortas were then cleaned of excess tissue and cut into circular shapes with a diameter of around 0.5 inches using a 0.5 inch circular punch[8, 7]. Circular test samples were stored in vials containing Phosphate Buffer Solution (PBS) and placed in a freezer under a constant temperature of -20° C. Before testing, vials were thawed in room temperature water for around 15 minutes and Vernier calipers were used to measure their diameter and thickness. Aorta samples were tested in an Anton Paar MCR-302 rheometer in a parallel plate configuration. The samples were placed one at a time on the bottom plate of the rheometer which consisted of a bath filled with PBS and 80-grit sandpaper adhered to its floor. The top plate of the rheometer, which also had 80-grit sandpaper adhered to it, initially compressed the samples by either 5, 10, 15, 20, or 25% strain over a span of 10 seconds, and then applied a torsional load of 0.5, 1.0, 1.5, or 2.0 mN-m over a span of 1 second. The combination of compression and torsion was then held for 1000 seconds while the rheometer measured the shear strain response of the aorta. Figure 1 shows a sample loaded in the rheometer. Ten samples were tested for each combination of compression strain and torsional load.

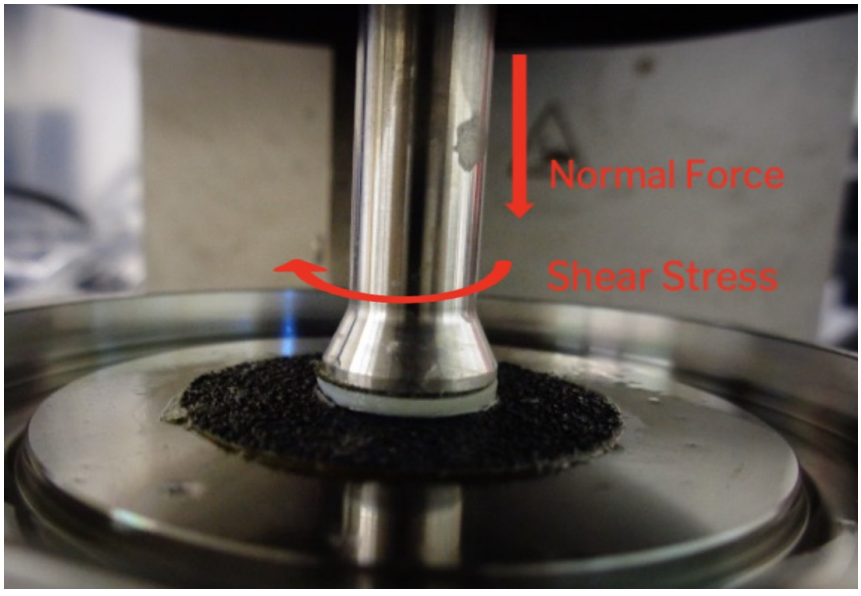

Fig. 1 Rheometer containing a sample with labels depicting how force is applied to it.

The experimental data was plotted on a shear strain in percent versus time in seconds graph. The graph was then converted into a logarithmic scale to enhance visualization and allow for clearer observation of common patterns [3].

Results

Figures 2, 3, and 4 show the averages of ten samples plotted on a shear strain versus time graph that were subjected to compressive strains ranging from 5% to 25% under constant applied torques of 0.5, 1.0 and 1.5 mN·m. Each curve on the figures represents the mean of these 10 independent samples at the different compressive strains provided within the

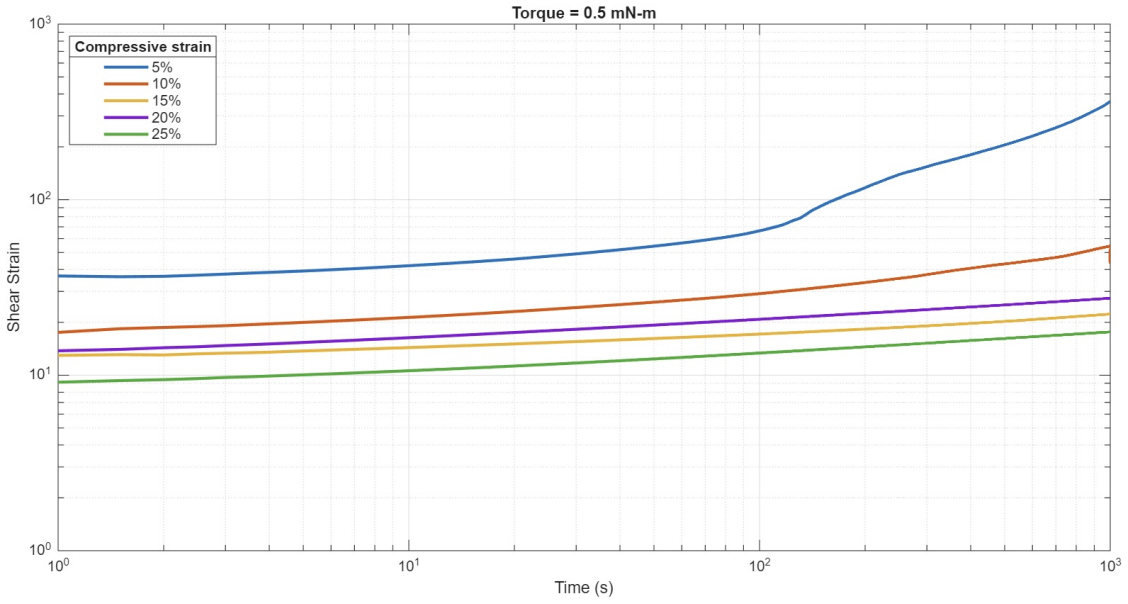

Fig. 2 Average shear strain (n=10) versus time for samples subjected to compressive strains ranging from 5% to 25% under a constant applied torque of 0.5 mN·m

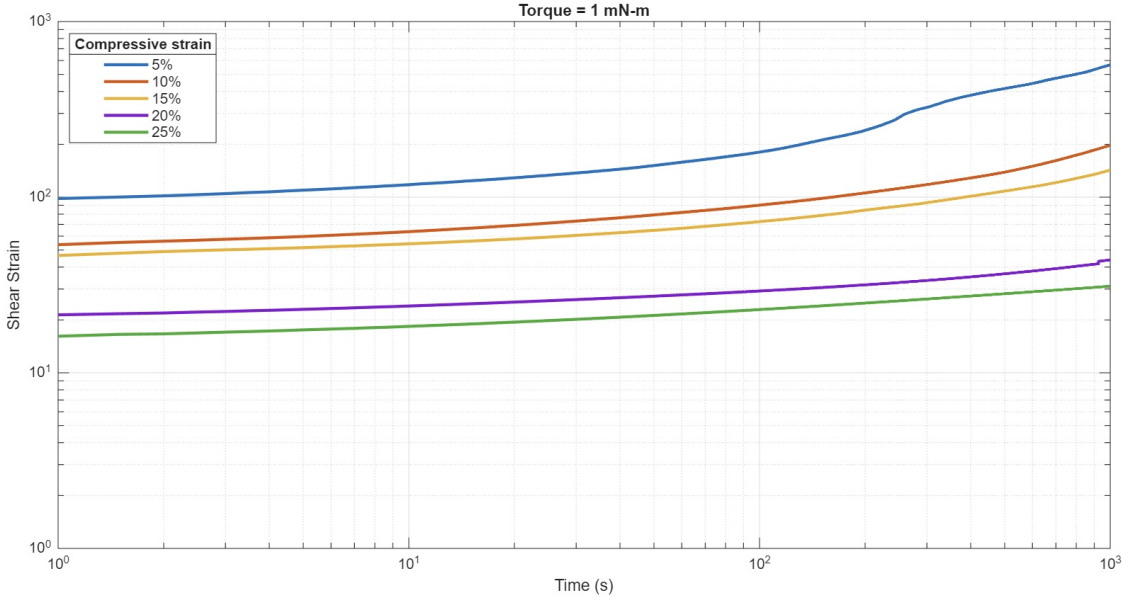

Fig. 3 Average shear strain (n=10) versus time for samples subjected to compressive strains ranging from 5% to 25% under a constant applied torque of 1.0 mN·m

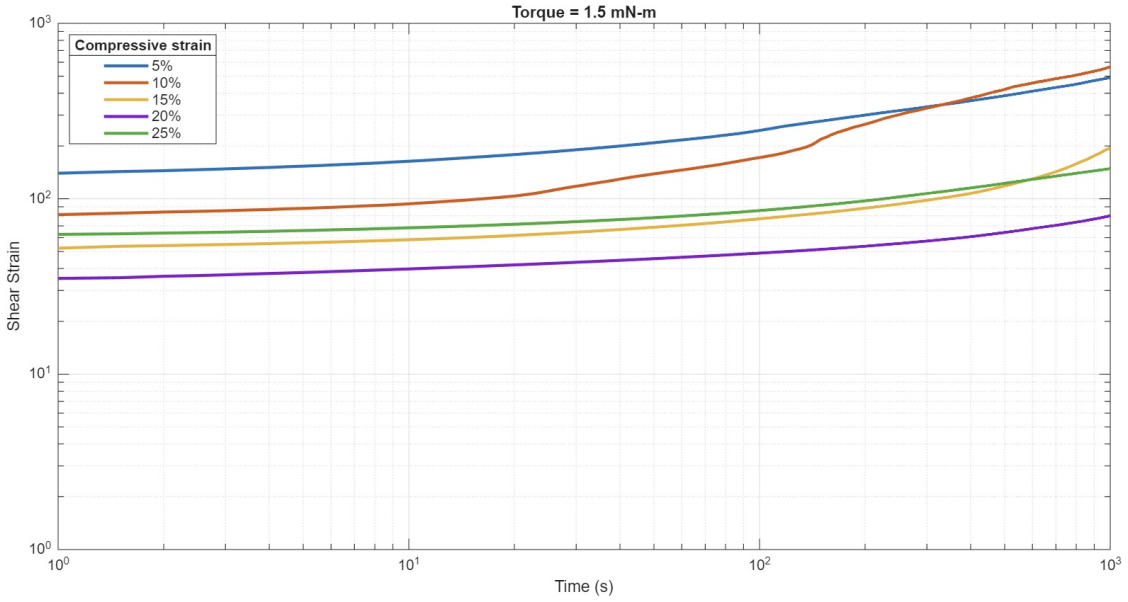

Fig. 4 Average shear strain (n=10) versus time for samples subjected to compressive strains ranging from 5% to 25% under a constant applied torque of 1.5 mN·m

key. The figures depict that lower compressive strains result in higher shear strains, and the behavior is mostly linear with a couple exceptions. The plotted data also displayed similar patterns amongst the ten individual samples within their respective combinations of compression strain and torsional load with some occasional outliers.

Discussion

During testing, it was observed that the more extreme parameters had unpredictable patterns and often "slipped" during testing. These events were a direct result of the internal microstructural tearing demonstrated at these higher torques, particularly at 500% shear strain in which layers of the aortic tissue would visibly separate. When plotted logarithmically, the shear strain versus time graphs displayed an approximately linear pattern. This demonstrates a power law relationship for the creep behavior of porcine aorta in the shear direction[12]. The data displays a seemingly inverse relationship between compression and resultant shear strain. This may be due to increased compression causing the fibers to stiffen, resulting in less shear strain. The behavior of the creep response appears noticeably different from the stress relaxation response of tests previously conducted in our lab.

Conclusions

This study highlights important trends related to the viscoelastic properties of porcine aortas when placed under different compressive strains and torsional loads. We found that increasing torque affects shear strain amplitude, but does not appear to change creep behavior. These findings can improve models used to simulate arterial behavior, leading to more accurate predictions of physiological and pathological conditions of the aorta and can also assist in the design of vascular grafts and other biomedical interventions.

References

1. Giulio Franchini, Ivan D Breslavsky, Gerhard A Holzapfel, and Marco Amabili. Viscoelastic characterization of human descending thoracic aortas under cyclic load. *Acta Biomaterialia*, 130:291–307, 2021.

2. Jonathan S Grashow, Michael S Sacks, Jun Liao, and Ajit P Yoganathan. Planar biaxial creep and stress relaxation of the mitral valve anterior leaflet. *Annals of biomedical engineering*, 34(10):1509–1518, 2006.
3. Felipe Guerrero, Valeria Aguado, Jhonathan Duque, Albert R Ortiz, José J García, and Daniel Gomez. Characterization of the uncertainty associated with viscoelastic creep model for guadua angustifolia. *Results in Engineering*, page 107951, 2025.
4. X Leng, X Deng, S Ravindran, A Kidane, SM Lessner, MA Sutton, and T Shazly. Viscoelastic behavior of porcine arterial tissue: Experimental and numerical study: Viscoelastic behavior of aortic tissue. *Experimental Mechanics*, 62(6):953–967, 2022.
5. Manoj Myneni and KR Rajagopal. Constitutive modeling of the mechanical response of arterial tissues. *Applications in Engineering Science*, 11:100111, 2022.
6. Manoj Myneni, Raghuveer Lalitha Sridhar, KR Rajagopal, and Chandler C Benjamin. Experimental investigation of the anisotropic mechanical response of the porcine thoracic aorta. *Annals of Biomedical Engineering*, Accepted for Publication.
7. Luc Nguyen, Manoj Myneni, Abdelrahman A Youssef, and Chandler C Benjamin. Effect of normal stress on the torsional shear response of the porcine descending aorta. In *Society for Experimental Mechanics Annual Conference and Exposition*, pages 21–24. Springer, 2022.
8. Luc Nguyen, Abdelrahman Youssef, Calvin Nguyen, Kirtan Patel, Jack Luce, Benjamin Tijerina, and Chandler C Benjamin. The stress relaxation response of the porcine descending aorta under combined normal and torsional loadings. In *Mechanics of Biological Systems and Materials and the Mechanics of Composite, Hybrid & Multifunctional Materials, Volume 3*, pages 19–27. River Publishers, 2025.
9. Caitlin M Pierlot, Andrew D Moeller, J Michael Lee, and Sarah M Wells. Biaxial creep resistance and structural remodeling of the aortic and mitral valves in pregnancy. *Annals of biomedical engineering*, 43(8):1772–1785, 2015.
10. Kumbakonam R Rajagopal and Keshava Rajagopal. Modeling of the aorta: complexities and inadequacies. *Aorta*, 8(04):091–097, 2020.
11. Akshay Rao, Manoj Myneni, CC Benjamin, and KR Rajagopal. High amplitude torsional shear of porcine thoracic aorta. In *Mechanics of Biological Systems and Materials & Micro-and Nanomechanics, Volume 4*, pages 37–40. Springer, 2020.
12. Dimitrios P Sokolis, Harisios Boudoulas, and Panayotis E Karayannacos. Assessment of the aortic stress–strain relation in uniaxial tension. *Journal of biomechanics*, 35(9):1213–1223, 2002.
13. Zhijie Wang, Mark J Golob, and Naomi C Chesler. Viscoelastic properties of cardiovascular tissues. *Viscoelastic and viscoplastic materials*, 2:64, 2016.
14. W Zhang, X Guo, and GS Kassab. A generalized maxwell model for creep behavior of artery opening angle. 2008.