Effect of Mild Blunt Trauma on Mechanical Properties of Aorta

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Abstract

Traumatic aortic rupture is a significant cause of death in motor vehicle accidents with aortic injuries leading to 20% of fatalities in motor vehicle crashes. The knowledge of the material properties of aortic wall is fundamental to the understanding of aortic rupture mechanisms and how a local tear propagates through the aortic wall. It is believed that non-fatal injuries may also lead to long-term cardiovascular disorders in many accident survivors, even with no significant structural damage at the time of accident. The aim of this study was to characterize mechanical properties change along the porcine thoracic aorta wall after a mild blunt trauma.

Materials and Method

Numerous studies have separately investigated mechanical, architectural and histological properties of aorta utilizing various techniques for determining soft tissues properties [1,2].

Five porcine aorta specimens were subjected to mild blunt trauma in a dynamic bending test setup (Fig. 1)[3]. 200-mm-long samples were pressurized to 15 kPa (110 mmHg) with room-temperature PBS and stretched up to 30% the initial length. The system was decelerated at 55G using an impact system with high repeatability.

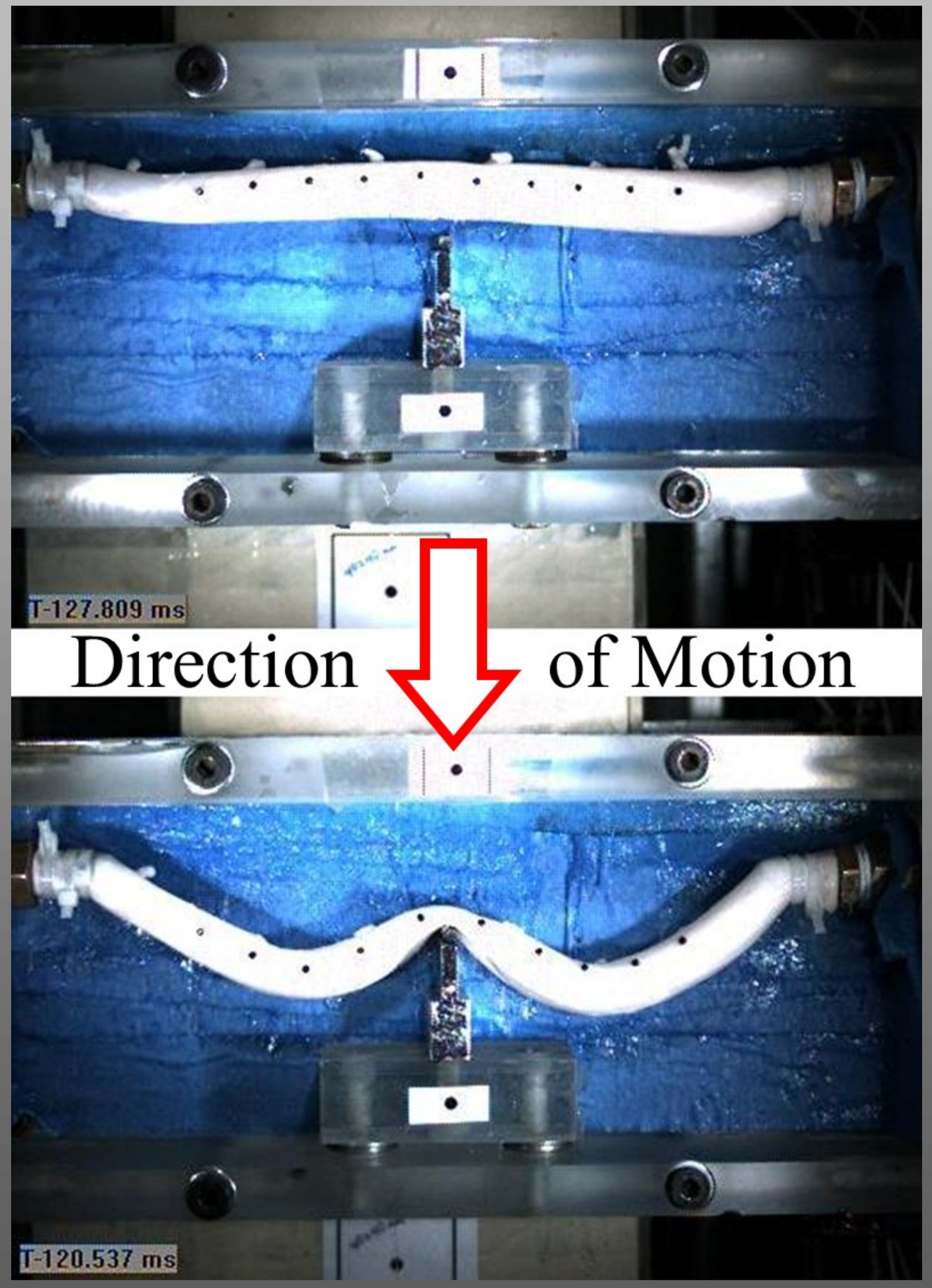

Figure 1. Pre-stretched aorta during motion before and after impact

Initiation of microstructural damage and failure mechanism of aorta was determined form the histological (Fig. 2).

Figure 2. Representative samples showing mild to severe delamination in thoracic porcine aorta due to impact (from left to right).

The mechanical properties of aorta wall were characterized using nanoindentation techniques with a conical indenter (fig 3).

The indentation tests were performed on the medial and anterior side of the impacted section (between 3rd and 4th intercostal arteries) and 4cm inferior to that section (between 5th and 6th intercostal arteries).

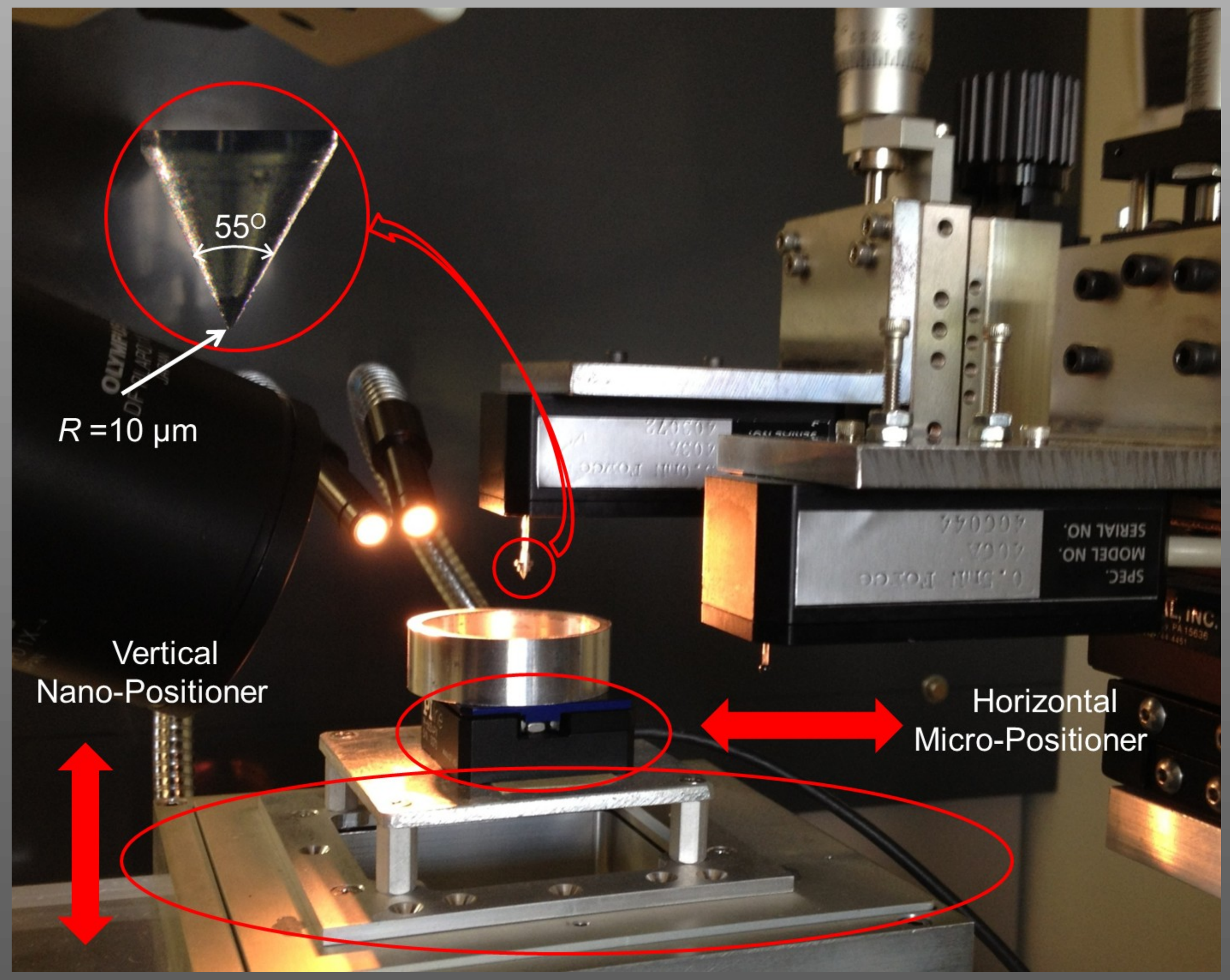

Figure 3: Experimental setup for nanoindentation

Samples were moved upward toward the indenter with a ramp and hold displacement with 40 µm indentation depth, 10 ms ramp time and 30 s hold time (Fig. 4)[4].

quasi-linear viscoelastic (QLV) model was used for modeling:

$$P(t)=\int_0^t G(t-\tau)(\partial P^e(h)/\partial h)(\partial h/\partial \tau)d\tau$$

$P^e(h)$: the instantaneous elastic force

$$P^e=\{2E\cot(\beta)/\pi(1-\nu^2)\}h^2$$

$G(t)$: the reduced relaxation function

$$G(t)=G_\infty+\sum_{i=1}^{4}G_i\exp(-\beta_i t)$$

G_i : relaxation amplitudes β_i :decay rates

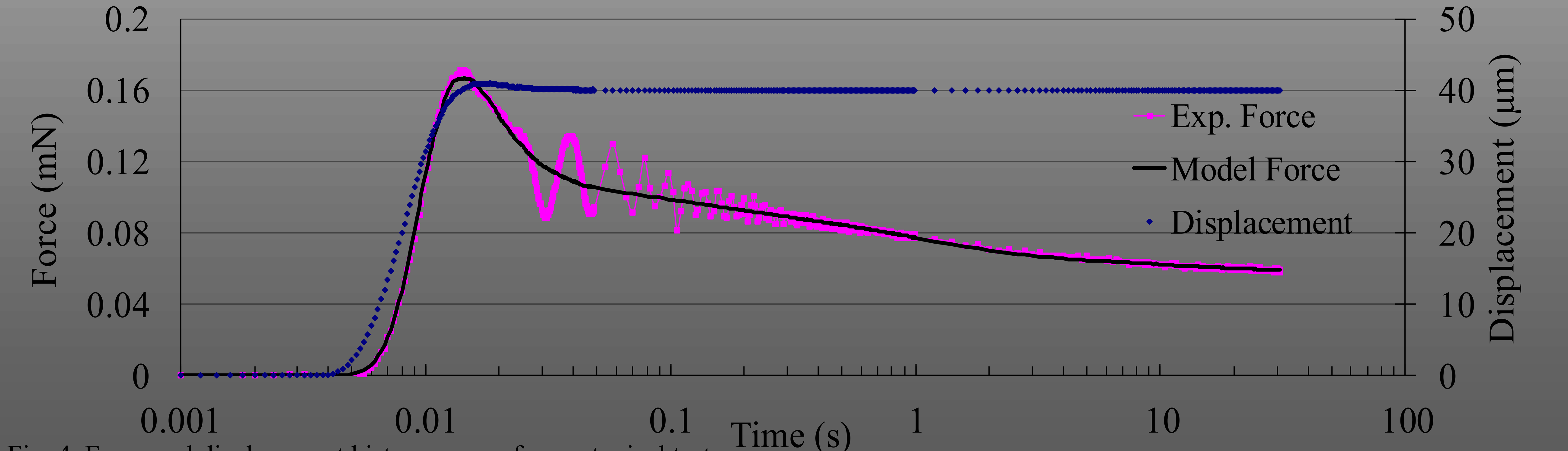

Fig. 4. Force and displacement history curves from a typical test.

Results & Discussion

Although there was no sign of structural damage in the histological results, the mechanical properties of aorta significantly changed as a result of impact. Instantaneous Young's Modulus at the site of impact was decreased by 39% (from 112.48±9.51kPa to 81.21±6.10kPa, Fig. 5). Moreover, comparison of the inner and outer halves of aorta wall thickness revealed that the elastic modulus was reduced more in the inner half portion, which indicates that the inner layer of aorta is more vulnerable than the outer layer.

In control samples generally anterior side is stiffer than medial side, but after impact on the anterior side the trend was changed and anterior side is more compliant than medial side (Fig. 6).

Considering the mechanism of partial aortic rupture and the risk of fatality of TAR, the results of this study are important to investigate local mechanisms of aorta deformation, force transmission, tear propagation and failure.

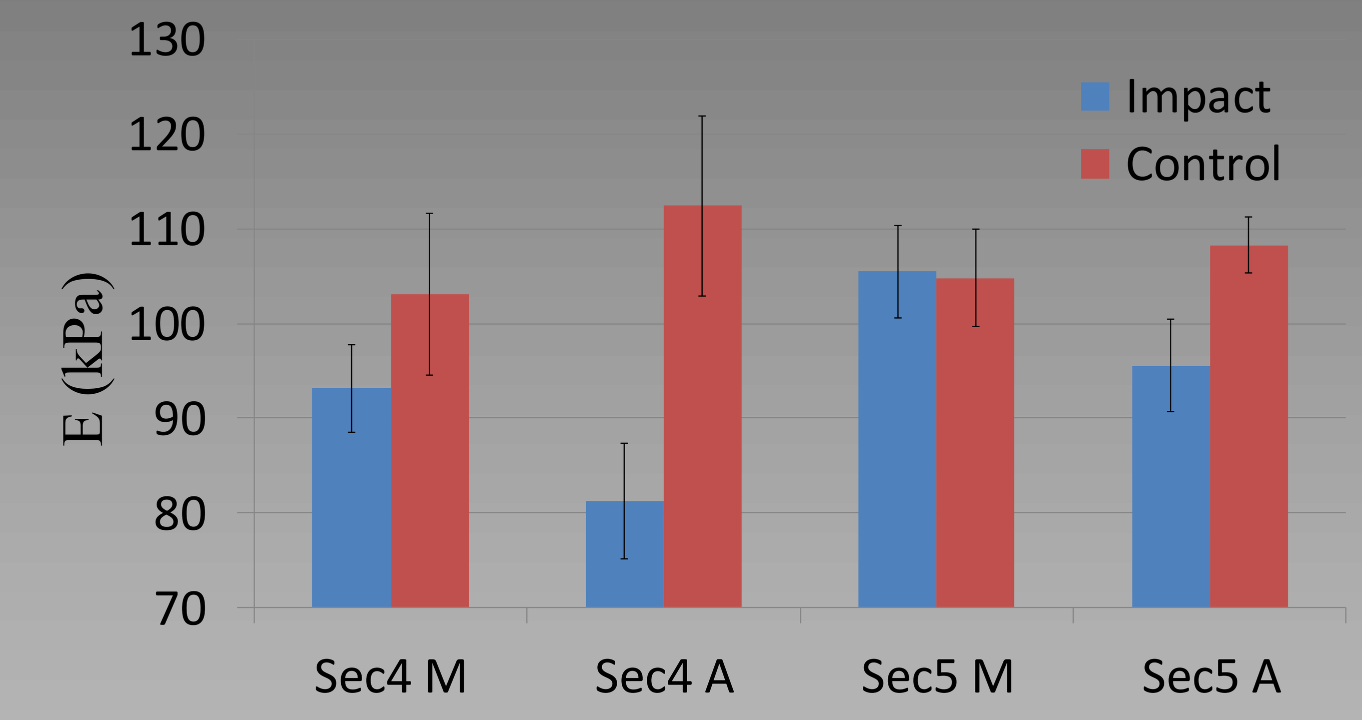

Figure 5. *t*-test comparison after impact with control group

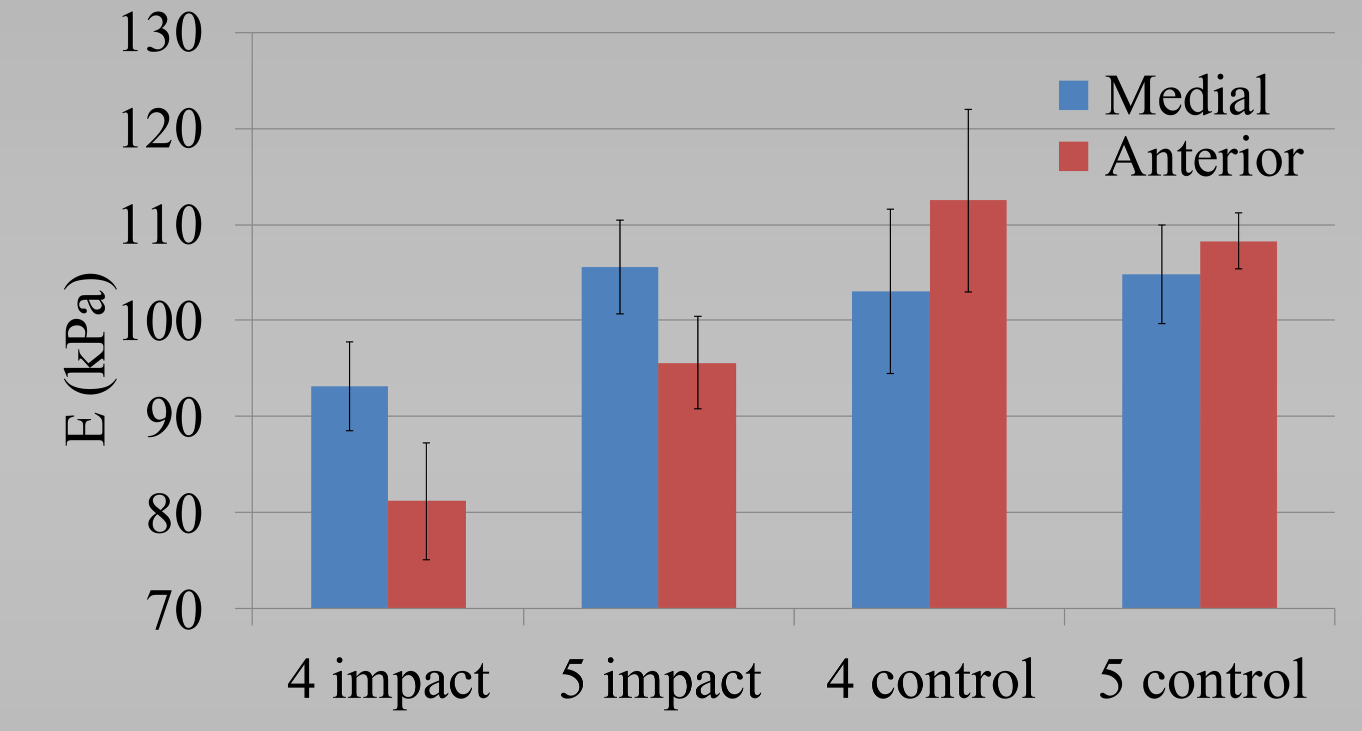

Figure 6. Circumferential changes before and after impact.

References

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