INTRODUCTION:
Noninvasive radiographic techniques, e.g., bone mineral density measured using dual x-ray absorptiometry or quantitative computed tomography, are the clinical standard in the diagnosis and treatment of osteoporotic vertebral fractures [1,2]. These measures are good predictors of ex vivo compressive strength [3-6]; however, they are poorly correlated with strength in anterior bending [7]. Because vertebral wedge fractures (the most commonly observed vertebral fracture type [8]) are associated with eccentric compression and bending loads [9], it is critical to develop non-invasive techniques that are capable of predicting strength under both compression and bending loading conditions. The relationship between vertebral strength in compression and anterior bending is not well established. Using a finite element technique, Crawford et al. [10] found that bending and axial rigidities were moderately correlated for the same vertebra (R² = 0.69); however, these results have not been validated experimentally. The purpose of this study was to assess differences in vertebral strength across loading modes. We conducted destructive biomechanical tests on donor-matched thoracic vertebrae in both uniform axial compression and anterior bending. Both tests had well defined loading conditions, and isolated vertebral bodies were used to eliminate the confounding effects of the intervertebral discs and posterior elements.

METHODS:
Sixty human thoracic vertebrae from 30 donors were dissected from fresh-frozen cadavers (T9 and T10; F = 10, M = 5; 87 ± 5 y.o.). The vertebrae were cleaned of the surrounding soft tissue; the posterior elements were transected at the pedicles; and the endplates were potted in bone cement. After potting, all specimens were wrapped in saline-soaked gauze and stored at −20 degrees Celsius until mechanical testing. Care was taken to minimize the number of freeze-thaw cycles for each vertebra.

One vertebra from each donor was destructively tested in axial compression, while the other vertebra was tested in anterior bending. Uniaxial compression tests were performed using a servohydraulic load frame (858 mini-bionix, MTS, Eden Prairie, MN) and a high-capacity load cell (AMTI MC6-5000, Advanced Mechanical Technology, Inc., Watertown, MA) (Figure 1). Specimens were preconditioned by applying 10 cycles of 100 N to 250 N compressive force at 0.1 Hz, followed by displacement-controlled loading at 1 mm/minute until the specimen reached its ultimate force.

Anterior bending tests were conducted using an industrial robot arm (MotoMan UP50, Motoman, Inc., West Carrollton, OH) that simultaneously compressed and flexed the vertebrae (Figure 1). Transverse plane shear force was minimized using roller bearings placed beneath the specimen, and a linear variable differential transformer (LVDT, SE 750, Macro Sensors, Pennsauken, NJ) was used to monitor specimen displacement relative to the center of moment of the load cell. Using load cell and LVDT data, bending moment was expressed about the geometric center of the specimen. Specimens were preconditioned (10 cycles of 100-300 N at 0.1 Hz [11]) and destructively loaded at 0.1 mm/sec axial displacement and 0.2 degrees/sec of anterior rotation.

RESULTS:
There were statistically significant inter and intra-donor differences between compression and bending failure loads. Across all donors, axial force was higher for compression specimens by 940 ± 152 N (2890 ± 1591 N for compression, 1766 ± 913 N for bending, p < 0.001 for matched pair comparison). Ultimate axial force in compression and bending for the same donor were moderately correlated (Figure 2).

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REFERENCES:

Figure 1: (left) Experimental set-up for (left) uniaxial compression and (right) anterior bending tests on isolated vertebral bodies.