INTRODUCTION:
Many studies of finger flexor tendon repair have focused on suture materials (Polyester, Nylon, Polyethylene), techniques (Modified Kessler, Modified Pennington, Tsuge), and knot-types (surgeon’s knot, square knots with varying numbers of throws) in hopes of identifying a combination with optimal breaking strength. These studies generally use relatively slow loading rates, < 1 mm/sec, to distract the repaired tendon to failure. However, normally individuals flex and extend their fingers at rates much higher than this. In addition, most often repairs fail from a forceful, sudden pull on the repair1, with loading rates that may be several orders of magnitude higher.

An important characteristic of tendons is that they are viscoelastic, with a stress-strain response that is a function of time1. This leads us to believe that the loading rate has an impact on the tendon failure strength and stiffness.

The purpose of this study was to characterize the effect of different loading rates on a repaired canine flexor digitorum profundus (FDP) tendon. Different velocities were chosen for their clinical significance. Many studies use 0.33 mm/sec as the linear velocity at which a tendon is distracted until failure. Slow finger motion, opening and closing a fist once per second, produces a rate closer to 84 mm/sec. We defined the upper limit of testing to be 590 mm/sec based on a study which estimated this to be the velocity of the wrist upon impact with the ground2.

MATERIALS AND METHODS:
Thirty six FDP tendons from canine hind legs were used. The animals had been sacrificed for other, IACUC approved, studies. The FDP tendons were isolated and transected at the proximal interphalangeal joint level. Tendons were repaired with a modified Kessler technique with a 3/0 Ethibond core suture and a running suture of 6-0 Prolene. Tendons were clamped into a servo-hydraulic testing machine for assessment of failure strength. A small, differential variable reluctance transmitter (DVRT) was fixed to either side of the laceration to measure gap formation. After ramped loading to 2N, a cyclic pre-load profile with 0.25-mm amplitude and 0.5 Hz frequency was applied for 10 cycles. 36 tendons, divided into three groups, were tested at 3 displacement rates: 0.33 mm/sec, 84 mm/sec, and 590 mm/sec. The tensile force and axial displacement were recorded at 1024 Hz during testing. Tendons were distracted until failure and the failure mode was recorded. Possible modes of failure included suture pullout, core suture knot untying, and breaking of the core suture. Peak force and stiffness of the repair were calculated from the load-displacement data collected. One-way analysis of variance (ANOVA) followed by a Tukey-Kramer post hoc test were used to compare the data among the three groups.

RESULTS:
Peak force was significantly greater (p<0.05) for the tendons that were distracted at 590 mm/sec than those that were distracted at 0.33 mm/sec. The lowest mean failure strength was seen in the tendons pulled at 0.33 mm/sec. Tendons pulled at 84 mm/sec did not differ significantly from either of the other two groups (Figure 1).

Stiffness for each of the three groups was also measured. Crosshead stiffness (N/mm) was significantly greater (p=0.05) for the tendons that were distracted at 590 mm/sec than those distracted at 84 mm/sec or at 0.33 mm/sec. The tendons exposed to a velocity of 0.33 mm/sec showed the lowest mean stiffness out of the three groups. Tendons pulled at 84 mm/sec did not differ significantly from the 0.33 mm/sec group (Figure 2).

DISCUSSION:
Prior to this study, the failure strengths of tendon repairs at normal physiologic motion and in instances of sudden fall were unknown. This study assigned quantitative values to different actions that have been identified to cause tendon rupture in prior studies. Our results clearly show that the failure strength of a tendon repair is significantly greater with an action such as a sudden fall (590 mm/sec) than with actions that are slower than normal physiologic motion (0.33 mm/sec).

Additionally, this study confirms the idea that distracting tendons until failure with a loading rate of 0.33 mm/sec, as has been done, is indeed a conservative approach for determining the effectiveness of tendon repair. Based on the results, repairs which have been tested at a low loading rate, such as 0.33 mm/sec, will be stronger at clinically relevant loading rates.

SIGNIFICANCE:
This study correlates repair rupture strength with loading velocity. Tendon repairs are stronger at higher loading velocities; thus laboratory testing at slower loading rates actually provides a conservative estimate of suture strength.

ACKNOWLEDGEMENTS:
This study was supported by NIH Grant T32 AR 056950.

REFERENCES: