Tether Tension Affects Vertebral Growth Modulation in a Novel Kyphotic Porcine Model

Matthew A. Halanski [1,2], James Sypherd[3], Max Twedt[4], Alex Farell[4], Ellen Leiferman[5], Brittney P. Kokinos[5], Cameron Jeffers[3], Augustus Malan[1], Susan Hamman[1], Tom Crenshaw[5]

[1]Phoenix Children's Hospital, Phoenix, AZ, [2]University of Arizona, Phoenix, AZ, [3]Arizona State University, Tempe, AZ, [4]University of Nebraska Medical Center, Omaha, NE, [5]University of Wisconsin-Madison, Madison, WI,

halanski@arizona.edu/tdcrensh@

Disclosures: The authors have nothing to disclose

INTRODUCTION: Spinal Deformities account for ~16,000 hospital admissions a year [1]. Posterior spinal fusion (PSF) has been the gold standard for pediatric spinal deformity treatment[2-3]. However, PSF is a highly invasive procedure with notable biomechanical concerns due to the loss of mobility and growth at the fused spinal levels [4]. Vertebral growth modulation through vertebral tethering has recently been explored as an alternative to PSF, however clinical tethering outcomes have been less consistent than suggested by early animal studies that extrapolated from the ability to create a spinal deformity in a straight animal spine, with the ability to straighten a curved spine of a child [3, 5]. In this study, we measured the differences that spinal deformity had on vertebral endplate loading under various tethering scenarios. Using a novel, diet induced, large animal (porcine) spinal deformity model[5], we studied the effects that spinal deformity and tether tension on radiographic changes in vertebral alignment, apical disc pressures, and regional vertebral growth

METHODS: Straight and kyphotic anatomic models (Sawbones, Bainbridge Is, WA) were instrumented with pedicle screws and Tekscan (South Boston, MA) Flexi-force sensors placed within the disc space of the central or apical vertebrae. Stiffness of the anterior spine was then varied and 0-50N of force applied through a handheld load cell attached to two (one left and one right) flexible tethers attached to the pedicle screws and loading of the anterior, middle, and posterior endplates was recorded. From 14 litters (10 dietary restricted, 4 controls) of mixed breed swine, 41 piglets, (24 kyphotic and 17 control) were selected and placed into one of three cohorts used in this study **(Fig 1)**. Cohort 1 –Baseline Model Characterization: Radiographic, Regional Vertebral Fluorochrome Growth Rates, and Intervertebral Disc Pressures (via Gaeltech, Isle of Skye, Scotland- pressure transducer)(**Fig 2**) of our kyphotic pigs and control herd pigs at ~10 and 12 weeks. (10 kyphotic and 10 control, 5 from each at each time point). Cohort 2-Posterior tether tension effect on radiographic parameters and disc pressures in both kyphotic and control spines. Two different instrumentation constructs were inserted, with screws at every level (N=3, N=4) versus every other level (N=3, N=3) using non—recovery and fresh cadaveric specimens, posterior tethers were places and tensioned at various loads (0-50N) and radiographic and disc pressure changes recorded. Cohort 3-Recovery Operative Spines Five kyphotic spines were instrumented at every other level with low tension. This cohort had difficulty and did not gain weight due to a host of post-operative complications. Simpler cohorts we instrumented including a single level tether was applied across the apical disc space. Low tension (5N) N=4 and high tension (25N) N=4 sub-cohorts were recovered and at two weeks, radiographic measures, disc pressures, and regional vertebral growth rates assessed. Pulsed fluorochrome labeling was performed 14 days (Alizarin Red) and within 24 hours (Oxytetracycline) prior to harvest. The apical vertebrae were resected en bloc and then fixed in 70% ethanol solution. Bones were sagittal sectioned into 1 mm thick slabs utilizing an Isomet Precision saw (Buehler Isomet 2000; Lake Bluff, IL) for epifluorescence. Alizarin complexone was optimally viewed with 510-560 nm excitation filter and 590 nm barrier filter, while oxytetracycline was viewed optimally with a 405 nm excitation filter and 470 nm barrier filter. Distances between labels were measured using a custom matlab image processing program. Radiography was performed using a portable radiography unit and measurements made on digital imaging system.

RESULTS: Our anatomic modeling demonstrated that at lower tether tensions ~<25N, the effects of endplate loading differed between the straight and kyphotic spine, in that the tether immediately produced the desired load gradient (higher posteriorly/lower anteriorly) across the endplate, but in the kyphotic deformed spine, initially "low" tether loads failed to reverse the more anteriorly loading occurring at rest and only overcame this loading to establish the desired gradient at higher tether loads. Interestingly, in both the straight and kyphotic spines compressed and rigidly inelastic anterior structures resulted in increased anterior loading with higher posterior tether tension, indicating the importance of disc mobility. Our animal modeling demonstrated that at 10 weeks of age our kyphotic piglets had greater (47+3° vs.39+4°) Cobb angle, slower anterior vertebral growth rate (59+18 vs 98+24 um/day) and lower disc pressures (77+16 vs 122+37 kPa) than their age matched controls. The kyphotic and control pig apical disc pressures behaved similarly, but both followed different trends depending on instrumentation pattern. For apical disc in constructs instrumented at every vertebral level, as tether tension increased, disc pressure decreased, conversely for discs within constructs instrumented at every other level, disc pressure was maintained or was slightly elevated . Regional vertebral growth rate data following surgery demonstrated more significant growth modulation in the high tension constructs than in the low tensioned constructs: anterior growth rate 152+53 vs 89+29 um/day (p=0.03), posterior growth rate 27+33 vs 72+17 um/day (p=0.02)(**Fig 3**).

DISCUSSION: The results of vertebral growth modulation depend on the tether-induced growth plate stress magnitudes and their relationship to affect growth. Differences in the reported results between historical animal data collected in a straight spine and early clinical human data collected in the deformed spine demonstrate the need to understand how the geometric differences of the vertebrae, disc spaces and baseline growth abnormalities of a deformed spine affect or are affected by attempts to create a therapeutic stress distribution across the growth plate. The current data further characterizes the kyphotic porcine deformity model and demonstrates the effect that posterior tethering has on disc pressure and differential vertebral growth. These *in vivo* data are in agreement with our anatomic modeling demonstrating a higher tether tension would be required to achieve a therapeutic load gradient in the deformed spine.

SIGNIFICANCE: The kyphotic pig model appears to be an adequate animal model on which to study vertebral growth modulation of a deformed spine. Growth modulation in the deformed spine was modeled to be dependent on tether tension and it was found to be so in vivo. These data combined with separate computational modeling (separate abstract) suggest that disc mobility is critical to successful growth modulation with a compressive tether.

REFERENCES: [1] USBJI+, 2008; [2] Larsen+, 2019; [3] Newton+, 2020; [4] Martin+, 2014; [5] Newton, 2010; [6] Halanski+, 2018

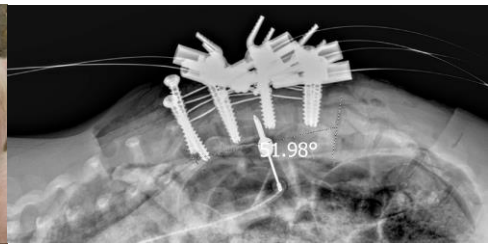

Figure 1. Lateral photograph of a Kyphotic pig. Figure 2. Lateral radiograph of instrumented kyphotic spine demonstrating pressure transducer in apical disc space. Figure. 3 Disc pressure with tether loading. Figure 4. Regional apical vertebral growth rates between Low and High tension tethers.