Biomechanical Analysis of Bone Density and Depth of Subsidence after Expandable Interbody Cage Placement

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Introduction

- **TLIF** – utilized to treat degenerative pathology, but role in restoring sagittal alignment limited by lordosis and height provided by the cage[1-10].
- Expandable technology has theoretical benefit of producing greater segmental lordosis and disc height restoration compared to static technology.
- Further, insertion of fully collapsed cage into small corridor has theoretically reduced risk of nerve root injury or end plate violation vs static cage[7].
- However, expandable TLIF cages have been shown to be associated with increased rates of both immediate-postoperative and long-term subsidence, which may ultimately negate any potential advantage in achieving greater lordosis and restoration of disc height compared to static cages[1-10].

Stryker Mojave™ expandable cage

Purpose

- Risk factors for subsidence with expandable TLIF cages are not clearly defined in the literature.
- While osteoporosis is an important and previously-identified risk factor for subsidence in general, Li et al. interestingly found that expandable TLIF cages had significantly less subsidence than static cages in patients with osteoporosis[1].
- The **purpose** of this study was to evaluate the depth of subsidence of an expandable TLIF cage at varying levels of bone density.
- We aimed to measure subsidence at both **constant input torque** and a **constant endplate force** as a surrogate for in vivo torque wrench torque-out and torque wrench feedback, respectively.
- This is the first study to evaluate expandible TLIF cage subsidence depth at varying levels of bone density stratified by both constant peak input torque and constant endplate force.

Methods

- Vertebral body wafers of differing densities were used to evaluate subsidence (mm): 5 (osteoporotic bone density), 10, 15, and 20 (higher-than-normal bone density) pounds per cubic foot (PCF).
- To simulate a maximal torque-out expansion point similar to that experienced in vivo, subsidence depth was measured and plotted when 1Nm of peak input expansion torque was achieved.
- To simulate a constant feedback force on the torque wrench felt by a surgeon during expansion in vivo, subsidence depth was measured and plotted when 150N of peak output force exerted by the expandable cage at the endplates was achieved.
- ANOVA was performed to determine if significant ($p<0.001$) differences in subsidence existed between different bone foam densities under both protocols.
- Pearson correlation coefficient was also utilized to evaluate for a relationship between input expansion torque and endplate contact force.

Results

Constant Peak Input Torque of 1Nm:

- Subsidence depth decreased with increasing bone foam density.
- Mean (± SD) subsidence depths at 1Nm of input torque were:
  - 2.34±0.548 mm for 5 PCF, 2.326±0.548 mm for 10 PCF, 1.219±0.24 mm for 15 PCF, and 1.13±0.109 mm for 20 PCF bone foam.
- Significant differences in subsidence depth were noted for the following pairs:
  - PCF 5 and PCF 15 (p=0.003); PCF 5 and PCF 20 (p=0.002); PCF 10 and PCF 15 (p=0.003); and PCF 10 and PCF 20 (p=0.002).

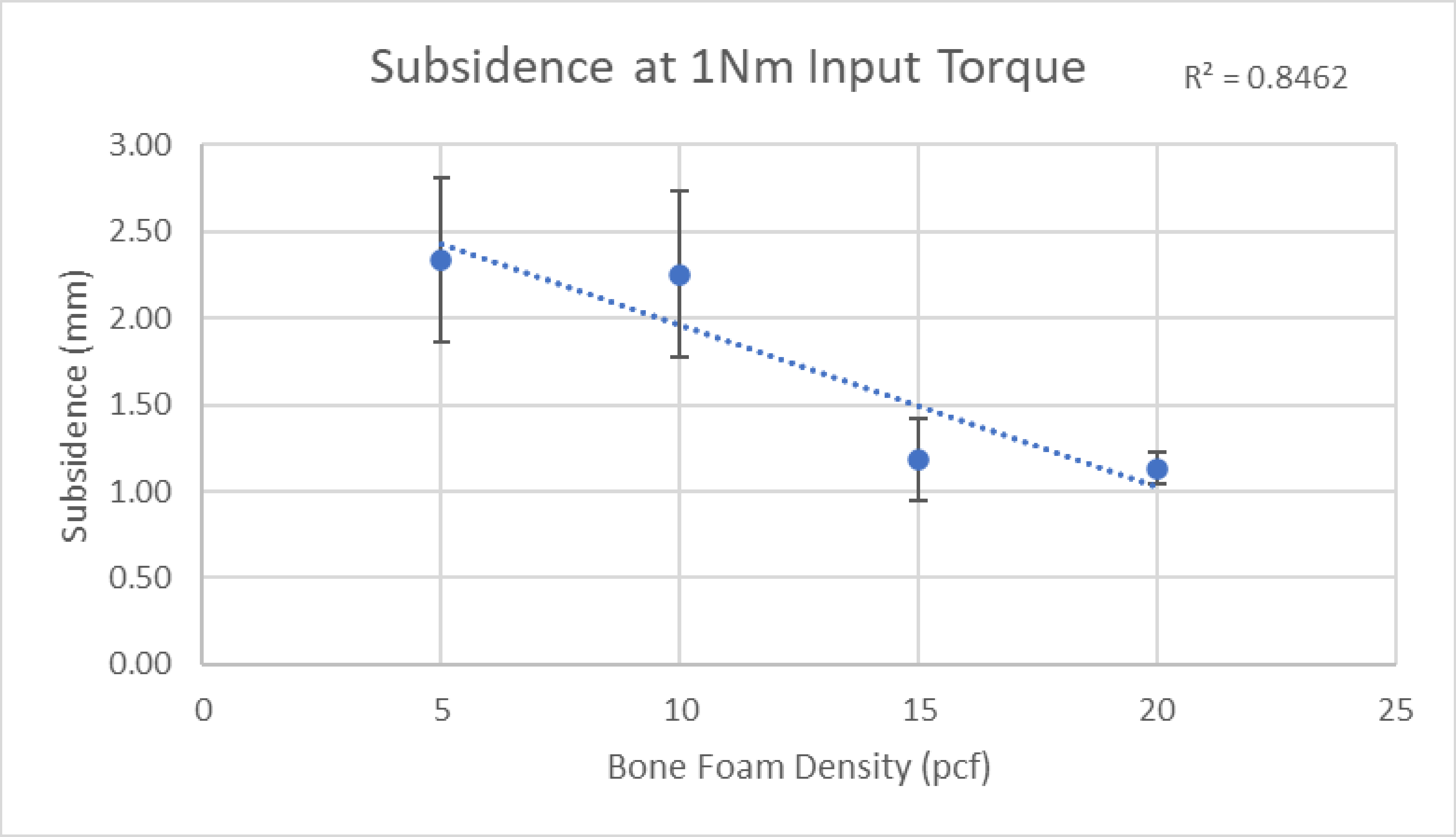

Fig 1. Plot of mean depth of subsidence (mm) by increasing bone foam density at a constant peak torque wrench input force of 1Nm. Subsidence values of cage expansion into a static measuring device were averaged over five trials per each of the four bone foam densities (5, 10, 15, and 20 pounds per cubic foot, PCF) when 1Nm of input torque was achieved.

Results

Constant Peak Output Force of 150N:

- Subsidence decreased with increasing bone foam density.
- The mean (± SD) subsidence depths at 150N output force were:
  - 2.04±0.326 mm for 5 PCF, 1.84±0.21 mm for 10 PCF, 1.106±0.217 mm for 15 PCF, and 1.108±0.24 mm for 20 PCF bone foam.
- Significant differences were noted for the following pairs:
  - PCF 5 and PCF 15 ($p<0.001$); PCF 5 and PCF 20 ($p=0.002$); PCF 10 and PCF 15 ($p=0.002$); and PCF 10 and PCF 20 ($p=0.007$).

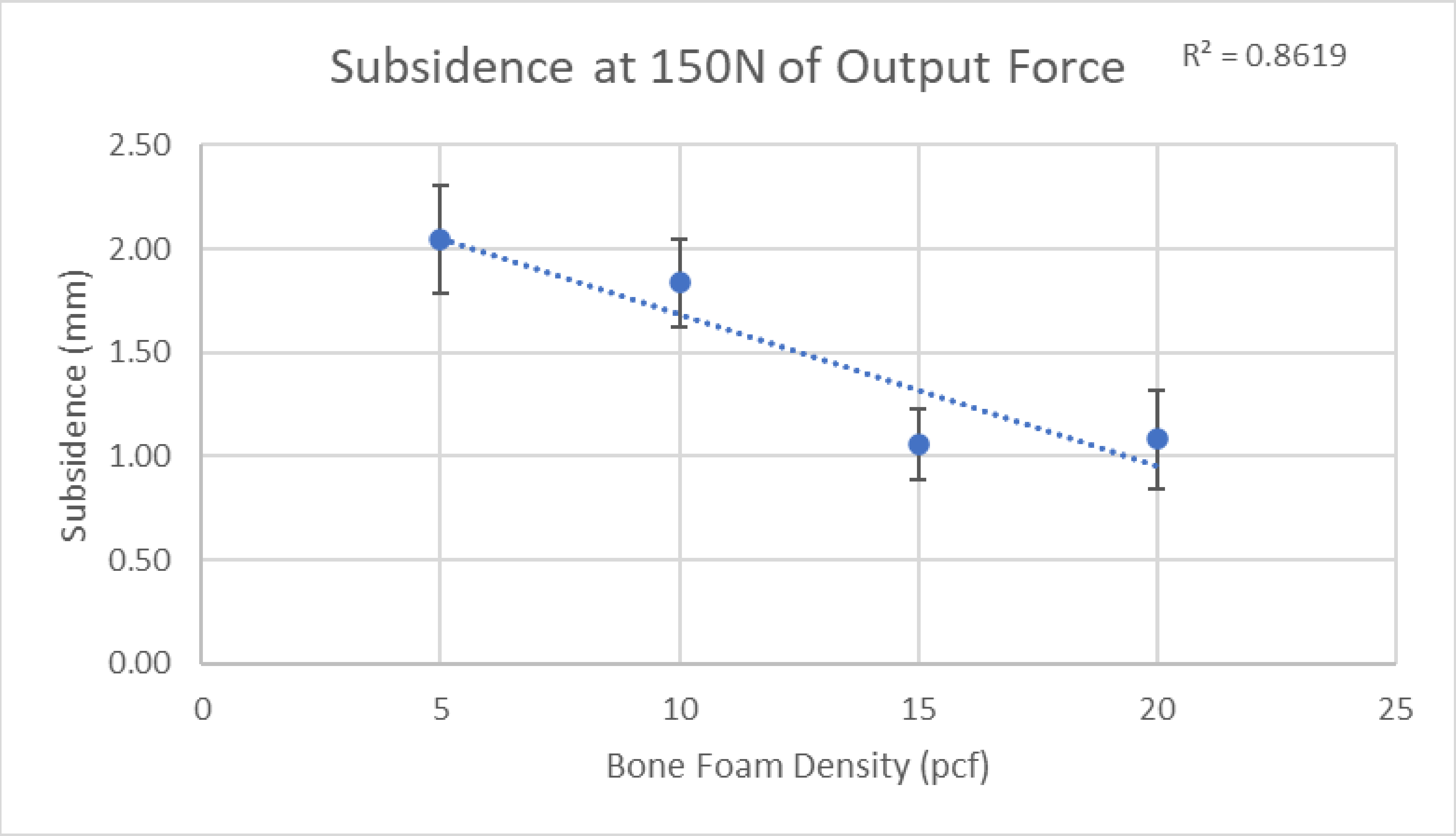

Fig 2. Plot of mean depth of subsidence (mm) by increasing bone foam density at a constant peak endplate output force of 150N. Subsidence values of cage expansion into a static measuring device were averaged over five trials per each of the four bone foam densities (5, 10, 15, and 20 pounds per cubic foot, PCF) when 150N of output force was achieved as input torque was increased from 0 to 1.5Nm.

Results

Northwell Health

Correlation between Force and Torque:

- Output force was positively correlated to the torque applied to expand the implant.
- Each 1Nm increase in input torque was associated with a 157.3 N increase in output force (R2 = 0.804) for this specific implant.
- This positive correlation was evident regardless of varying bone foam densities.
- Furthermore, the Pearson correlation coefficient between the output force and torque applied was found to be 0.897 with a p-value < 0.001, suggesting a statistically significant relationship between the two variables of output contact force and input torque.

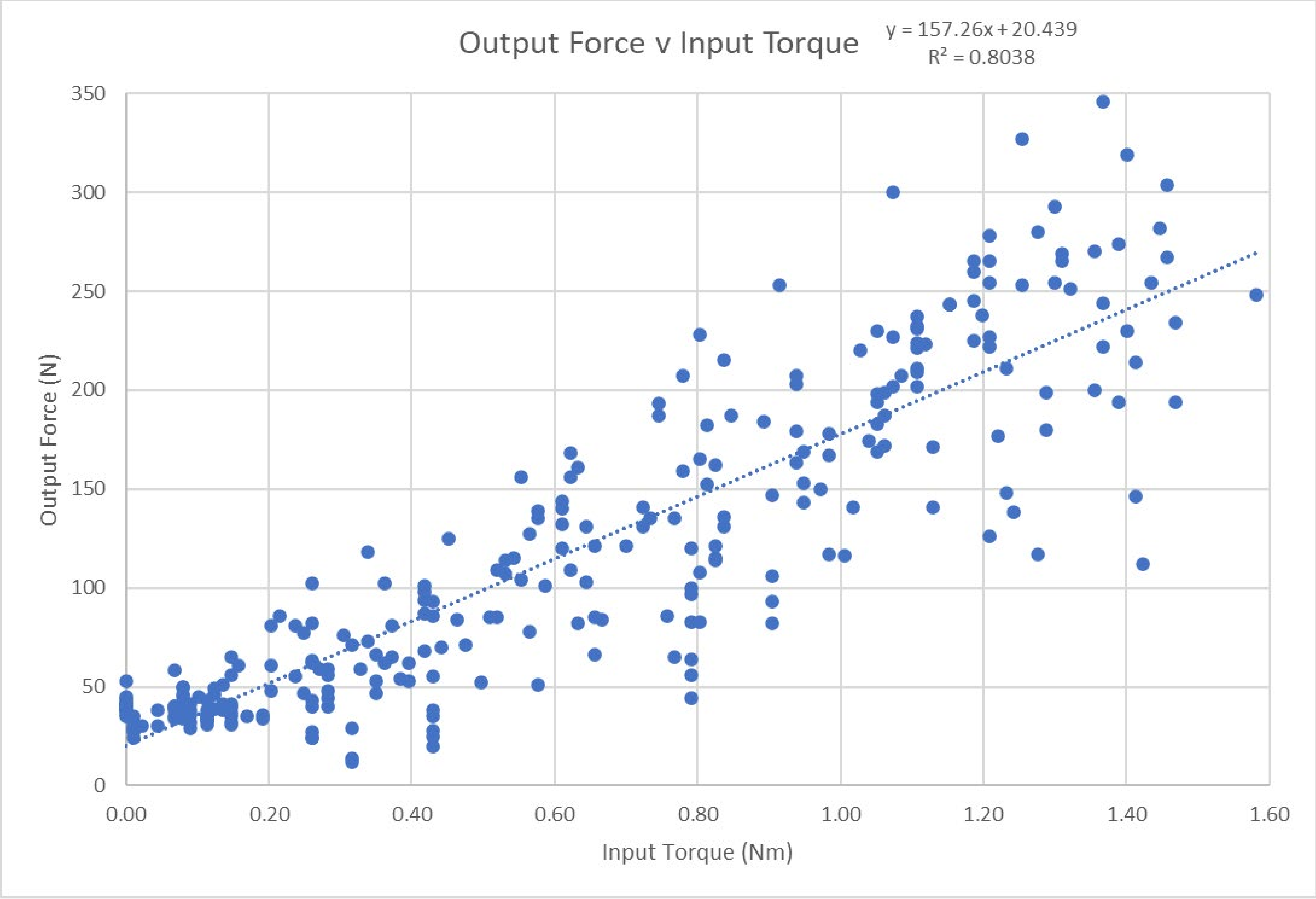

Fig 3. Plot of endplate output contact force and torque wrench input torque from 0 to 1.5Nm for all foam densities).

Discussion

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- Depth of subsidence of an expandable TLIF cage was evaluated in vertebral body bone foam with differing density ranging from osteoporotic to above normal bone quality.
- At a constant expansion torque of 1Nm, an implant will subside further into lower density bone.
    - ***Thus, to apply the same distraction force, an implant on lower density bone will lose more expansion height to subsidence***.
- At a constant output endplate force of 150N, subsidence similarly increased as bone density diminished.
    - ***Consequently, maximal disc height index will be diminished and desired lordosis and sagittal balance may not be achievable as the cage subsides into low density bone***.
- The cages continued to expand as input torque increased to achieve the 1Nm input peak value and the 150N output endplate force value, thereby suggesting that lower levels of input torque were required to achieve the same depth of expansion, or subsidence, into cancellous bone, and lower output forces were felt at the endplates at a constant depth of expansion, as bone density diminished.

Discussion

- These findings can be extrapolated to an ***in vivo*** situation when the torque out limit is achieved while expanding an interbody cage:
    - In osteoporotic bone, greater depths of subsidence would be expected at torque wrench torque-out limits compared to patients with robust bone.
    - Thus, in severely osteoporotic patients where haptic feedback during cage expansion may be reduced and the resultant over-distraction risk is significantly elevated, the process of “tapping” a static cage through the insertional corridor may be a safer option.
- **Limitations**
    - Our study is limited by the use of one type of expandable TLIF cage. Endplate contact force will vary by cage size. Therefore, if for instance a larger cage is used, a higher input torque will be achieved to achieve the same endplate force and associated subsidence. The results of this study therefore cannot be generalized to cages beyond the one utilized in this study.
    - Unlike cadaver studies utilizing larger segments of the spine, or in vivo studies, our cages were expanded against a static device, which does not accurately represent or account for the dynamic forces exerted by an expanding cage.

References

1. Li Y, Liu S, He Z, Yu S. Comparison of Long-Term Efficacy of MIS-TLIF Intraoperative Implants in Patients with Osteoporosis. Comput Math Methods Med. 2022;2022:2565391.
2. Kwok M, Zhang AS, DiSilvestro KJ, Younghein JA, Kuris EO, Daniels AH. Dual expandable interbody cage utilization for enhanced stability in vertebral column reconstruction following thoracolumbar corpectomy: A report of two cases. N Am Spine Soc J. 2021;8:100081.
3. Boktor JG, Pockett RD, Verghese N. The expandable transforaminal lumbar interbody fusion - Two years follow-up. J Craniovertebr Junction Spine. 2018;9(1):50-55.
4. Hou Y, Yuan W. Influences of disc degeneration and bone mineral density on the structural properties of lumbar end plates. Spine J. 2012;12(3):249-256.
5. Okano I, Jones C, Salzmann SN, et al. Endplate volumetric bone mineral density measured by quantitative computed tomography as a novel predictive measure of severe cage subsidence after standalone lateral lumbar fusion. Eur Spine J. 2020;29(5):1131-1140.
6. Jones C, Okano I, Salzmann SN, et al. Endplate volumetric bone mineral density is a predictor for cage subsidence following lateral lumbar interbody fusion: a risk factor analysis. Spine J. 2021;21(10):1729-1737.
7. Amirouche F, Solitro GF, Magnan BP. Stability and Spine Pedicle Screws Fixation Strength-A Comparative Study of Bone Density and Insertion Angle. Spine Deform. 2016;4(4):261-267.
8. Kwon AJ, Hunter WD, Moldavsky M, Salloum K, Bucklen B. Indirect decompression and vertebral body endplate strength after lateral interbody spacer impaction: cadaveric and foam-block models. J Neurosurg Spine. 2016;24(5):727-733.
9. Cheng BC, Swink I, Yusufbekov R, Birgelen M, Ferrara L, Coric D. Current Concepts of Contemporary Expandable Lumbar Interbody Fusion Cage Designs, Part 2: Feasibility Assessment of an Endplate Conforming Bidirectional Expandable Interbody Cage. Int J Spine Surg. 2020;14(s3):S68-S74.
10. Cheng BC, Swink I, Yusufbekov R, et al. Current Concepts of Contemporary Expandable Lumbar Interbody Fusion Cage Designs, Part 1: An Editorial on Their Biomechanical Characteristics. Int J Spine Surg. 2020;14(s3):S63-S67.