Human Rib Failure Strain in Dynamic Frontal Loading at the Antero-Lateral Location

Amanda M. Agnew, Yun-Seok Kang

I. INTRODUCTION

Experimental studies using complete post-mortem human subjects (PMHS) commonly rely on strain gauges attached to the external (cutaneous) surface of ribs to identify fracture timing as well as measure strain magnitudes during thoracic loading [1]. Since it is unfeasible to also adhere gauges to the internal (pleural) surface of the rib when thoracic integrity must be maintained, it is unknown how the pleural rib cortex behaves during such events. Furthermore, identifying rib failure strain magnitude is a crucial component when constructing computational models of the human thorax in motor vehicle crash scenarios [2]. The objectives of this study were to explore age-associated trends in failure strain and identify a relationship between tensile and compressive failure strain.

II. METHODS

One-hundred eighty whole mid-thoracic human ribs (levels 4-7) from 113 PMHS were dynamically impacted (1-2 m/s) in a custom pendulum fixture mimicking a frontal impact scenario (Fig. 1; see [3] for further experimental details). Strain gauges (SG) were adhered to the pleural and cutaneous surface of each rib at 30% and 60% of the total curve length from head to costochondral joint. Only data at the time of failure from the antero-lateral (60%) cutaneous and pleural gages (CSG2 and PSG2, respectively) are included here. In this set-up, a 2D bending scenario was created in which the cutaneous rib cortex experienced tension (CSG2) and the pleural cortex experienced compression (PSG2) (Fig. 1).

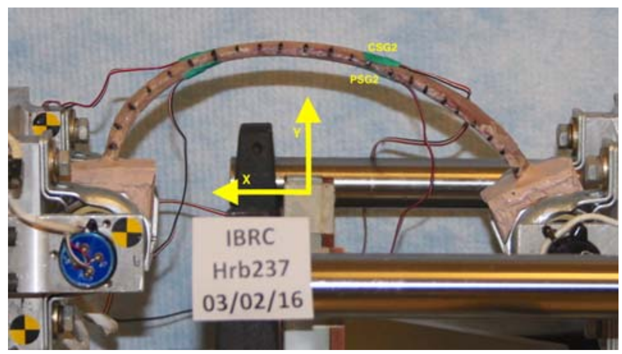

Fig. 1.Test-set up and strain gauge locations.

III. INITIAL FINDINGS

No sex differences were found for either cutaneous or pleural failure strain (p=0.5 and p=0.9, respectively), so further analysis included both sexes. Descriptive statistics for cutaneous (tensile) strain for each decade of age are provided in Table I. Ages ranged from 6-108 years with a median of 51 years. Tensile failure strain significantly decreased with increasing age (Fig. 2; ANOVA, p<0.0001). A statistically significant relationship was identified between cutaneous (tensile) and pleural (compression) failure strain (Fig. 3; p<0.001). A linear regression provides a predictive equation showing moderate success of CSG2 in explaining the variance in PSG2. Tensile failure strain is greater than compressive strain for the majority of tests (i.e., most points fall below the thin line).

TABLE I
CSG2 DESCRIPTIVE STATISTICS BY AGE*

Age Decade	***0 (0-9)***	***10 (10-19)***	***20 (20-29)***	***30 (30-39)***	***40 (40-49)***	***50 (50-59)***	***60 (60-69)***	***70 (70-79)***	***80 (80-89)***	***90 (90-99)***	***100 (100-109)***
n	4	8	23	13	23	18	20	25	21	10	1
Mean	14040	17219	16290	13026	12907	13133	10841	11958	8867	9867	3131
SD	2838	7355	7126	5221	5615	4474	4452	3430	3166	2572	-

*All strain data are presented in units of microstrain

*A. Agnew is an Assistant Professor at The Ohio State University in Columbus, OH USA (+1-440-668-4945, amanda.agnew@osumc.edu). Both authors are affiliated with the Injury Biomechanics Research Center (IBRC) at The Ohio State University.

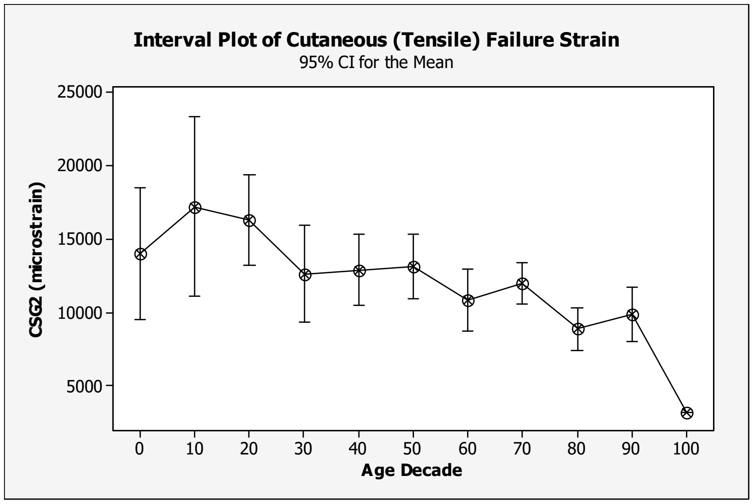

Fig. 2. Interval plot showing 95% confidence intervals for the mean tensile (cutaneous) failure strain by age decade. Mean tensile and compressive failure strain decreased with increasing age (only tensile is shown).

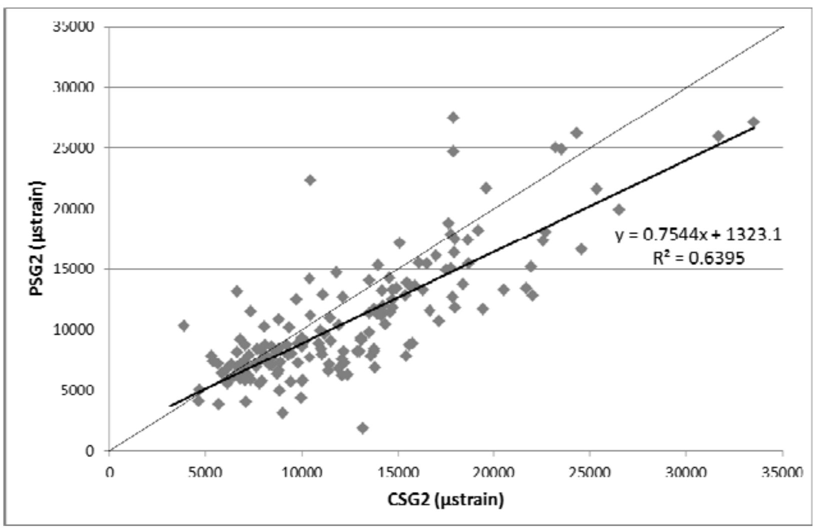

Fig. 3. Scatterplot showing the relationship between absolute values of cutaneous/tensile failure strain and pleural/compressive failure strain (linear regression, $p<0.001$, $R^2=0.64$).

IV. DISCUSSION

The decrease in tensile strain magnitude with increasing age found here is consistent with trends reported in [4] from coupon testing, but they also identified sex differences that were not found in our study. If compressive and tensile strain were assumed equal, based on the relationship shown in Fig. 3 we would often be over-predicting compressive (pleural) strain in the rib based on known tensile (cutaneous) values. Some report no difference in strain behavior in tension versus compression [5], however [6] presents slightly higher tensile strains than compression. Both studies utilize similar loading conditions to those in the current study, but their sample sizes are significantly smaller. The current study has the benefit of a much larger sample size than comparative studies [4-6], and therefore greater confidence in results.

V. REFERENCES

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Acknowledgements: The experimental data analyzed in this work were obtained from previous studies funded by NHTSA, Autoliv, and/or Honda. Thanks also to John H. Bolte IV and Michelle M. Murach as well as the donors.