Microfractures in Elderly Ribs: Contributions to Bone Quality

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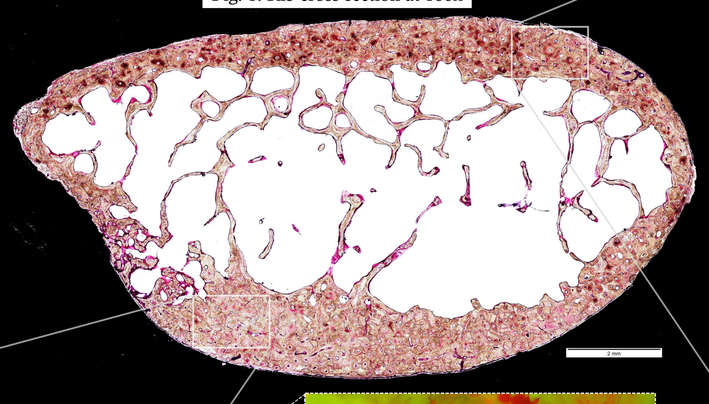
INTRODUCTION

- Age-related fragility fractures are a growing health concern, especially as the proportion of older adults in the population increases. Falls and motor vehicle crashes are the top injurious mechanisms of death in the elderly (Dellinger & Stevens 2006); both of which are high risk for thoracic injuries. Rib fractures are the most common thorax injury (Yee et al 2006) and can affect morbidity and mortality in elderly individuals. The risk of their occurrence increases significantly with age (Bergeron et al 2003).
- Senile osteoporosis can rapidly affect ribs (Epker & Frost 1965), making them a logical yet overlooked skeletal element for evaluation of bone loss. Clinical diagnoses of bone fragility associated with osteoporosis often rely on relatively inaccurate measures of bone quantity, but fail to measure the contribution of poor bone quality.
- Fatigue induced microfractures in the rib occur as a result of cyclic loading from respiration (Frost 1960). While this damage may be insignificant in young bone, an inefficient remodeling process in aging individuals results in disrepair of microfractures, allowing their accumulation to reach harmful levels (Norman & Wang 1997). It is established that microfracture accumulation affects the mechanical integrity of bone and can lead to catastrophic failure. However, it is unknown to what extent they exist in elderly human ribs and their role in determining bone fragility.
- The objective of this research is to utilize histomorphometry to aid in understanding microscopic adaptations of the human rib and their impact on health by showing that microfractures have the potential to contribute to differential bone quality in the elderly population. This is accomplished by exploring inter- and intra-individual variation in microfractures accumulated *in vivo*.

MATERIALS & METHODS

- Left and right 6th ribs were removed from 10 elderly (mean age= 84.7 years) fresh post-mortem human subjects (PMHS). Table 1 provides demographic information. The sample is random and assumed to be representative of a "typical" elderly population.
- Two cm sections were removed from each undecalcified mid-shaft rib (50% of total curve length). Sections were stained *en bloc* in Basic Fuchsin Hydrochloride and embedded in methylmethacrylate (MMA). Transverse sections were cut at the region of interest and thin-sections were prepared according to standard histological procedures.
- Figures 1-4 illustrate the collection method for microfracture data. Inter- and intra-individual variation of histomorphometric variables (Table 2) were analyzed in a two-way mixed model using analysis of variance (ANOVA). Pleural and cutaneous cortices were compared within ribs using paired t-tests.

Fig. 1. Rib cross-section at 100x



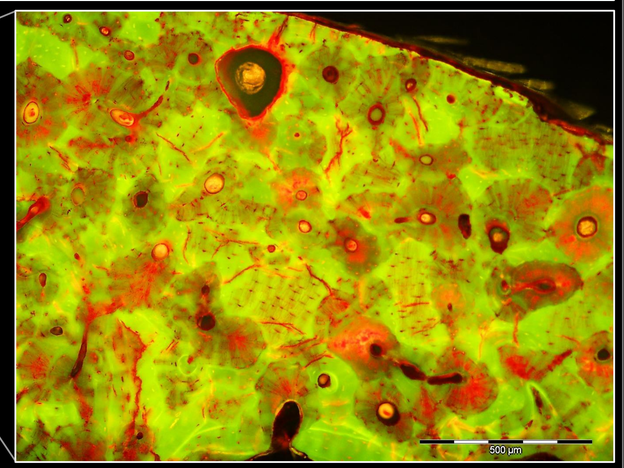


Fig. 2. Microfractures observed at 100x

Table 1. PMHS demographics

Subject	Sex	Age
A	M	88
B	F	92
C	F	77
D	M	76
E	F	91
F	M	83
G	M	90
H	M	82
I	F	88
J	F	80

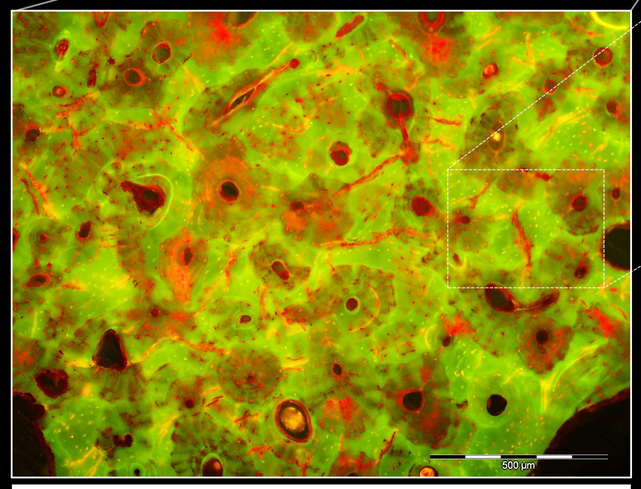


Fig. 3. Microfractures observed at 100x

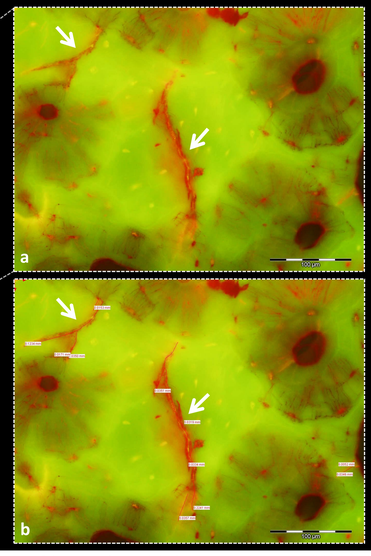


Fig. 4. Observations (a) & measurements (b) at 400x

Table 2. Histomorphometric variables

Primary Parameters		Calculated Parameters		
Name	Abbr.	Name	Abbr.	Formula
Microcrack Number	Cr.N	Absolute Cortical Area	$Ct.Ar_A$	Ct.Ar-Po.Ar
Microcrack Length	Cr.Le	Microcrack Density	Cr.Dn	Cr.N/AB.Ar
		Microcrack Surface Density	Cr.S.Dn	Cr.N*Cr.Le/$Ct.Ar_A$

RESULTS & DISCUSSION

- ANOVA results (Table 3) reveal significant differences in microfracture accumulation between individuals ("subject"), but not within ("side" and "interaction"). Figures 5A and 5B illustrate Cr.Le differences between and within subjects, respectively. Figures 6A and 6B illustrate Cr.Dn differences between and within subjects, respectively. Figures 7A and 7B illustrate Cr.S.Dn differences between and within subjects, respectively.
- Few investigations prior to the current study have quantified microfractures in human ribs. Burr & Stafford (1990) and Frost (1960) report Crack Number (Cr.N) values in ribs of 3.6 ± 2.87 and 7.46 ± 5.67, respectively, while the mean Cr.N identified in this study is 650.87 ± 495.08. The significant difference is attributed to age differences in the study samples. These findings further validate the necessity to evaluate elderly rib quality.
- Microdamage accumulates when bone remodeling is suppressed (Hirano et al. 2000; Mashiba et al. 2001) and can result in a significant reduction (~20%) in bone toughness (Burr 2003), therefore increasing bone fragility. Additionally, suppression of remodeling is often intentionally induced by bisphosphonate treatment (Mashiba et al. 2000), a common clinical treatment for osteoporosis.

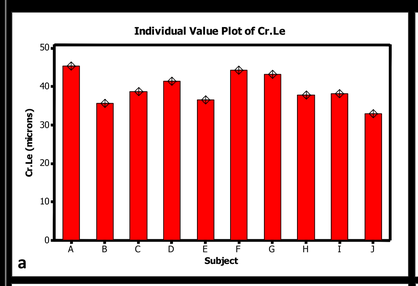
Table 3. ANOVA results for microcrack variables of cutaneous and pleural cortices independently. Significant p-values ($p<0.05$) are highlighted in red.

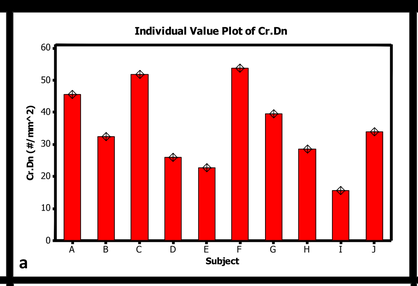
Variable	Source	DF	Cutaneous Cortex		Pleural Cortex	
			F-stat	P-value	F-stat	P-value
Cr.Le	Side	1	0.31	0.67	0.02	0.90
	Subject	9	8.88	**0.001**	4.80	**0.01**
	Interaction	9	0.66	0.72	1.45	0.29
Cr.Dn	Side	1	0.16	0.75	1.45	0.44
	Subject	9	4.44	**0.01**	3.54	**0.03**
	Interaction	9	2.69	0.07	1.65	0.23
Cr.S.Dn	Side	1	0.05	0.84	1.11	0.48
	Subject	9	4.69	**0.01**	4.66	**0.01**
	Interaction	9	4.08	0.02	2.41	0.10

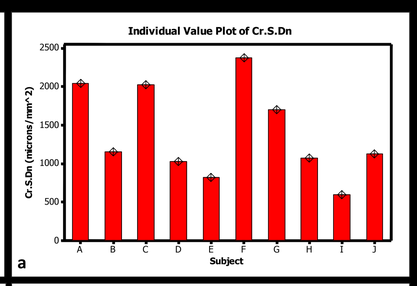
- Only insignificant differences were found in crack location, with slightly more microfractures accumulating in the cutaneous cortex (Table 4). Additionally, the cutaneous cortex was found to have significantly less absolute cortical area than the pleural. The distribution of these features suggests a priority may be to preferentially maintain a higher bone quality in the pleural cortex.

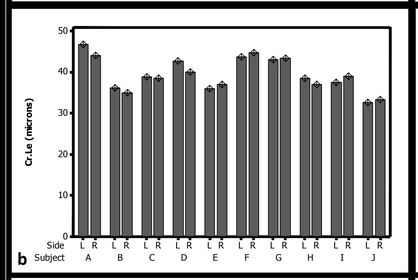
Table 4. Paired t-test results comparing microcrack accumulation between cortices

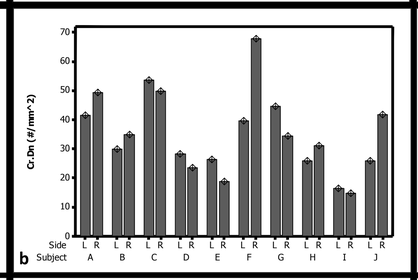
	Cutaneous mean	Pleural mean	P-value
$Ct.Ar_A$	7.93	9.54	<0.0001
Cr.Dn	37.96	31.93	0.186
Cr.S.Dn	1536	1265	0.157











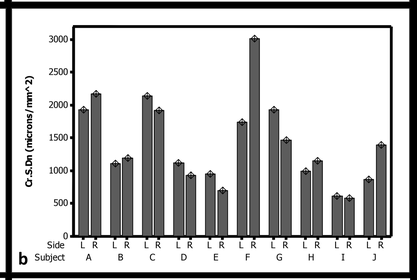


Figure 5. Crack Length a) subject variation and b) side variation by subject. L = left, R = right.

Figure 6. Crack Density a) subject variation and b) side variation by subject. L = left, R = right.

Figure 7. Crack Surface Density a) subject variation and b) side variation by subject. L = left, R = right.

CONCLUSIONS

- Inter-individual variation in microfracture accumulation in the elderly has the potential to contribute to differential fragility. Future work will incorporate both the evaluation of *in vivo* microfracture accumulation as well mechanical testing to quantify the role of microdamage in determining bone strength in elderly ribs.
- Knowledge of the mechanisms involved in deterioration of bone quality is important to identify the bone's natural mechanically adaptive environment and to establish future methods to combat fragility fractures in the high-risk elderly population.

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