MDCT-based finite element analysis of vertebral fracture risk: how much dose is needed?

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Purpose

The purpose of this work was to compare vertebral failure loads predicted from finite element (FE) analysis of patients with and without osteoporotic vertebral fractures (OVFs) at virtually reduced dose levels to standard-dose exposure from multi-detector computed tomography (MDCT) imaging and to evaluate whether ultra-low dose derived FE analysis can still differentiate between the patient and a control group.

Methods

Sixteen subjects were evaluated at standard-dose MDCT (Table 1), eight with and eight without OVFs. Images were reconstructed at virtually reduced dose levels (Figure 1). Failure load was determined at L1-3 from FE analysis and compared between standard, half, quarter, and tenth doses (Figure 1) and used to differentiate between a fracture and a control group.

Parameter	Value
Tube Voltage (kVP)	120
Field of View (cm)	200
Beam collimation (mm)	0.625
Slice thickness (mm)	0.3
Helical Pitch	0.758 - 0.914
CTDI$_{vol}$ (mGy)	7.66 (2.3 – 13.7)
Tube current (mA)	200 - 400
Exposure (mAs)	112 (33 – 201)

Table 1: Scan parameters of the MDCT protocol
CTDI$_{vol}$:volume CT dose index.

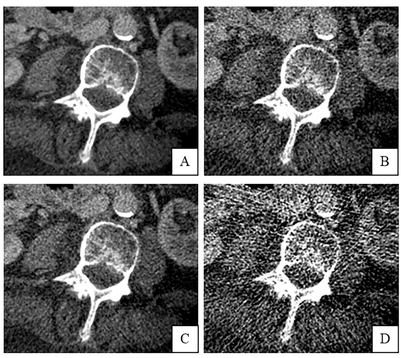

Figure 1: MDCT with dose reduction
Illustrations of changes in image quality with dose reduction from standard (A) to half (B), quarter (C), and tenth dose (D).

Results

Changes in image quality with quarterly dose reductions from standard dose are illustrated in Table 2. Failure load derived at standard dose (3254 ± 909 & 3794 ± 984 N) did not significantly differ from half (3390 ± 890 & 3860 ± 1063 N) and quarter dose (3375 ± 915 & 3925 ± 990 N) but was significantly higher in the tenth dose (4513 ± 1762 6 4766 ± 1628 N) for the fracture and control group, respectively (Table 3). Failure load differed significantly between the two groups at standard, half, and quarter doses, but not at tenth dose (Figures 2 & 3). Receiver operating characteristic (ROC) curve analysis also demonstrated that standard, half, and quarter doses can significantly differentiate the fracture from the control group.

	Fracture	Control	p value
Standard Dose	3254 ± 909	3794 ± 984	0.0373*
Half Dose	3390 ± 890	3860 ± 1063	0.0305*
Quarter Dose	3375 ± 915	3925 ± 990	0.0233*
Tenth Dose	4513 ± 1762	4766 ± 1628	0.458
p value (standard vs half)	0.718	0.670	-
p value (standard vs quarter)	0.606	0.592	-
p value (standard vs tenth)	0.00198*	0.0354*	-

Table 3: FE-predicted failure load values for the fracture and control group
Data provided as means ± standard deviation (SD).

Conclusion

MDCT enables a dose reduction of at least 75% compared to standard dose for an adequate prediction of vertebral failure load based on non-invasive FE analysis. Although direct clinical application has yet to be evaluated, our approach may reflect a promising step towards reductions in radiation exposure for patients with spinal fractures when undergoing MDCT in the context of clinical diagnostics.

	Standard Dose		Half Dose		Quarter Dose		Tenth Dose	
Parameter	Fracture	Control	Fracture	Control	Fracture	Control	Fracture	Control
Image Noise (HU)	30.6 ± 4.9	35.6 ± 7.1	40.5 ± 4.9	55.6 ± 26.7	57.8 ± 7.9	64.6 ± 7.2	130.1 ± 33.9	158.4 ± 40.2
SNR	4.3 ± 1.6	4.9 ± 1.3	3.2 ± 0.9	3.4 ± 1.1	2.4 ± 0.7	2.8 ± 0.6	1.3 ± 0.6	1.3 ± 0.3
CNR	7.6 ± 2.2	7.8 ± 2.0	5.6 ± 1.6	5.6 ± 1.9	4.1 ± 1.0	4.6 ± 1.6	2.0 ± 0.8	2.0 ± 0.8

Table 2: Quantitative image analysis comparing the fracture to the control group for all doses
Data provided as means ± standard deviation (SD). HU: Hounsfield Units, SNR: Signal-to-noise ratio, CNR: Contrast-to-noise ratio.

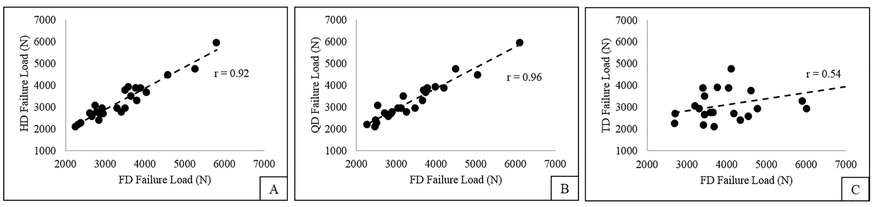

Figure 2: Correlations of failure loads in the fracture group
This figure plots the correlations for FE-predicted failure loads for individual doses, which were half dose (HD; A), quarter dose (QD; B), and tenth dose (TD; C) as a function of full dose (FD) for the fracture group.

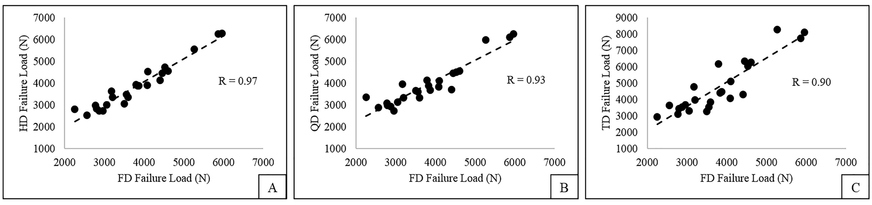

Figure 3: Correlations of failure loads in the control group
This figure shows the correlations for FE-predicted failure loads for individual doses, which were half dose (HD; A), quarter dose (QD; B), and tenth dose (TD; C) as a function of full dose (FD) for the control group.