Vertebral Fracture Assessment (VFA) Misclassifies Crush Type Fractures

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INTRODUCTION: Nearly half of prevalent vertebral fractures go undiagnosed [**5-7**]. Therefore, accurate and timely detection of vertebral fractures is of critical importance. Methods for vertebral fracture assessment (VFA) are widely available on most dual energy x-ray absorptiometry (DXA) scanners, wherein vertebral height data from lateral images are used to determine the presence of wedge, biconcave, or crush deformities. An unusually low proportion of crush deformities (0–3%) have been reported in relevant VFA literature [**4-9**], substantially lower than expectations from earlier quantitative morphometry studies [**10-11**]. The specific objective of this study was to establish the extent to which fracture status varies between values calculated within VFA software and those recalculated using the crush fracture definition originally proposed by Genant [**12**].

METHODS: Under IRB approval and informed consent, 191 participants with or without a history of clinically established vertebral fracture (135 female, 56 male; Age 50-88), were imaged using a Hologic Horizon A DXA system, and vertebral fracture status was determined using the default output from the VFA software. Vertebral fracture status was then recalculated from vertebral height data extracted from VFA reports (anterior: H_a, middle: H_m, posterior: H_p) using height ratios described by Genant (wedge: H_a/H_p, biconcave: H_m/H_p, and crush: H_{pi}/H_{pi+1} or H_{pi}/H_{pi-1}, where H_{pi+1} and H_{pi-1} are the posterior heights of adjacent superior and inferior vertebral levels) [**12**]. If wedge, biconcave, or either crush ratios were 20-25%, 25-40%, or >40%, the vertebra was scored as having a mild, moderate, or severe fracture, respectively. Generalized linear mixed models and McNemar's test were used to assess differences in vertebral fracture type and patient fracture status, respectively, between the default VFA and Genant methods. Models included method (Default VFA or Genant) as a fixed effect with subject and vertebral level as random effects. Analyses were performed in R with significance at $p < 0.05$ (RStudio, version 2024.4.2).

RESULTS: Among 191 patients, 2043 visualized vertebrae were analyzed. Using the default output from VFA software, 84 fractures were identified among 45 patients (62% wedge, 37% biconcave, and 1% crush; **Fig 1A**). One vertebra was incorrectly identified by the VFA software as type crush (an unusually shaped L4 with the posterior height shorter than anterior) (**Fig 2B**). When Genant's criterion for crush fracture was utilized, a significantly higher number of patients were identified with fractures ($p < 0.003$; 101 fractures among 56 patients), the resulting distribution by type having a significantly higher proportion of crush fractures ($p < 0.0001$; 60% wedge, 20% biconcave, and 20% crush; **Fig 1B**). There were 11 vertebrae for which VFA identified a vertebra as having a vertebral deformity (wedge, biconcave) that were identified as type crush when using Genant's criteria. For both approaches, most fractures were mild or moderate (82-84%), and the majority (>80%) were observed at mid-thoracic (T6-T8) levels and thoraco-lumbar (T11-L1) levels (**Fig 3**).

DISCUSSION: Using the default VFA output, crush fractures are either misclassified or not identified at all, regardless of severity. When the conventional definition of crush deformity was applied, patient fracture status changed from nonfractured to fractures in 12 patients (e.g., **Fig 2A**). After recalculation using Genant's criteria, the resulting distribution by fracture type (60.4% wedge, 19.8% crush and biconcave **Fig 1B**) was in line with studies predating VFA [43-62% wedge, 30-38% crush, 8-19% biconcave; **10-11**].

We observed that the VFA software defines crush deformities by the ratio of posterior to anterior height (H_p/H_a; **Fig 2B**), rather than the conventional definition (H_{pi}/H_{pi+1} or H_{pi}/H_{pi-1}) [**9**]. To the authors' knowledge, the only evidence of this ratio being used previously were a) one early study where no such "posterior wedge" fractures were either identified [**13**] and another that removed H_p/H_a [**14**] on the advice of [**13**], and b) a 1947 study examining Hp/Ha as a morphometric wedging index to assess back pain in war veterans [**15**]. It is possible the confusion owes early nomenclature which describes the crush ratio as H_p/H_{pa} (where the subscript pa refers to posterior-adjacent, and not anterior) [**12**]. Notably, in later work by Genant, this nomenclature (H_{pa}) was revised to H_{pi}/H_{pi+1} and H_{pi}/H_{pi-1} (where subscripts i+1 and i-1 refer to levels superior and inferior to the index level) [**16**]. Adding to this confusion, a commonly referenced figure from [**12**] depicts a crush deformity with reduced posterior height, but normal anterior height. It is reasonable to expect that such ambiguity may have led to the errant application of H_p/H_a in VFA software as the diagnostic criterion for crush deformity.

It must be noted the current findings are limited to observations from a dataset from a single Hologic densitometer, as we do not have access to scanners from other manufacturers. Future work should confirm if this issue is present in other scanners.

An example calculation tool is available upon request to derive bone status as proposed by Genant using height data extracted from VFA reports.

SIGNIFICANCE/CLINICAL RELEVANCE: The current implementation of VFA defines crush fractures by an unconventional height ratio criterion, resulting in many fractures being missed entirely. Considering the current role of VFA in clinical practice and large research studies, the VFA classification method for crush fracture should be reviewed, and existing literature using VFA should be examined critically in light of these findings.

REFERENCES: [1] Delmas 2005, JBMR 20:557-64, [2] Carberry 2013, Radiology 268:120-26, [3] Williams 2009, Eur J Radiol 69:179-83, [4] Jager 2010, CARJ 61: 194-200, [5] Howat 2007, Clin Endocrinol 67:923-30, [6] Yakemchuk 2012, Clin Radiol 67:1061-68, [7] Johansson 2018, Osteoporos Int 29:89-99, [8] Hospers 2009, Radiology 251:822-28, [9] Deleskog 2016 Osteoporos Int 27:2317-26, [10] Eastell 1991, JBMR 6:207-15, [11] Cooper 1992, JBMR 7:221-27, [12] Genant 1993, JBMR 8:1137-48, [13] McCloskey 1993, Osteoporos Int 3:138-147, [14] Black 1999, JBMR 14:90-101, [15] Fletcher 1947, Am J Roentgenol Radius Ther 57:232-38, [16] Genant 1996, JBMR 11:984-96.

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IMAGES AND TABLES:

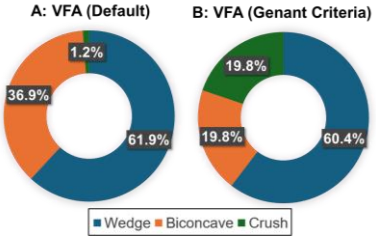

Fig 1. Distribution by fracture type for A) VFA, and B) VFA using Genant's crush criterion.

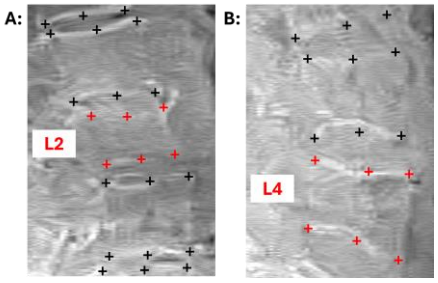

Fig 2. Representative cases where A) VFA classified L2 as normal, whereas Genant criteria classified as crush (severe), and B) VFA classified L4 as crush (mild), whereas Genant criteria classified as normal.

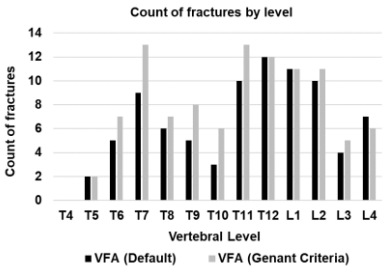

Fig 3. Count of deformities by vertebral level for VFA (black bars) and VFA using Genant's crush criterion (grey bars).