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The size of lumbar vertebral endplate areas—Prediction by anthropometric characteristics and significance for fatigue failure due to whole-body vibration

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Abstract

The sizes of vertebral endplates co-determine the ultimate strength of spinal units. The health risk associated with fatigue failure after repetitive dynamic loads caused, e.g., by whole-body vibration (WBV), could depend on the size of endplate area, too. An easy low-cost prediction of the latter would be of practical interest. CT-scans of lumbar spinal units of 53 male donors (33.2 ± 5.8 yr) were used to determine accurately the size of the cross-sectional areas of endplates L3–L5. Anthropometric measurements were obtained during coroner's inquest. The correlations between these measurements and the endplate areas were examined. The results do not permit a prediction of the endplate area by anthropometric parameters. This contradicts earlier findings that describe close correlations between the size of intervertebral discs and the size of the endplates and external diameters of large joints. Thirty of 53 spinal units were selected and loaded with static and dynamic compression (5 Hz, 100,000 cycles). The results of these experiments are compared with a method to predict fatigue failure by the predictors size of endplate area, bone mineral density, static and peak-to-peak dynamic loads.

Relevance to industry

External anthropometric characteristics cannot be used to predict the size of lumbar vertebral endplates which are relevant to the individual tolerance towards WBV. The results suggest a critical interpretation of current guidelines for the evaluation of WBV and other workloads linked with repetitive strain of the lumbar spine. Large normal ranges of spinal compression strength emphasize the importance of individual characteristics for health risk assessment and occupational health care.

Keywords: Endplate; Lumbar spine; Anthropometry; Correlation; Bone mineral density; Compression; In vitro

1. Introduction

Current guidelines for the evaluation of whole-body vibration (WBV) with respect to health consider mainly the risk for the lumbar spine caused by compression (ISO 2631-1, 1997; ISO 2631-5, 2004). Both standards suggest ranges between the lower and upper margins of the health guidance caution zone (ISO 2631-1, 1997) or of the factor *R* for the assessment of adverse health effects (ISO 2631-5, 2004) with relations between them of about 1:2 or 1:1.5, respectively. These ranges may reflect the variability of the exposure–effect relationships, but scientific arguments for their extent are not available. ISO 2631-5 (2004) provides only one value, 0.25 MPa, for the static compression of the lumbar spine. In this standard, the computations of the spinal responses are performed by different *constant* model parameters for horizontal (*x*- or *y*-axes) and vertical (*z*-axis) directions, i.e., without any consideration of individual conditions, although the significance of anthropometric data like body mass and size of endplates is

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mentioned in Annex A. Constant factors are also given for each axis to calculate an equivalent static stress by the equivalent acceleration dose of the predicted acceleration response in the spine, thus suggesting constant individual conditions at these stages of the evaluation procedure.

The examination of load–tolerance relationships is an important trend of actual research (Marras, 2004). Various individual factors like work-style, physiological status, genetic factors and acquired vulnerabilities are relevant for the prediction of the individual tolerance (Cole and Rivilis, 2004), but individual mechanical approaches seem to be of major importance (McGill, 2004). Data of epidemiologic research indicate a considerable between-subject variability of long-term effects caused by similar exposure conditions (Bovenzi and Hulshof, 1999; Seidel, 1993; Seidel and Heide, 1986). Some constitutional factors were supposed to cause an increased susceptibility, but there is no conclusive evidence that would permit reliable conclusions or quantification (cf. Seidel and Heide, 1986). Generally, between-subject differences have been largely neglected in epidemiologic research on WBV, although selection phenomena suggest their major importance (Seidel, 1993). The size of the endplate area was supposed to be of crucial significance for the individual health risk (Seidel et al., 1998, 2001), since the spinal stress, i.e., compressive force divided by the endplate area, is inversely proportional to it (Genaidy et al., 1993). The endplate area is known to co-determine the ultimate strength of vertebrae (Brinckmann et al., 1988, 1989; Edmondston et al., 1994). Even though several factors such as physical activity, living condition, and age may influence the properties of the spine, it has been proposed that the size of spinal structures correlates with other dimensions of the skeleton. Colombini et al. (1989) reported a close correlation between externally accessible anthropometric characteristics and the disc area, backed up later by Turk and Celan (2004). The former results were applied to predictions of WBV-related strain (Seidel et al. 1998, 2001). Drerup et al. (1999) reported a correlation between similar externally accessible anthropometric characteristics and the inferior endplate area of L3. However, it is questionable whether such relationships can be established for a homogeneous group of young men (20–40 yr), who are often within the focus for questions concerning low back pain due to WBV-load in the workplace.

So far, various equations to predict vertebral strength for application in ergonomics rely on age and/or gender, body mass, spinal level (Genaidy et al., 1993; ISO 2631-5, 2004; Jäger, 2001; Seidel et al., 1998). To the authors' knowledge, bone mineral content and bone mineral density (BMD) have not been considered so far in this context, although there is experimental proof for their significance as far as the ultimate compressive strength of vertebrae is concerned (Brinckmann et al., 1989; Cheng et al., 1997, 1998; Hansson et al., 1980, 1987; Imai et al., 2006; Lochmüller, 1998; McCubbrey et al., 1995; Renau et al., 2004; Singer et al., 1995).

Computer models can be used for the investigation of the influence of WBV in the workplace on spinal behaviour (Seidel, 2005). These models should ideally be based on parameters derived from in vivo and/or in vitro studies. Especially for in vivo studies it would be desirable to non-invasively obtain further information concerning vertebral body geometry. Since the improved prediction of individual vertebral strength is very significant for an individual health risk assessment and occupational health care, the aim of this study was to investigate the potential of selected anthropometric measurements for the prediction of spinal endplate size. In order to illustrate the significance of the latter, the outcome of fatigue tests with spinal units will be compared with theoretical predictions considering different factors.

2. Methods

Anthropometricl measurements (cf. Wilke et al., 2001 for definitions and methods) from 53 donors (33.2 ± 5.8 yr) were obtained during coroner's inquest. These were body mass, body height, height of shoulder, height of elbow as well as the diameters of ankle, knee, elbow and wrist (Table 1). According to Colombini et al. (1989) two parameters were calculated in order to predict the sizes of lumbar discs. Those were the average square thickness ($\mathrm{AST_{Col}}$) and the bony structure weight ($\mathrm{SW_{Col}}$):

$$\mathrm{AST_{Col}} = \left(\frac{\mathrm{WB}+\mathrm{EB}+\mathrm{KB}+\mathrm{AB}}{4}\right)^2, \tag{1}$$

$$\mathrm{SW_{Col}} = \mathrm{AST_{Col}} \cdot \mathrm{BH} \cdot 1.1, \tag{2}$$

with wrist breadth (WB), elbow breadth (EB), knee breadth (KB), ankle breadth (AB) and body height (BH).

Turk and Celan (2004) recommended a modified calculation of the average square thickness ($\mathrm{AST_{Turk}}$):

$$\mathrm{AST_{Turk}} = \left(\frac{\mathrm{WB}+\mathrm{EB}+\mathrm{KB}}{3}\right)^2. \tag{3}$$

Table 1
Anthropometric characteristics

	N	Minimum	Maximum	Mean	SD
Age (yr)	53	20	42	33.26	5.87
Body mass (kg)	53	52.3	135.0	82.66	16.24
Body height (cm)	53	165.0	200.0	179.92	7.36
Acromial height (cm)	53	141	174	154.77	7.10
Elbow height (cm)	53	110	141	122.57	6.86
Wrist breadth (cm)	53	4.80	6.70	5.93	0.37
Elbow breadth (cm)	53	6.20	10.60	8.33	0.98
Knee breadth (cm)	53	8.40	14.50	10.52	1.29
Ankle breadth (cm)	53	5.60	9.50	6.92	0.78
$\mathrm{AST_{Col}}$	53	43.23	97.52	63.32	11.38
$\mathrm{AST_{Turk}}$	53	25.0000	56.25	38.72	7.15
$\mathrm{SW_{Col}}$	53	8179.23	20,166.23	12,541.93	2376.35

SD—standard deviation. $\mathrm{AST_{Col}}$—average square thickness defined by Colombini et al. (1989), $\mathrm{AST_{Turk}}$—average square thickness defined by Turk and Celan (2004), $\mathrm{SW_{Col}}$—bony structure weight defined by Colombini et al. (1989).