Vibration Safety Limits for Magnetic Resonance Elastography

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Introduction:

An essential step in most approaches for magnetic resonance elastography (MRE) is to generate acoustic mechanical waves within the object, usually via some form of coupled mechanical driver. Motivated by an increasing volume of human imaging trials of MRE, the objective of this study was to re-survey existing regulatory guidelines for human vibration exposure, and to evaluate their applicability and implications for dynamic MRE.

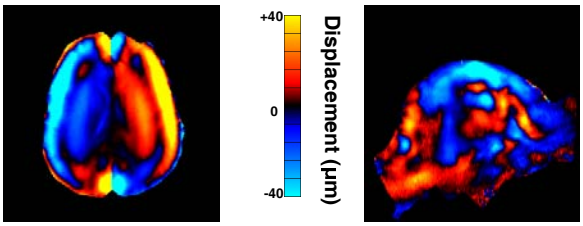
Methods:

The effects of whole body vibration are most severe at frequencies in the 1-30 Hz range, and include motion sickness, loss of equilibrium, degraded fine motor performance, visual blurring, and general discomfort. Most standards for whole body vibration are designed to specify maximum values for chronic exposure (residential) or occupational exposure, and most standards for hand/limb exposure are designed to reduce the risk of injury from chronic occupational exposure (power tools), including traumatic vasospastic disease, neurosensory injuries, carpal tunnel syndrome, and tendonitis.

In the US, there are no Federal regulations mandating maximum occupational vibration exposure [1]. Existing published ISO standards are used as recommendations for equipment engineers and ergonomists to minimize the occurrence of vibration related disorders or performance effects. The standards do not represent values above which no person should ever be exposed and specifically are far below the thresholds for acute injury [2].

In 2002, the European Parliament adopted a standard, setting RMS vibration limits of 5 m/sec^2 and 1.15 m/sec^2 for extremity and whole body "daily" exposures respectively [3]. Higher frequencies are "ISO-weighted" to allow higher acceleration limits, as are shorter durations.

Because the information acquired in MRE experiments is measured as displacement (d_{max}) and the EU exposure standards are in terms of RMS acceleration (a_{rms}) the following conversions below must be made:



Brain (80 Hz Breast (90 Hz

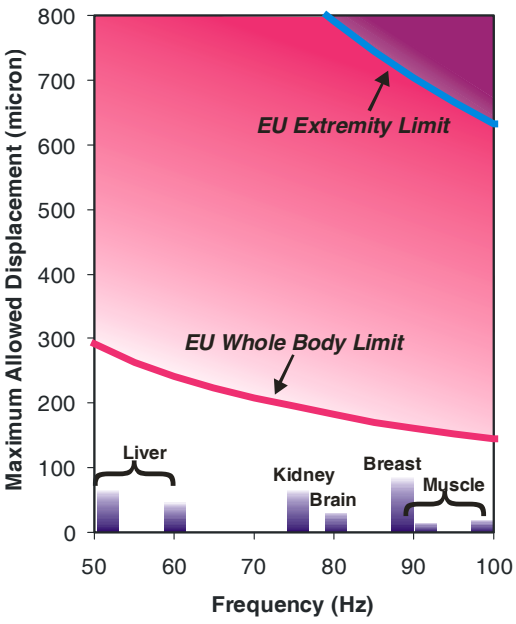


Fig.1

$x_{max} = d_{max}*\sin(\omega t)$
$v_{max} = dx_{max}/dt = \omega*d_{max}*\cos(\omega t)$
$a_{max} = dv_{max}/dt = -\omega^2*d_{max}*\sin(\omega t)$

$x_{RMS} = d_{max}/2^{.5}$
$v_{RMS} = \omega*d_{max}/2^{.5}$
$a_{RMS} = \omega^2*d_{max}/2^{.5}$

Results:

The following analysis was conducted to determine if the typical mechanical wave amplitudes used in MRE are likely to exceed the EU vibrational exposure standards.

Taking into account typical total imaging times and duty cycles, we assumed a total exposure duration of 15 minutes. The ISO standard specifies the following conversion factor F for a daily exposure time D (in hours) that is different than 8 hrs: $F = (8 / D)^{.5}$. The ISO standard also defines weighting factors that allow higher acceleration limits at frequencies above 16 Hz.

For the graph in Figure 1 we applied the ISO frequency weighting factors and computed the peak displacement limits allowed by the EU standard as a function of frequency, for a 15 minute (daily) vibration exposure. We evaluated the range of observed peak displacements in representative MRE studies of the liver, brain, kidney, breast and skeletal muscle and show these values in the same figure.

Discussion and Conclusion:

The results indicate that the typical vibrational displacements used in MRE studies are well below the values that would be permitted by even the conservative EU whole body vibration standard. We conclude that the EU guidelines of 2002 represent a useful standard that will be readily accepted by Institutional Review Boards for defining maximum vibrational amplitudes that can be used for MRE in humans.

References:

[1] MJ Griffin, "Handbook of Human Vibration", 1990.
[2] International Standards Organization; www.iso.org
[3] Directive 2002/44/EC of the European Parliament