The quality of a finite-element model of the middle ear strongly depends on its geometry and on the choice of material properties. Uncertainties in the former can arise, for example, from image blurring, or from the image-segmentation process due to limited spatial resolution and contrast. Likewise, uncertainty in the choice of material-property parameters can arise from lack of measurement, errors in size, or variability among tissues.

When parameter values are uncertain, the one-factor-a-time method is commonly used to investigate the effects of parameter variations. However, it does not take into account the possibility of interactions among parameters. Such interactions mean that the model parameters' effects on model behaviour are being considered. It will be interesting to extend the analysis in this way to include more parameters, and to explore interactions among them.

Methods
Taguchi Method
The procedure for applying the Taguchi method is as follows:

1. Select parameters and levels of interest.
2. Map the factors and values to the OA.
3. Perform the simulations.
4. Map the factors and values to the OA.
5. Analyze the results and draw conclusions.

A Middle-Ear Finite-Element Model
A 3-D finite-element model of an adult human middle ear was generated based on a microscopic computed tomography (CT) data set with 12-μm axial slice thickness.

The tympanic membrane (TM), including pars flaccida and pars tensa, was clamped at its border. Similarly, the sphenoid sinus, maxillary sinus and sinoid cavities were clamped. A rigid pressure of 1Pa was applied normal to the TM surface.

The models' material properties consist of the structures 'Young's modulus (YM) and Poisson's ratio (PR)'. Their values were obtained from the literature (Funnell, 1996; Kakuse, 1994; Koike et al., 2002; Funnell, 1997; 2002; 2003; 2004; 2005; 2006). The same value, 0.3, was used for the two parameters across the data set.

The model was exercised for static loading, expressing the effects of material properties on the behaviour of the middle-ear model. The results are summarized in Table 2. The simulated displacement for the TM is 2% of the experimentally measured value, and the simulated displacement for the stapes is about 1/3 of the measured value. These results are close enough to serve as a basis for an exploration of the effects of parameter variations.

Discussion
Quantitatively, the parameters' lines and Young's modulus contribute more than 50% of the overall middle-ear volume displacement, but less than 47% of that of the footplate displacement.

We observed that a strong interaction exists between the Young's modulus of the incudomalleal ligaments and paras-tensa thickness. It is important to take this interaction into account when studying the parameter's effect on model behaviour is being considered. It will be interesting to extend the analysis to include more parameter levels, and to see if the interaction is still present in a more realistic model.

Conclusions
This is the first time that interactions between parameters in a middle-ear finite-element model are being studied.

The Taguchi method is an efficient and effective method for analyzing parameter sensitivity and interactions.

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References