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Letter to the Editor: Current progress in patient-specific modeling by Neal and Kerckhoffs (2010)

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Abstract

A recent review article on 'Current progress in patient-specific modeling' in *Briefings in Bioinformatics* contains the statement summarizing the results of our previous study 'On the unimportance of constitutive models in computing brain deformation for image-guided surgery' published in *Biomechanics and Modeling in Mechanobiology* as confirmation of adequacy of linear elastic model for such computation. The purpose of this Letter to the Editor is to clarify this statement by informing the Readers of *Briefings in Bioinformatics* that our study indicates the following: (i) a simple linear elastic constitutive model for the brain tissue is sufficient when used with an appropriate finite deformation solution (i.e. geometrically non-linear analysis); and (ii) Linear analysis approach that assumes infinitesimally small brain deformations leads to unrealistic results.

Keywords: *brain; constitutive models; patient-specific modeling; non-linear finite element analysis; brain shift; real-time computation*

We read the survey of recent advancements in patient-specific modeling by Neal and Kerckhoffs [1] with great interest. We are honored that Neal and Kerckhoffs [1] found our article 'On the unimportance of constitutive models in computing brain deformation for image-guided surgery' [2] worth mentioning in their survey of 130 articles. However, we would like to clarify Neal and Kerckhoffs [1] summary of our findings.

Neal and Kerckhoffs [1] on page 117 write that we 'found that the linear elastic model, the least complex, performed just as well as hyperviscoelastic and hyperelastic alternatives in predicting intra-operative positions of brain landmarks. They recommend using the simpler model because it affords a 29% savings in computational time . . .'. As Neal and Kerckhoffs [1] do not make it clear that they refer to the linear elastic constitutive model, this statement can confuse the readers by suggesting that the results we presented in Wittek *et al*. [2] confirm the adequacy of linear elasticity for computation of deformations within the brain due to craniotomy-induced brain shift.

In Wittek *et al*. [2], we analyzed the effects of the constitutive model complexity when predicting the brain deformations due to craniotomy-induced brain shift using the finite deformation theory. For comparison, we also used geometrically linear analysis

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that relies on oversimplifying assumption that the brain deformations are infinitesimally small. Based on these analyses, in Wittek *et al.* [2] (Figure 4 on p. 82), we present the unequivocal evidence that geometrically linear modeling approach leads to unrealistic, localized brain deformations. As explained in Wittek *et al.* [2], the reason for this inadequacy of the linear model is that the assumption about infinitesimally small deformations, which implies that the equations of solid mechanics governing the brain model behavior are integrated over the initial (i.e. undeformed) brain geometry, is in contradiction with large deformations (order of $\geq$10 mm) occurring during neurosurgery. A number of recent studies conducted by our group have confirmed this fact [3–6].

For practical guidance regarding computational biomechanics of the brain for neurosurgery modeling, we would summarize as follows the results presented in Wittek *et al.* [2]:

- The linear elastic constitutive model for the brain tissue, the least complex, performs just as well as hyperviscoelastic and hyperelastic alternatives in predicting intra-operative positions of brain landmarks when used with an appropriate geometrically non-linear (finite deformation) solution method.
- Unrealistic brain deformations are predicted by linear analysis that assumes infinitesimally small brain deformations.
- While applicable to a wide variety of neurosurgical situations, the modeling approach used in Wittek *et al.* [2] does not extend to cutting and/or tissue removal and other problems where the accurate stress computation is of importance.

Key Points

- We wish to clarify the statement in review article by Neal and Kerckhoffs [1] that interprets our findings published in Wittek *et al.* [2] as confirmation of adequacy of linear elastic model for computation of brain deformation for image-guided surgery.
- In this Letter to the Editor, we summarize the key findings of the study by Wittek *et al.* [2] in the context of article by Neal and Kerckhoffs [1]:
  - The linear elastic constitutive model for the brain tissue performs just as well a more complex hyperviscoelastic and hyperelastic alternatives in predicting intra-operative positions of brain landmarks when used with an appropriate geometrically non-linear (finite deformation) solution method.
  - Unrealistic brain deformations are predicted by linear analysis that assumes infinitesimally small brain deformations.
  - While applicable to a wide variety of neurosurgical situations, the modeling approach we used in Wittek *et al.* [2] does not extend to cutting and/or tissue removal and other problems where the accurate stress computation is of importance.

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