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Peer Review

Review of: "Next-Generation Space Cardiology: Developing a COMSOL-Enabled Digital Heart Twin for Long-Duration Missions"

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This manuscript introduces a computational framework for simulating cardiovascular adaptation under spaceflight-specific conditions using a COMSOL-based digital heart twin. The topic is highly relevant within the emerging domain of space medicine, where the capacity to anticipate and mitigate cardiac deconditioning in altered gravitational environments remains a priority. The ambition of the work is evident and commendable, particularly in its attempt to align advanced modeling with UAE biomedical and space medicine objectives. Conceptually, the study demonstrates translational potential, as it proposes a simulation environment that could support both astronaut health monitoring and terrestrial telemedicine applications.

However, while the topic and intent are valuable, the manuscript presents several significant limitations that prevent its publication in its current form. Most notably, the text reads as a grant proposal rather than a scientific article. The scope is too broad and speculative, incorporating multiple future development modules (such as radiation fibrosis modeling, AI-driven diagnostics, and pharmacokinetic integration) that dilute the central scientific contribution. The author is advised to restructure the manuscript entirely and consider dividing it into two or more distinct papers: one focusing on the scientific and technical development of the digital heart twin model, and another on its envisioned implementation strategy and translational roadmap.

With respect to the technical content, I understand and agree that the core idea and computational approach have merit for both research and potential clinical applications. However, the manuscript fails to justify the use of COMSOL compared to other computational platforms like Abaqus, ANSYS, or FEBio,

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which are widely adopted in high-fidelity biomechanical modeling. Furthermore, the finite element methodology underlying the model is not sufficiently explained. The modeling strategy appears to rely heavily on incorporating variables and equations from heterogeneous sources without demonstrating compatibility or physiological validity. The author seems to assume that combining multiple variables—some of which may originate from incompatible domains or non-analogous boundary conditions—will inherently produce a high-fidelity model. This is not scientifically accurate. The construction of a credible cardiac model requires rigorous anatomical selection, clearly defined population parameters, and consistent physiological assumptions, all of which are lacking in this manuscript. The current approach risks creating a model that is a superficial accumulation of variables rather than a scientifically grounded simulation. The same concern applies to the choice of mechanical properties, which are not sufficiently validated. If an approach or data source cannot be validated or justified within the modeling framework, its inclusion undermines the integrity of the system as a whole. Lastly, the validation strategy itself is underdeveloped and weak; I encourage the author to revise this section thoroughly following the feedback outlined here.

In addition to these technical concerns, the manuscript contains a number of major and minor issues that affect its overall clarity and scholarly contribution. The validation results, though promising at a surface level (e.g., reporting R^2 or RMSE values), lack contextual detail—such as the number of subjects or conditions tested—and are not supported by statistical ranges or sensitivity analyses. The figures, while visually appealing, are not well-integrated into the narrative and require more explanatory detail to be useful. The manuscript also tends to overuse technical jargon and neologisms, which detract from clarity and readability. Peer-reviewed sources should be prioritized over preprints where possible, and the reference list would benefit from more focused inclusion of foundational studies in computational cardiac modeling.

To move this work forward, the author should narrow the scope of the manuscript and explicitly define the core scientific objectives. A clearer presentation of the finite element modeling process is essential, including population specificity, boundary conditions, choice of mechanical laws, and rationale for simulation parameters. The validation section requires significant expansion with transparent data sources, comparison against astronaut and analog datasets, and sensitivity testing to ensure robustness. These changes would not only strengthen the credibility of the model but also support its future translational use.

Declarations

Potential competing interests: No potential competing interests to declare.