Effectiveness of a stand-alone cage in a cervical spine – a finite element study

Febin Chris Asir J. A., Aju Bosco, Davidson Jebaseelan D., Pugazhenthi Subramanian Kalaimani,
Karthik Banurekha Devaraj, Balaji Harinathan, Narayan Yoganandan

Abstract The anterior cervical discectomy and fusion (ACDF) is a surgical procedure that is widely used in the treatment of degenerative disc diseases and herniated discs at the cervical spine. The intervertebral disc is removed as part of the procedure and replaced by an implant, which is a cage, along with a set of screws and plates to restore stability and prevent implant migration. The stand-alone cage, has an innovative design that either includes integrated screw-holders or pyramidal teeth that securely anchor the cage to the vertebrae. This study employs finite element analysis (FEA) to evaluate the performance of a stand-alone cage (Cedix-p) used in a single-level ACDF procedure by focusing on its impact on the range of motion (ROM) in the cervical spine. A previously validated FE model of the cervical spine, consisting of vertebrae C2-T1, is used to simulate physiological loading conditions like flexion-extension, before and after a single-level ACDF surgery. The ROM is then analysed before and after the surgical intervention, which is then used to assess the effectiveness of the stand-alone cage. The findings show that with the operated functional spine unit (FSU), the ROM is significantly reduced.

Keywords Cervical spine, Finite Element Analysis (FEA), Range of Motion (ROM), stand-alone cage. Anterior cervical discectomy and fusion (ACDF)

I. INTRODUCTION

Anterior cervical discectomy and fusion (ACDF) with a cage, along with plating, is the common surgical procedure, but due to post-operative complications, stand-alone cages are now seen as a promising alternative [1]. Studies have shown that there is no significant difference in fusion rates and pain parameters between the two fusion techniques [2]. A stand-alone cage is better suited for single-level ACDF surgery due to shorter operation times and reduced adjacent segment disease [3]. Nowadays, various stand-alone cages are widely used in spinal surgeries and it is important that they are thoroughly tested [4]. Finite element analysis (FEA) is an effective tool that is used to evaluate the performance of the stand-alone cage [5]. The current study focuses on the effectiveness of using a stand-alone cage (Cedix-P) for a single-level ACDF surgery at the C4-C5 functional spine unit (FSU) of a validated FE model of the cervical spine.

II. METHODS

Computational Modeling

The development of the finite element model (FEM) of the cervical spine with its components has been described previously in [6-7]. The FEM of the cervical spine is validated by comparing responses from post-mortem human subject (PMHS) cervical column [8]. In order to model the anterior cervical discectomy and fusion (ACDF), the intervertebral disc, consisting of the annulus ground and the nucleus at the functional spine unit (FSU) C4-C5, is removed from the validated FEM of the cervical spine, which is in an intact state (Fig. 1). Linear hex elements are used to model the stand-alone cage (Cedix-p, Jayon implants Pvt. Ltd., Palaghat, Chennai) along with a small amount of bone graft, which is placed at the large central canal of the stand-alone cage (Fig. 1). The cage is then placed at the C4-C5 FSU (Fig. 1). The material modeling of the FEM of the cervical spine is obtained from literature [9]. The stand-alone cage (Cedix-p) is modeled to represent titanium alloy (Ti-6Al-4V), with elastic modulus of 113.8 GPa and Poisson's ratio of 0.34 [10]. Bonded contact is given for the interface between the bone graft and the stand-alone cage. The surface

Davidson J.D. (tel: +919445122485; e-mail: davidson.jd@vit.ac.in) is a Professor and Febin C. A. J. A. is an undergrad engineering student at the Center for Human Movement Analytics and School of Mechanical Engineering at Vellore Institute of Technology, Chennai, India. A. Bosco is a Professor and Spine Surgeon at Madras Medical College, Chennai, India. P. S. Kalaimani, K. B. Devaraj and B. Harinathan are research assistants and N. Yoganandan is a Professor at Medical College of Wisconsin, USA.

contact between the stand-alone cage setup and the vertebrae at the C4-C5 junction is assigned with tied constraint.

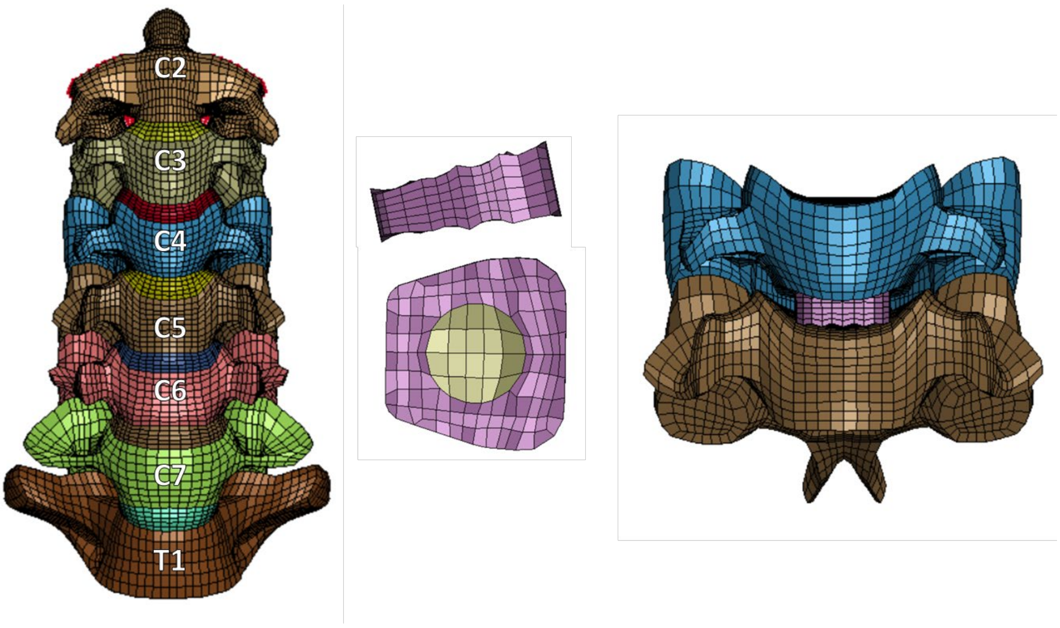

Fig. 1. The validated finite element model of the cervical spine in intact state (left), the stand-alone cage along with bone graft at the central canal (middle), and the anterior cervical discectomy and fusion (ACDF) done at the functional spine unit (FSU) C4-C5 (right).

In the intact cervical spine and the ACDF model of the cervical spine, the inferior nodes of T1 vertebra are constrained. Bending moment of 2 Nm is applied at the sagittal plane (Fig. 2) to exercise both flexion and extension loads [11]. The models are solved using LS-DYNA (R.11.0.0) software.

III. RESULTS

The maximum range of motion (ROM) is measured for both the intact and the ACDF model. The maximum ROM at the functional spine unit C4-C5 is then compared. It is observed that for the ACDF model, the ROM is 0.90° at that particular FSU during flexion, while for extension the maximum ROM is 0.87°. The maximum ROM for all the FSUs in the cervical spine for both models is shown in Fig. 2 and Fig. 3.

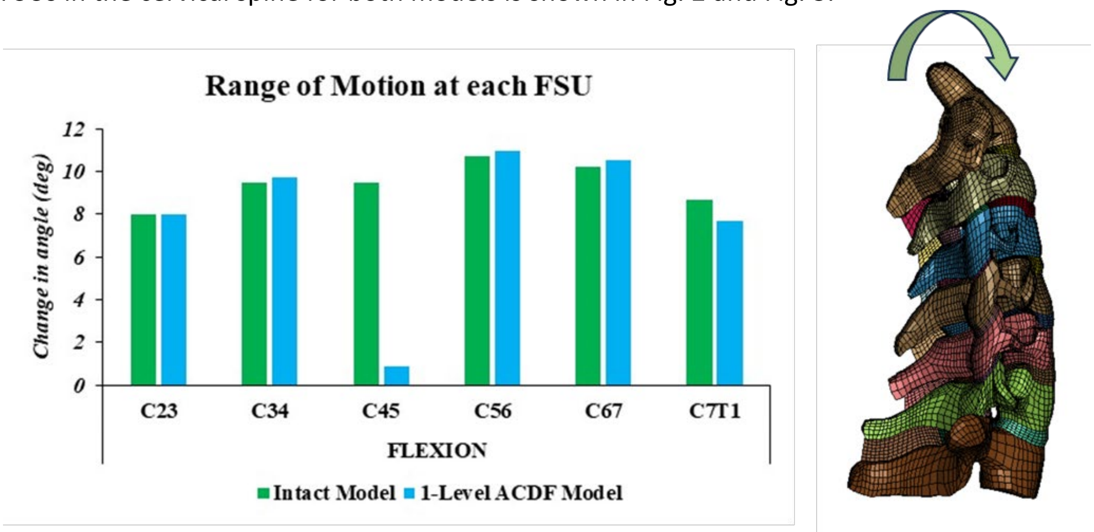

Fig. 2. Comparison of range of motion between intact model and ACDF model during flexion.

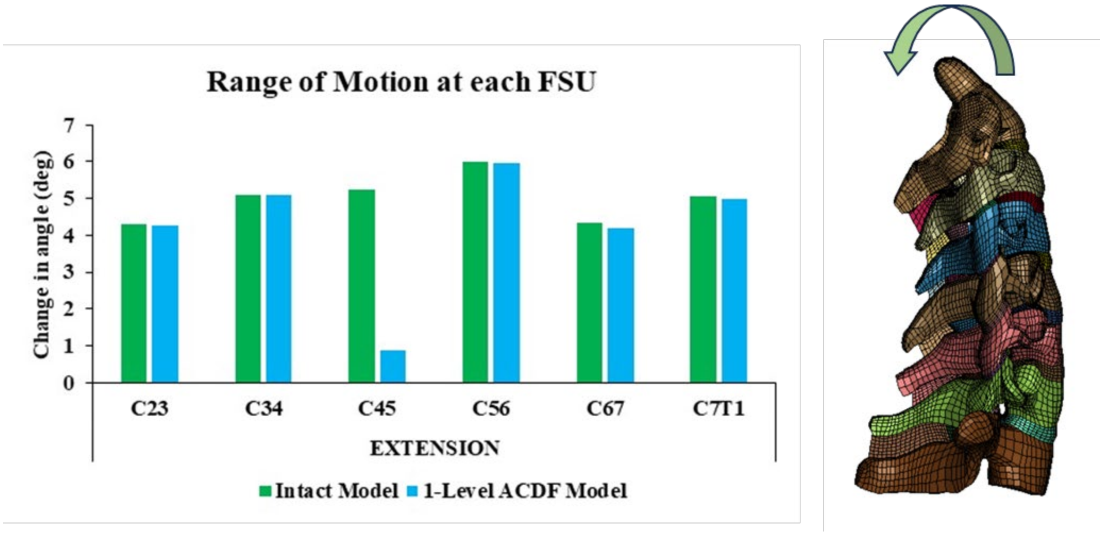

Fig. 3. Comparison of range of motion between intact model and ACDF model during extension.

At the adjacent segments, the ROM is almost the same during extension between the models. In flexion, there is minimal increase. The pressure at the intervertebral disc (IVD) at the adjacent levels was measured and found to have minimal differences between intact model and the ACDF model during flexion and extension (Fig. 4).

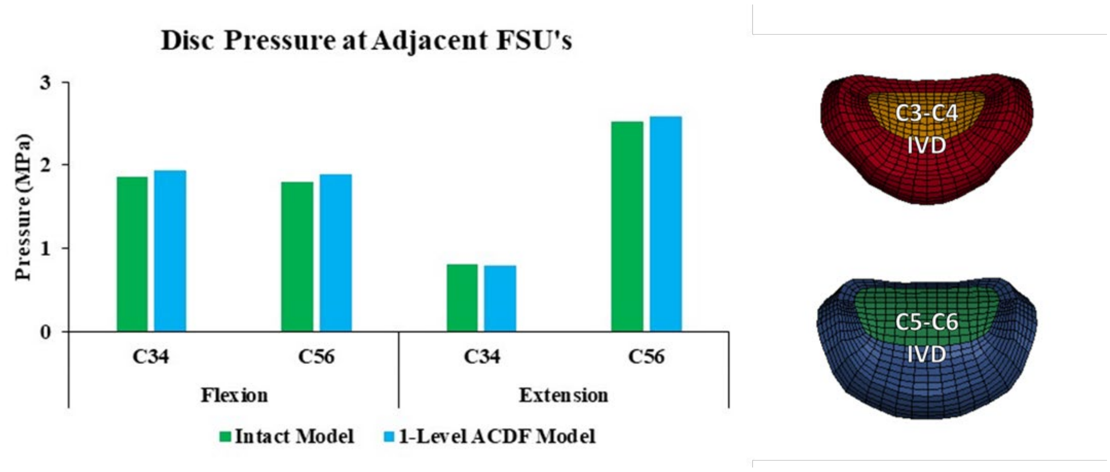

Fig. 4. Comparison of range of motion between adjacent functional spine units (FSUs) and between the intact model and ACDF model during the physiological motions.

The maximum stress at the Cedix-p stand-alone cage is 128 MPa and 112 MPa during flexion and extension, respectively. At the bone graft, which is located at the central canal of the stand-alone cage, the maximum stress is 9.6 MPa when the model is at flexion and 9.2 MPa during extension.

IV. DISCUSSION

The results of this study provide insights into the effectiveness of using the Cedix-p stand-alone cage for the single-level ACDF surgery. The significant reduction of the ROM at the operated FSU C4-C5 confirms the ability of the cage to anchor onto the vertebra, thereby restricting its motion due to a textured profile and providing primary stability. Understanding the radiological outcomes for using stand-alone cage for the ACDF surgery is important as studies report that cage subsidence is more prevalent when using stand-alone cage compared to cages with fixation plates [2][12]. During the modeling process, we decided to keep the endplates at the FSU as the removal of endplates is found to increase cage subsidence [13]. An *in vitro* investigation suggests that the footprint geometry and texture of a stand-alone cage does not appear to influence cage subsidence, rather subsidence depends more on the density of the bone [14], thus the textured profile of the stand-alone cage might not have an effect on subsidence. Moreover, many studies reveal that cages with fixation plates have a higher rate of intra-operative blood loss and post-operative outcomes and complications, like dysphagia, while use of the stand-alone cage is found to have a lower incidence of adjacent segment degeneration (ASD) [3]. The minimal difference in adjacent-level disc pressure observed in our study suggests that the stand-alone cage may not contribute significantly to ASD. There is an inherent limitation in using the stand-alone cage (Cedix-p) when the disc space is significantly large, as its design causes it to taper in thickness from front to back, potentially limiting its ability to maintain proper alignment and stability when used without fixation systems. However, the use of the stand-alone cage (Cedix-P) at C4-C5 FSU is found to be effective and can be beneficial when selected based on clinical scenario.

V. CONCLUSION

To summarise, the stand-alone cage used in our study is found to significantly reduce range of motion (ROM) at the operated functional spine unit (FSU), which is the primary objective of anterior cervical discectomy and fusion (ACDF) surgery. Minimal difference in disc pressure at the adjacent levels suggests that the use of stand-alone cage might not promotive adjacent segment degeneration. The use of stand-alone cages in ACDF surgery can be particularly beneficial for patients from economically disadvantaged backgrounds due to their lower operating costs and reduced hospital stays. Clinicians should weigh these benefits alongside the clinical outcomes when selecting the appropriate surgical technique for ACDF.

VI. ACKNOWLEDGEMENTS

The authors would like to acknowledge the ANRF-SERB-CRG grant File no. CRG/2023/004727.

VII. REFERENCES

[1] Kapetanakis, S., Thomaidis, T., *et al.* (2017) Single anterior cervical discectomy and fusion (ACDF) using self-locking stand-alone polyetheretherketone (PEEK) cage: evaluation of pain and health-related quality of life. *Journal of Spine Surgery*, **3**(3): pp. 312–322.

[2] Zawy Alsofy, S., *et al.* (2020) Comparison of stand-alone cage and cage-with-plate for monosegmental cervical fusion and impact of virtual reality in evaluating surgical results. *Clinical Neurology and Neurosurgery*, **191**: p. 105685.

[3] Elias, E., Daoud, A., Smith, J., Elias, C., Nasser, Z. (2024) Assessing Surgical Outcomes for Cage Plate System versus Stand-Alone Cage in Anterior Cervical Discectomy and Fusion: A Systematic Review and Meta-Analysis. *World Neurosurgery*, **131**(5): pp. 202–215.

[4] Wang, R. and Wu, Z. (2023) Recent advancement in finite element analysis of spinal interbody cages: A review. *Frontiers in Bioengineering and Biotechnology*, **11**(2): pp. 45–56.

[5] Ahn, C. H., *et al.* (2023) Comparing zero-profile and conventional cage and plate in anterior cervical discectomy and fusion using finite-element modeling. *Scientific Reports*, **13**(1): pp. 1–11.

[6] John, J. D., Arun, M. W. J., Gurunathan, S. K., Yoganandan, N. (2017) Cervical spine finite element model with anatomically accurate asymmetric intervertebral discs. Summer Biomechanics and Biotransport Conference, 2017, Tucson, AZ, USA.

[7] John, J. D., Saravana Kumar, G., Yoganandan, N. (2019) Cervical spine morphology and ligament property variations: A finite element study of their influence on sagittal bending characteristics. *Journal of Biomechanics*, **85**: pp. 18–26.

[8] Wheeldon, J. A., Pintar, F. A., Knowles, S., Yoganandan, N. (2006) Experimental flexion/extension data corridors for validation of finite element models of the young, normal cervical spine. *Journal of Biomechanics*, **39**(2): pp. 375–380.

[9] Purushothaman, Y., Yoganandan, N., Jebaseelan, D., Choi, H., Baisden, J. (2020) External and internal responses of cervical disc arthroplasty and anterior cervical discectomy and fusion: A finite element modeling study. *Journal of the Mechanical Behavior of Biomedical Materials*, **106**: p. 103735.

[10] Sun, J., *et al.* (2021) A lattice topology optimization of cervical interbody fusion cage and finite element comparison with ZK60 and Ti-6Al-4V cages. *BMC Musculoskeletal Disorders*, **22**(1): pp. 1–14.

[11] Wheeldon, J. A., Stemper, B. D., Yoganandan, N., Pintar, F. A. (2008) Validation of a finite element model of the young normal lower cervical spine. *Annals of Biomedical Engineering*, **36**(9): pp. 1458–1469.

[12] Han, S. Y., Kim, H. W., Lee, C. Y., Kim, H. R., Park, D. H. (2016) Stand-Alone Cages for Anterior Cervical Fusion: Are There No Problems? *Korean Journal of Spine,* **13**(1): pp. 13–19.

[13] Pinder, E. M., Sharp, D. J. (2016) Cage subsidence after anterior cervical discectomy and fusion using a cage alone or combined with anterior plate fixation. *Journal of Orthopaedic Surgery (Hong Kong),* **24**(1): pp. 97–100.

[14] Suh, P. B., Puttlitz, C., Lewis, C., Bal, B. S., McGilvray, K. (2017) The effect of cervical interbody cage morphology, material composition, and substrate density on cage subsidence. *Journal of the American Academy of Orthopaedic Surgeons,* **25**(2): pp. 160–168.