

Conventional plate fixation versus intramedullary nailing for distal radius fractures: a comparative finite element study

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Research Article

Keywords: distal radius fracture, finite element analysis, conventional plate fixation, intramedullary nail, construct stiffness, implant stress

Posted Date: May 28th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-9290018/v1>

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Additional Declarations: Competing interest reported. The corresponding author holds a patent related to the subject matter of this manuscript, which may be considered a potential competing interest. The other authors declare that they have no competing interests.

Abstract

Background

Distal radius fractures are commonly treated with plate fixation or intramedullary fixation, but construct-level trade-offs between stiffness and implant stress remain incompletely defined. This study compared conventional plate fixation and intramedullary nailing using a computed tomography-based finite element model.

Methods

A distal radius model and 2 fixation constructs were reconstructed from the source engineering report. Material properties, contacts, and boundary conditions were assigned in Ansys Workbench. The proximal radius was fully constrained. Axial compression (50–250 N), palmar flexion (50–250 N), dorsiflexion (50–250 N), internal rotation (1 N·m), and external rotation (1 N·m) were applied. Total displacement and maximum equivalent stress were extracted for direct descriptive comparison. No inferential statistical tests were performed because this was a deterministic finite element comparison.

Results

Across all loading conditions, conventional plate fixation showed lower displacement, indicating greater construct stiffness, whereas the intramedullary nail showed lower maximum equivalent stress. At peak axial compression (250 N), displacement was 1.1485 mm for the plate and 1.4940 mm for the nail, while stress was 747.67 versus 661.20 MPa. Under palmar flexion, displacement was 4.2659 versus 4.7072 mm and stress was 2447.1 versus 2218.4 MPa. Under dorsiflexion, displacement was 4.2660 versus 4.7645 mm and stress was 2448.3 versus 2232.5 MPa. Under internal and external rotation, the nail showed 6.2% higher displacement but approximately 12.0% lower stress than the plate.

Conclusions

Conventional plate fixation provides superior construct stiffness, whereas intramedullary nailing reduces implant stress. Plate fixation may therefore be preferable when maximal maintenance of reduction and anti-rotation control are priorities, whereas intramedullary fixation may be advantageous when a less invasive, lower-stress construct is desired for selected fracture patterns.

Background

Distal radius fractures are one of the most common fractures encountered in orthopaedic practice and continue to generate substantial medical and socioeconomic burden [1]. Their incidence increases in both older adults, particularly women with fragility mechanisms, and younger active patients who sustain

higher-energy trauma [1]. Because displaced and unstable distal radius fractures may lead to malunion, altered wrist biomechanics, pain, and loss of function, stable fixation that permits early motion remains a major surgical objective.

Plate-based fixation has become a standard internal fixation strategy for unstable distal radius fractures because it can provide subchondral support and reliable restoration of alignment [2, 7]. Nevertheless, plate fixation still requires wider exposure and may be associated with tendon irritation, nerve symptoms, hardware-related problems, and reoperation in a subset of patients [5]. By contrast, intramedullary fixation was developed as a less invasive alternative intended to reduce soft-tissue stripping and hardware prominence while preserving adequate stability for selected extra-articular and simple intra-articular fractures [3, 6]. Randomized and meta-analytic studies have suggested that intramedullary nailing can achieve clinical outcomes comparable with volar plate fixation in selected patients, with some evidence of better short-term recovery [3, 4].

Finite element analysis (FEA) offers a controlled framework to compare internal fixation strategies under standardized loading conditions and to visualize the mechanical trade-offs that may not be obvious from clinical endpoints alone. Prior randomized trials, retrospective comparisons, and systematic reviews have generally suggested that intramedullary fixation can achieve clinical and radiographic outcomes comparable to volar plate fixation in selected extra-articular or simple intra-articular fractures, whereas volar plates may retain advantages in reduction control and construct stiffness [8–15]. Cadaveric and construct-level biomechanical studies have likewise shown that volar locking plate performance depends on implant design, screw configuration, and plate position [16–20].

The purpose of this study was therefore to compare a conventional plate construct with an intramedullary nail construct for distal radius fracture fixation using a finite element model reconstructed from computed tomography data. We hypothesized that the conventional plate would provide greater construct stiffness, whereas the intramedullary nail would reduce implant stress.

Methods

Study design and model reconstruction

This was a deterministic comparative finite element study. A distal radius model was reconstructed from computed tomography (CT) imaging and processed through Mimics 20.0, Geomagic 2012, SolidWorks 2015, and Ansys Workbench 18.0. The source engineering report described three fixation systems (new plate, conventional plate, and intramedullary nail); in the present manuscript, only the conventional plate and intramedullary nail constructs were extracted and reorganized to match the clinical comparison of interest. After three-dimensional reconstruction, implant models were assembled with the distal radius model and a fracture interface with a 2-mm callus layer was generated. Representative reconstruction, assembly, and meshing steps are shown in Fig. 1.

Meshing was performed with a bone element size of 1.0 mm and an implant/screw element size of 0.5 mm using Solid187 solid elements. Node and element counts in the original report were 447,820 and 290,656 for the conventional plate model, and 489,978 and 300,969 for the intramedullary nail model. Mesh convergence was evaluated in the engineering report using the intramedullary nail model; the difference in maximum equivalent stress between 0.25-mm and 0.5-mm meshes was 1.2%, which was below a commonly accepted 5% convergence threshold. Accordingly, a 0.5-mm implant mesh was retained for subsequent calculations.

Material properties, contacts, and boundary conditions

Material parameters in the engineering report were assigned as follows: cortical bone, elastic modulus 13,800 MPa and Poisson ratio 0.3; cancellous bone, 690 MPa and 0.3; early callus, 0.2 MPa and 0.167; implant material, 110,000 MPa and 0.3. Screw-plate interfaces were defined as bonded. Screw-bone interactions were defined as frictional contacts with a coefficient of 0.65, and the callus-bone interface was defined as bonded.

The proximal radial head was fully constrained. Loads were applied to the distal articular surface in five loading categories: axial compression, palmar flexion, and dorsiflexion at 50, 100, 150, 200, and 250 N; and internal rotation and external rotation at 1 N·m. The two primary outcome measures were total displacement of the construct, used as a stiffness-related indicator, and maximum equivalent (von Mises) stress of the implant system, used as a strength-related indicator. Because this was a deterministic FEA comparison, no inferential statistical tests were performed; outcomes were compared descriptively across loading conditions.

Results

Axial compression

Under axial compression, total displacement increased progressively with increasing load for both constructs, but the conventional plate consistently showed smaller displacement than the intramedullary nail across the entire 50–250 N range. At the peak load of 250 N, the conventional plate reached a total displacement of 1.1485 mm, whereas the intramedullary nail reached 1.4940 mm. In contrast, the intramedullary nail showed lower maximum equivalent stress than the conventional plate at each load level; at 250 N, the corresponding peak stress values were 661.2 MPa and 747.67 MPa, respectively. Thus, relative to the intramedullary nail, the conventional plate reduced peak displacement by 23.1%, whereas the intramedullary nail reduced peak implant stress by 11.6% (Table 1; Figs. 2–5).

Palmar flexion

Under palmar flexion, both constructs again demonstrated load-dependent increases in displacement and implant stress. The conventional plate maintained smaller total displacement from 50 to 250 N, reaching 4.2659 mm at 250 N compared with 4.7072 mm for the intramedullary nail. However, the intramedullary nail maintained lower maximum equivalent stress, with peak values of 2218.4 MPa for the intramedullary nail and 2447.1 MPa for the conventional plate at 250 N. At the peak palmar-flexion load, the conventional plate reduced displacement by 9.4%, whereas the intramedullary nail reduced implant stress by 9.3% (Table 1; Figs. 2–5).

Table 1
Peak-load displacement and stress comparison.

Loading condition	Peak load	Plate displacement (mm)	IM nail displacement (mm)	IM nail vs plate (disp.)	Plate stress (MPa)	IM nail stress (MPa)	IM nail vs plate (stress)
Axial compression	250 N	1.1485	1.4940	+ 30.1%	747.67	661.20	-11.6%
Palmar flexion	250 N	4.2659	4.7072	+ 10.3%	2447.1	2218.4	-9.3%
Dorsiflexion	250 N	4.2660	4.7645	+ 11.7%	2448.3	2232.5	-8.8%
Internal rotation	1 N·m	0.43334	0.46014	+ 6.2%	1215.4	1069.5	-12.0%
External rotation	1 N·m	0.43334	0.46014	+ 6.2%	1215.4	1069.5	-12.0%

Dorsiflexion

Under dorsiflexion, the conventional plate also produced a stiffer construct, with total displacement of 4.2660 mm at 250 N compared with 4.7645 mm in the intramedullary nail group. The stress response showed the opposite trend: maximum equivalent stress was 2448.3 MPa in the conventional plate construct and 2232.5 MPa in the intramedullary nail construct at 250 N. Accordingly, the plate reduced peak displacement by 10.5%, whereas the intramedullary nail reduced peak implant stress by 8.8% at the highest dorsiflexion load. The peak-stress cloud maps indicated that stress concentration remained localized to the fixation devices rather than being diffusely distributed along the radial shaft (Table 1; Figs. 2–5).

Internal rotation

Under 1 N·m internal rotation, the conventional plate again demonstrated the smaller total displacement, measuring 0.43334 mm compared with 0.46014 mm for the intramedullary nail. In contrast, the intramedullary nail showed the lower maximum equivalent stress, with a peak value of 1069.5 MPa

compared with 1215.4 MPa in the conventional plate group. Therefore, under internal rotation the plate reduced rotational displacement by 5.8%, whereas the intramedullary nail reduced peak implant stress by 12.0% (Table 1; Figs. 2–5).

External rotation

Under 1 N·m external rotation, an essentially identical response pattern was observed. The conventional plate showed a smaller total displacement than the intramedullary nail (0.43334 mm vs 0.46014 mm), whereas the intramedullary nail showed lower maximum equivalent stress than the conventional plate (1069.5 MPa vs 1215.4 MPa). These findings confirm that the rotational trade-off seen under internal rotation was preserved under external rotation, with the conventional plate favoring construct stiffness and the intramedullary nail favoring lower implant stress (Table 1; Figs. 2–5).

Discussion

The most important finding of this finite element comparison was that the conventional plate construct and the intramedullary nail construct exhibited a clear mechanical trade-off. The plate provided greater stiffness under every tested loading mode, whereas the intramedullary nail consistently reduced implant stress. This pattern was preserved across axial compression, bending-type loads, and rotational loading, which increases confidence that the observation reflects a construct-level difference rather than an isolated loading artifact.

The greater stiffness of the conventional plate construct is biomechanically plausible. A plate positioned close to the distal metaphysis provides a broader buttress effect and distributes fixation points across the distal fragment, thereby increasing resistance to translational and angular displacement. This interpretation is consistent with prior biomechanical work showing that volar plate constructs are stiffer than intramedullary constructs in unstable extra-articular distal radius fractures [2, 7]. In the present analysis, the superiority of the conventional plate was most obvious under axial compression and remained evident under both palmar and dorsal bending-type loads.

By contrast, the intramedullary nail construct showed lower maximum equivalent stress in every loading condition. This likely reflects the more central load-sharing pathway and the relatively larger effective implant diameter described in the engineering report, which may reduce local peak stress concentrations within the implant system. From a mechanical standpoint, lower implant stress may be beneficial for strength reserve and fatigue tolerance, although stress alone does not determine clinical success. The intramedullary construct therefore appears to exchange some stiffness for lower implant stress.

The rotational findings deserve special attention. The report itself emphasized that the stiffness disadvantage of the intramedullary nail was particularly evident in anti-rotation performance, and the present re-analysis confirms this impression. Under both internal and external rotation, the nail showed 6.2% greater displacement than the plate, whereas its stress remained 12.0% lower. This suggests that

rotational control may be the most sensitive domain in which plating retains a mechanical advantage. Clinically, this may be relevant when metaphyseal comminution, unstable fracture geometry, or rehabilitation demands make rotational stability a priority.

The present results align reasonably well with published clinical and biomechanical literature. Konstantinidis et al. reported a biomechanical analysis of volar plate and intramedullary nail fixation showing differences in stability between these constructs [2]. Alluri et al. found that volar plate fixation was biomechanically stiffer than intramedullary fixation, although both maintained acceptable postoperative reduction under early rehabilitation loads [7]. Clinically, Plate et al. found that intramedullary nailing and volar plating produced comparable outcomes in unstable distal radius fractures, while Chen et al. later concluded in a meta-analysis of randomized trials that intramedullary fixation offered improved short-term clinical outcomes but no significant long-term disadvantage in selected fracture patterns [3, 4]. Taken together with the present findings, these studies suggest that the mechanical inferiority of intramedullary fixation in stiffness does not automatically preclude satisfactory clinical performance, particularly when patient selection is appropriate.

The current comparison also offers a practical decision-making perspective. If the overriding surgical priority is maximal maintenance of reduction and stronger anti-rotation behavior, the conventional plate construct appears mechanically preferable. If the clinical scenario favors a less invasive approach with limited soft-tissue stripping and lower implant stress, intramedullary fixation may remain an attractive option for selected extra-articular and simple intra-articular fractures [3, 6]. In this sense, the present finite element results do not identify a universally superior implant; instead, they clarify the biomechanical compromise associated with each construct. These implant-specific trade-offs should also be interpreted against the broader epidemiological burden of distal radius fractures and the recognized complication profile of volar plate fixation reported in recent population-based and systematic-review studies [21–24].

This study has several limitations. First, it was derived from an engineering finite element report based on a single anatomic reconstruction, which limits generalizability. Second, the material models were simplified and did not account for anisotropy, bone quality variation, ligament constraints, tendon forces, or biologic healing progression. Third, the analysis was static rather than cyclic and therefore cannot directly address fatigue failure or reduction loss over time. Fourth, although the source report included a mesh convergence analysis, mechanical validation with cadaveric or clinical data was not performed within the present manuscript. Finally, because the original report modeled three constructs, the present manuscript represents a focused two-construct reorganization of that dataset rather than a de novo simulation.

Conclusions

In this finite element comparison of distal radius fixation strategies, the conventional plate construct consistently provided greater stiffness, while the intramedullary nail construct consistently produced

lower implant stress. The difference in stiffness was especially apparent under rotational loading. These findings support conventional plate fixation when maximal reduction control is required and support intramedullary nailing as a mechanically acceptable minimally invasive alternative when lower implant stress and reduced soft-tissue disruption are prioritized in appropriately selected fractures.

Abbreviations

CT, computed tomography

FEA, finite element analysis

MPa, megapascal

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request. All numerical results supporting the conclusions of this study are included in this published article and its figures.

Competing interests

The authors declare that they have no competing interests.

Funding

This work was supported by the scientific research fund of Aerospace Center Hospital (No. 2023YK24).

Authors' contributions

JM and YL drafted the manuscript. FG prepared the figures. EW and XL prepared the tables. All authors reviewed the manuscript and approved the final manuscript.

Acknowledgements

Not applicable.

Authors' information

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Figures

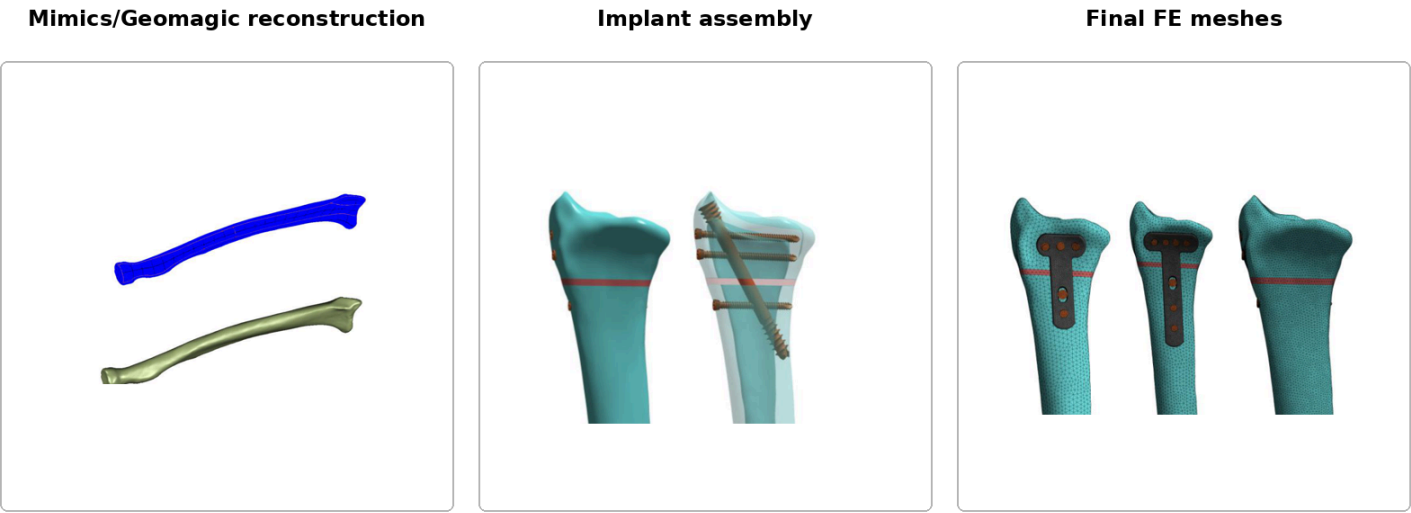


Figure 1

Modeling workflow. Reconstruction, assembly, and meshing steps of the distal radius models.

Construct stiffness comparison

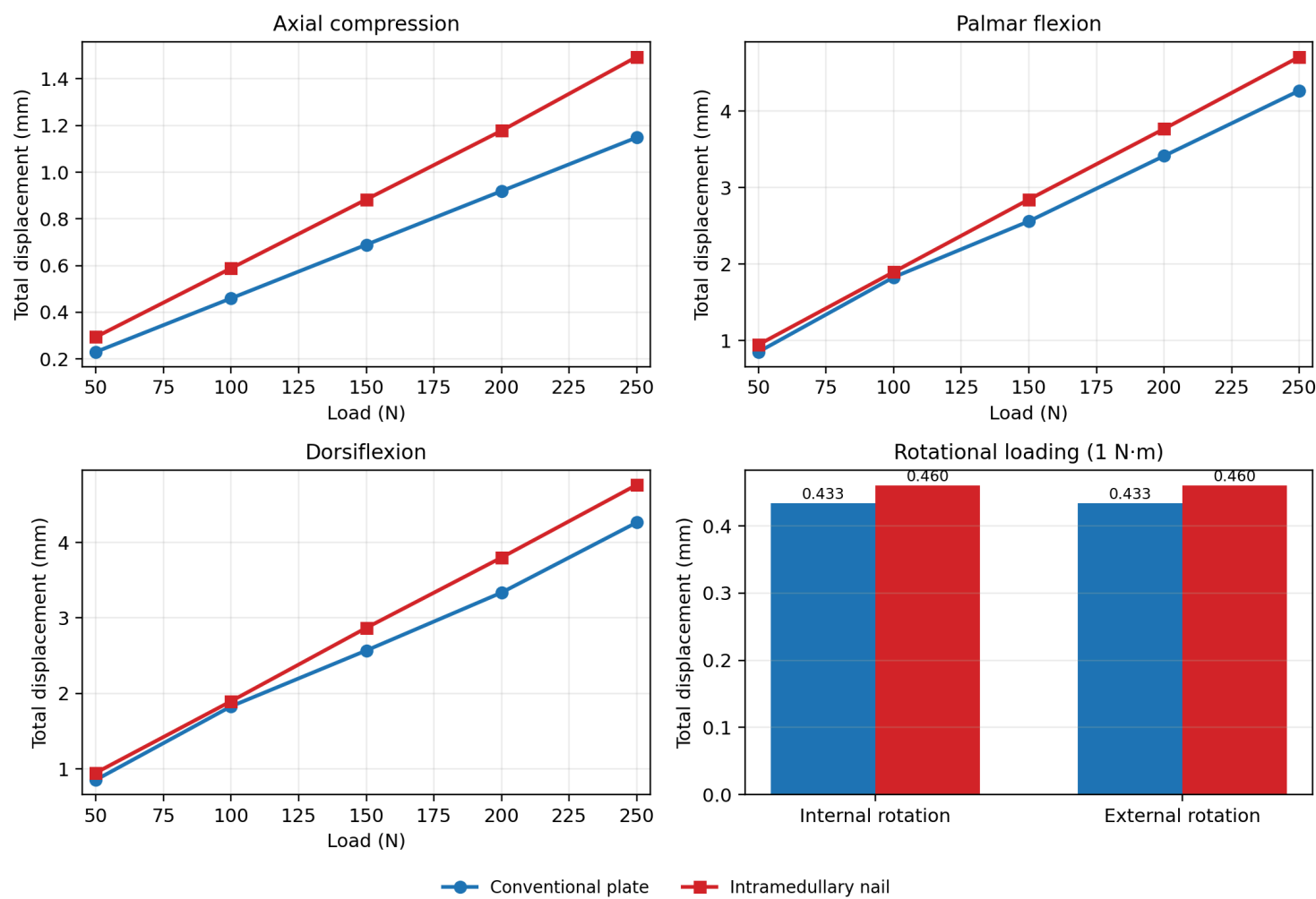


Figure 2

Construct stiffness comparison. Total displacement of the conventional plate and intramedullary nail under axial, bending, and rotational loading.

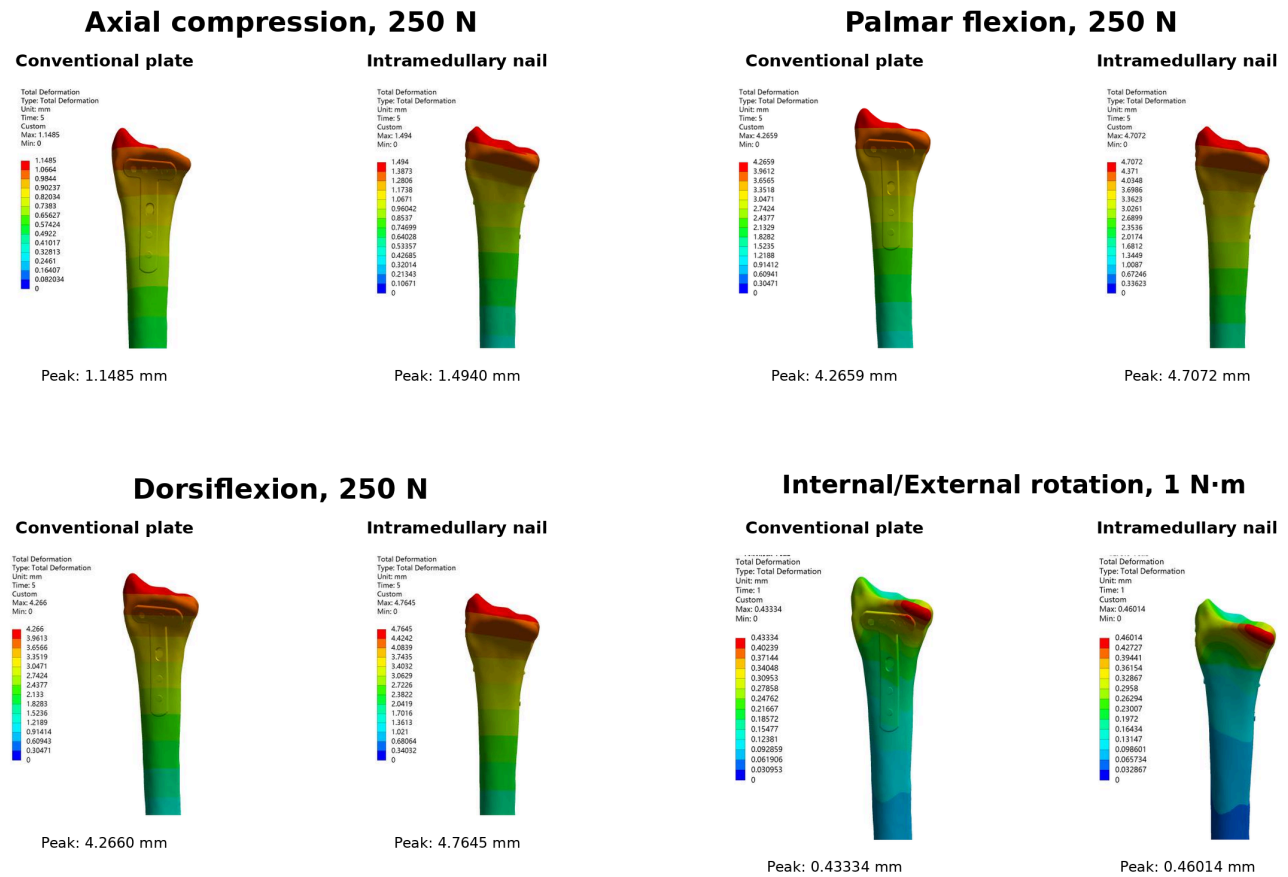


Figure 3

Peak-load total deformation. Peak-load deformation maps for both constructs under axial compression, palmar flexion, dorsiflexion, and rotational loading.

Implant stress comparison

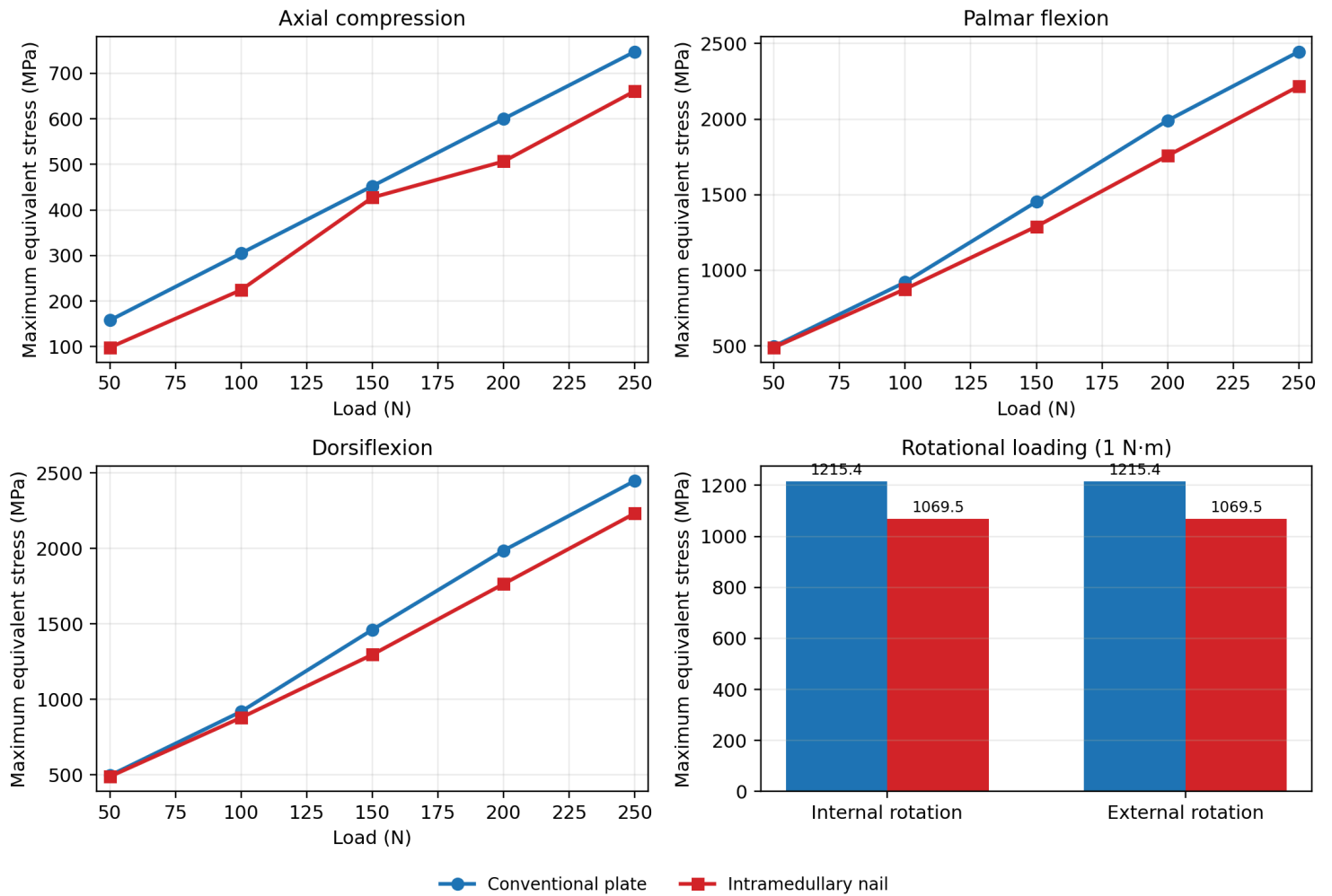


Figure 4

Implant stress comparison. Maximum equivalent stress of the conventional plate and intramedullary nail under axial, bending, and rotational loading.

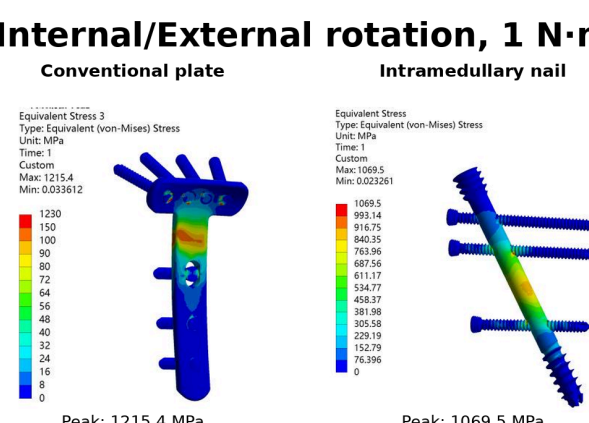
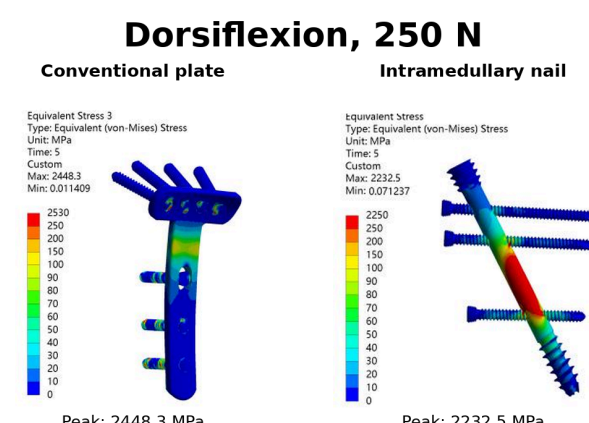
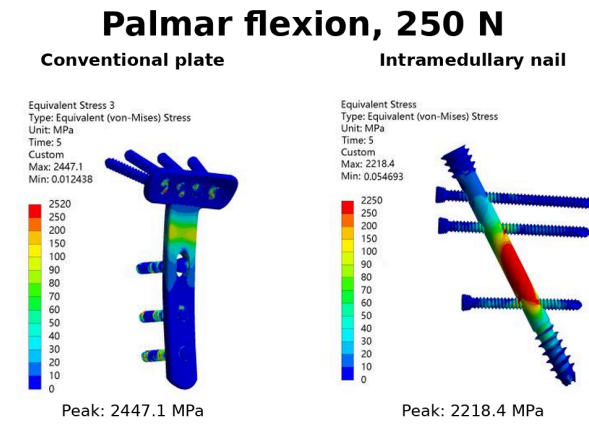
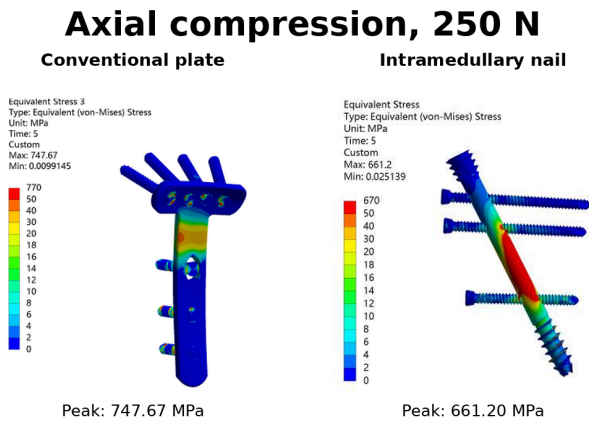


Figure 5

Peak-load stress cloud maps. Peak-load von Mises stress distributions for both constructs under the four peak-load conditions.