The biomechanics of combined lateral and posterior plates for treating proximal humerus fractures with medial column defects

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Abstract

Background. We investigated the therapeutic effects associated with the combined use of lateral and posterior plates for treating complex proximal humerus fractures. Methods. We used in vitro biomechanical experiments and computer three-dimensional finite element analyses to investigate the biomechanical properties of combined lateral and posterior plates when treating proximal humerus fractures. Eighteen left SAWBONE (Pacific Research Labs) humerus bones were randomly divided among three groups. We established a medial column defect model for surgical neck fractures in each bone specimen and achieved fixation using a proximal humerus locking plate. Each of the three groups used a different fixation method. Group A used a Proximal Humerus Internal Locking System (PHILOS) plate support only. Group B used the PHILOS plate with a posterior locking plate (but without medial column support screws). Group C used the PHILOS plate with both the posterior locking plate and medial column support screws. We subjected three sets of specimens to axial compression, torsion, shear compression, model failure, fatigue testing, and micro-strain analyses. Results and conclusions. In vitro biomechanical analysis and three-dimensional finite element analyses showed that the PHILOS plate, in combination with the posterior locking plate and medial column support screws (Group C), had significantly enhanced biomechanical properties when compared with traditional single plate supports.

Background

Recent years have seen increasing numbers of patients treated for proximal humeral fractures, largely as a result of societal aging. As per the Neer fracture classification system, complex three- and four-part fractures account for approximately 65% of all osteoporotic fractures because of relative ease with which metaphyseal fractures occur in these bones [1, 2]. Historically, treatment of these types of fractures involved humeral reduction with a locking plate and medial support screws. However, during the postoperative period many patients continue to suffer from loss of the neck-shaft angle, humeral head varus deformities, and abnormal shoulder function [3, 4]. Treatment approaches that achieve secure internal fixation while mitigating the likelihood of postoperative complications are urgently needed. However, despite the fact that treatment of proximal humerus fractures with medial column defects is a “hot topic” in the field of osteopathic medicine, there are no standard treatments for this condition [5, 6]. Although treatments that combine locking plates with medial support screws have achieved satisfactory results, the effective treatment of comminuted metaphyseal fractures remains a challenge. We examined the therapeutic effects of various combinations of lateral and posterior plates and medial column support screws for treating proximal humerus fractures order to provide a clinical treatment reference.

Methods

Operative materials and pathway

The hospital ethics committee approved all study-related procedures. We used 18 synthetic left human humerus bones (SAWBONES; Pacific Research Labs) with specially created structural defects [7] (Figure

1A, 1B). All proximal humerus fractures were fixed using six sets of locking plates and matching screws (Depuy Synthes). The 18 bones were randomly divided among three groups, resulting in three groups of six bones each. Then, we created a comminuted (two-part) fracture model of the humerus surgical neck for each bone. All the specimens were taken from the humeral heads and cut while preserving 220 mm. We established a horizontal line 10 mm below the humerus surgical neck and used a Stryker oscillating saw (saw blade thickness 1 mm) to cut the bone along this line. The saw was able to cut through the entire cortex, creating a greater tuberosity osteotomy along the 50° humerus coronal oblique line.

The medial cortical defect model was completed according to the Sanders method, as follows. An osteotomy was created 5 mm parallel to the distal end of the fracture line. We preserved the 1/3-peripheral cortex of the lateral greater tuberosity of the proximal humerus for plate fixation. The plate was placed on the lateral side of the humerus. The upper end was 8-10 mm from the apex of the greater tuberosity, and the medial side was 5 mm from the outer side of the intertubercular groove. The posterior plate was placed at the junction of the posterior metaphysis and the humeral surgical neck.

Group A bones underwent fixation using a Proximal Humerus Internal Locking System (PHILOS) plate support alone (Figure 1C, 1D). Group B bones were fixed using a PHILOS plate and posterior plate, but without medial column support screws (Figure 1E, 1F). Group C specimens were fixed using a PHILOS plate, a posterior plate, and medial column support screws (Figure 1G, 1H). A 20 cm long distal humerus specimen was resected 15 cm from the fracture line. The distal clamp of the specimen was fixed and embedded at a depth of 12 cm within denture base resin.

Axial compression test

The top of the humeral head of each bone was subjected to vertical and vertical-downward pressures [8]. Each test was completed in triplicate using a preload of 50 N, a loading speed of 5 mm/min, and a maximum displacement of 1 mm. After each test we recorded the maximum load and created a load curve by recording the test data and calculating the compressive stiffness. The average value of the maximum load and compressive stiffness was also calculated.

Anti-twist test

We used a biomechanical tensile torsion test fixture with evenly distributed clamps and two circular holes that were 8 mm in diameter [9]. Eight semi-threads that were 5.7 cm long and had a diameter of 8 mm were used with universal friction bolts that were passed through the circular holes to fix each humerus head. Each test was completed in triplicate using a preload of 0 N•m, a rate of 12°/min, and a maximum torsion angle of 120°. Maximum torque values were recorded after each test and used to draw the loading curve and calculate the torsional stiffness. We used average values of maximum torque and torsional stiffness.

Shear compression test

Each humerus was placed in 20° abduction to simulate upper limb support when falling. In this position, the proximal humerus receives shear weight forces which easily lead to fracture [10]. We applied vertical down-pressure on the top of the humeral head, with a preload of 50 N, a rate of 5 mm/min, and a maximum displacement of 1 mm. Each test was completed in triplicate, and we recorded the maximum load each time. Each loading curve was constructed according to load data and used to calculate compression stiffness of each bone using the average maximum load and compression stiffness values.

Model failure test

We tested the tibial position using shear compression, with a preload of 50 N and a rate of 5 mm/min [11]. The test was stopped when the bone fractured, the plate or the screw broke, and the load reached its peak value. We considered the maximum load to be the model failure load.

Fatigue test

We preloaded each bone with 50 N. According to the anatomical structure of the shoulder joint and Poppen and Walker’s method, forces are largest when a normal shoulder joint is abducted 90° under physiological conditions. We used a load of 600 N, a frequency of 1 Hz, and 10,000 loading repetitions and compared displacement size before and after loading.

Resistance strain gauge test

Four strain gauges were placed on the medial and lateral sides of the proximal and distal ends of the fracture. We then completed the axial compression test, torsion test, shear compression test, and fatigue test. We recorded the maximum strain observed during the axial compression test (displacement 1 mm), the torsion test (torsion angle 5°), the shear compression test, and the fatigue test (where 600 N loads were applied 10,000 times). We additionally recorded changes in maximum strain associated with 1 mm displacements.

Computer-based three-dimensional finite element analysis

After providing written informed consent, the first author of this study (age 28 years, height 174 cm, and body mass 70 kg) underwent an x-ray examination to exclude shoulder joint lesions and injuries, and a shoulder joint CT scan. Imaging data obtained by CT scan was entered into Materialise's Interactive Medical Image Control System (MIMICS) 17.0 software (Materialise, Belgium) in DICOM 3.0 format to create a three-dimensional model of a proximal humeral fracture and internal fixation. The solid geometry model was then mesh-optimized using the MIMICS 17.0 FEA software module. Cortical bone, cancellous bone, and titanium were regarded as isotropic materials. The mesh node model information was exported, and we used ANSYS (Canonsburg, PA) software to read and generate a three-dimensional finite element model for static structural analyses. The material properties included cortical bone (elastic modulus 2000 MPa, Poisson's ratio 0.3), cancellous bone (elastic modulus 100 MPa, Poisson's ratio 0.26), and the plate (elastic modulus 120,000 MPa, Poisson's ratio 0.3). For the distal end of the humerus fixed boundary conditions, we applied 600 N axial pressure to the humeral head, and the specimen was abducted by 20°. The 600 N axial load was also used to simulate shear forces on the humerus that are sustained during a typical fall. The head were combined to perform 5×N•m torsional loading and we observed the model's stress distribution characteristics under maximum physiological and experimental stressors.

Statistical analysis

The data were analysed using SPSS 19.0 statistical software (IBM Corp., Armonk, NY). Data are expressed as means ± standard deviations. We compared measures across the three groups using one-way ANOVA and the Student–Newman–Keuls (SNK) method, as appropriate. $P < 0.05$ indicated statistical significance.

Results

Axial compression test

Group C performed better than Group B, which lacked medial column support screws. Further, Group B performed better than Group A, where only a PHILOS plate support was used. These differences were statistically significant (Fig. 2A).

Biomechanical analysis of compressive stiffness revealed that Group C (dual plate with medial column support screw) performed significantly better than both Groups B (dual plate and dual plate fixation) and A (Fig. 2B).

Significant between-group differences were observed when we subjected the axial loads to FEA. Group C exhibited significantly reduced maximum displacement of the humerus compared to Group B (simple dual plate fixation), which in turn exhibited significant less displacement than Group A (single plate fixation) (Fig. 2C).

Failure Model Test

There were significant between-group differences in the failure loads of the three groups. Once again, Group C performed significantly better than Group B and both Groups C and B performed significantly better than Group A (Fig. 3A).

Discussion

As our knowledge of proximal humeral fractures increases, patient-centric clinical results become more critical, and surgical techniques more refined. Unfortunately, internal fixation of proximal humeral fractures with unstable displacements remains challenging, especially in patients with osteoporosis [12–14]. One option for treating this type of fracture involves use of a lateral locking plate; however, this method is associated with a high (49%) rate of complications and can produce deformations during healing. Medial column failure can result in inversion deformities, followed by screw penetration, plate rupture, movement restrictions, and early joint disease [15]. Therefore, medial column stability is essential for successful fixation.

Various locking plate-based methods are used to support the medial column in cases of complex humeral fractures. Past reports have indicated that use of a locking plate, in combination with bone grafting, can provide additional medial support and prevent internal flip deformities during healing [16, 17]. Use of a locking plate plus bone grafting is an effective means of treating these types of fractures; however, such techniques are technically challenging and associated with a higher risk of infection and disease transmission. Further, the materials used in this treatment are often in short supply.

Double plate fixation (involving a lateral locking plate combined with a medial support plate) has also been used to treat proximal humeral fractures. The double plate system can prevent deformities during healing as well as collapse of the humeral neck-axis secondary to severe compression [18, 19]. However, only a few patients have undergone this procedure, and its biomechanical properties remain poorly studied.

The locking plate combined with bone grafting provides direct double-column support and partial torsional stability without direct medial fixation, while the double plate system provides direct lateral fixation plus indirect medial support [20, 21]. Our results indicated that use of a fixing method in combination with a medial support provided more effective double-column support and anti-rotational stability, and better fixation of complex fractures. These findings stand in contrast to past investigations which compared surgical and non-surgical treatments of Neer class 3 or 4 partial fractures and found no significant differences in treatment outcomes between the two methods. Other studies showed that there were no differences between locking plate and semi-joint osteoplasties [22, 23].

When fixing complex fractures, bone cement should be used to fix large humeral nodules and medial wall defects, followed by bone grafts and screws to strengthen fixation. Extroverted insertion fractures have a much better prognosis than three- and four-part fractures so, in patients with these types of complex fractures, medial supports are particularly important. A randomised study comparing complex fractures treated with and without the use of medial support screws found a significant decrease in the surgical failure rate in the medial support screw group (3.4% vs. 23.1%)[24].

Conclusions

The results showed that when the locking plate was used to treat proximal humeral fractures, use of a lateral plate with the medial column support screws resulted in better biomechanical stability than the traditional single plate in cases where the bone cortex did not support the proximal humerus. The combination of PHILOS plate fixation with medial column support screws and a posterior locking plate produced markedly better fixation than that produced by simple dual plates. Consequently, we recommend combined use of the PHILOS plate with medial column support screws and a posterior locking plate for treating patients with proximal humeral fractures and medial column defects.

Declarations

List of abbreviations

PHILOS: Proximal Humerus Internal Locking System; MIMICS: Materialise's Interactive Medical Image Control System;

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Availability of data and materials

All data generated or analysed during this study are included in this published article.

Author’s contributions

Xinlong Ma and Yakui Zhang designed the research. Xuedong Zhang, Yuechao Dou and Xuefei Wang conducted the research. Bin Lu performed the statistical analysis. Xuedong Zhang and Jianxiong Ma wrote the paper. All authors read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Consent for publication

Written informed consent was obtained from all authors.

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Figures

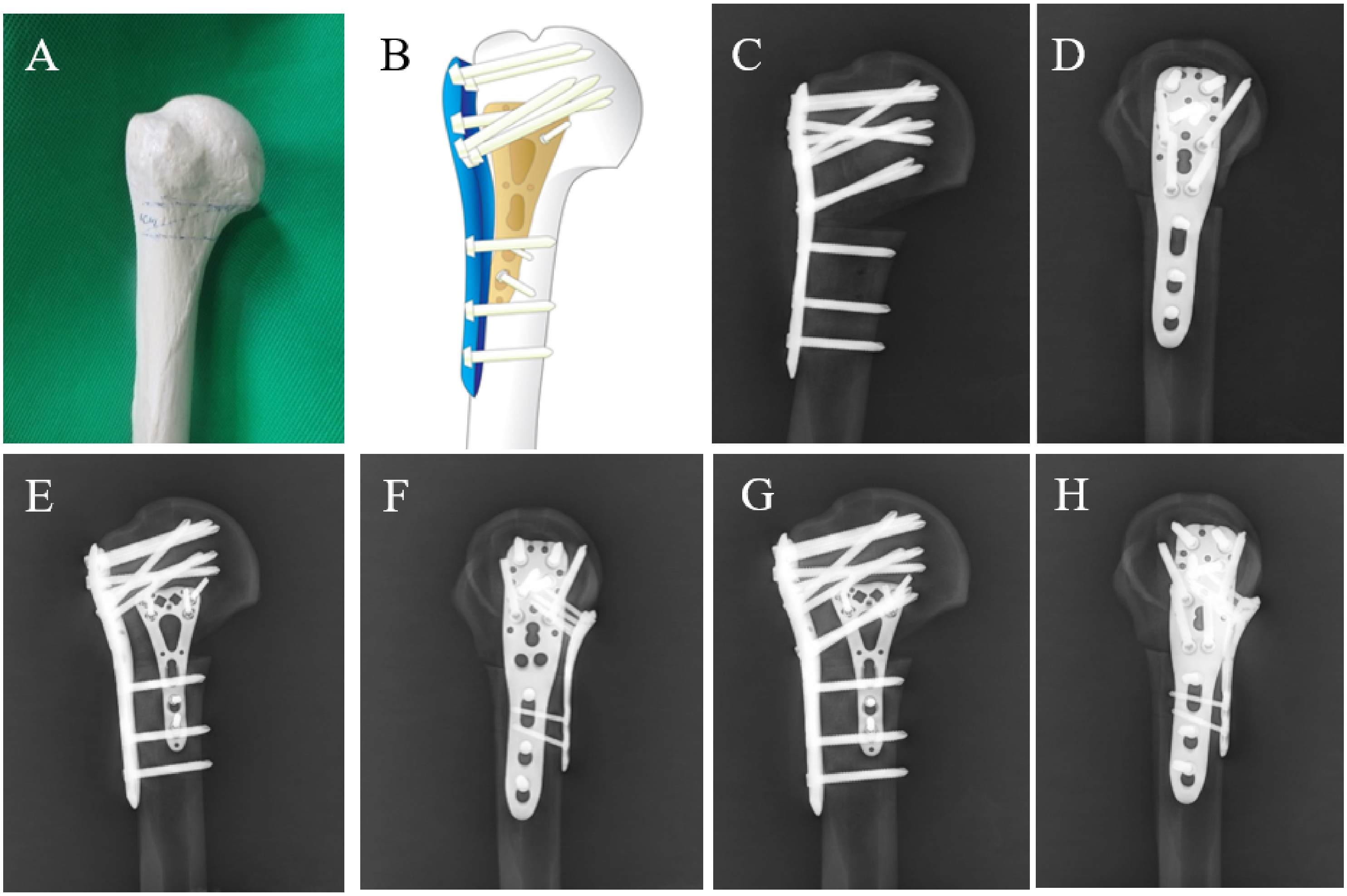

Figure 1

Three different methods of internal fixation. A: left humerus (SAWBONES); B: depiction of the PHILOS plate and posterior plate; C, D: x-ray of a single PHILOS plate fixation in Group A; E, F: x-ray of the PHILOS plate without a medial side column support and a posterior plate in Group B; G, H: x-ray of the PHILOS plate with medial column support screws and a posterior plate in Group C.

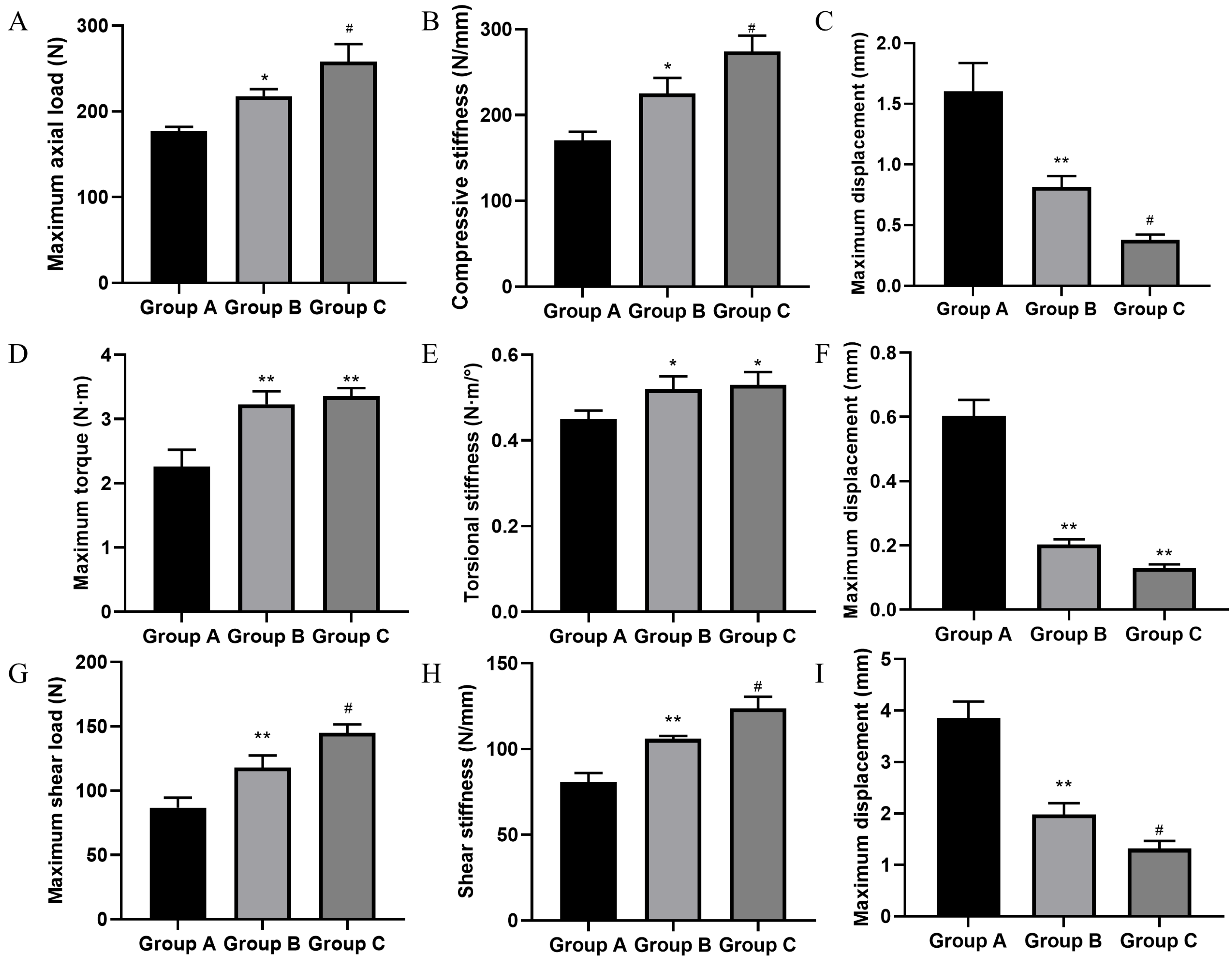

Figure 2

Biomechanical analysis in vitro and finite element analysis. A-C, Axial compression test analysis in vitro (A, B) and finite element analysis (C); D-F, Anti-twist test analysis in vitro (D, E) and finite element analysis (F); G-H, Shear compression test analysis in vitro (G, H) and finite element analysis (I). *P<0.05, **P<0.01, Group B compared with Group A; #P<0.05, ##P<0.01, Group C compared with Group B

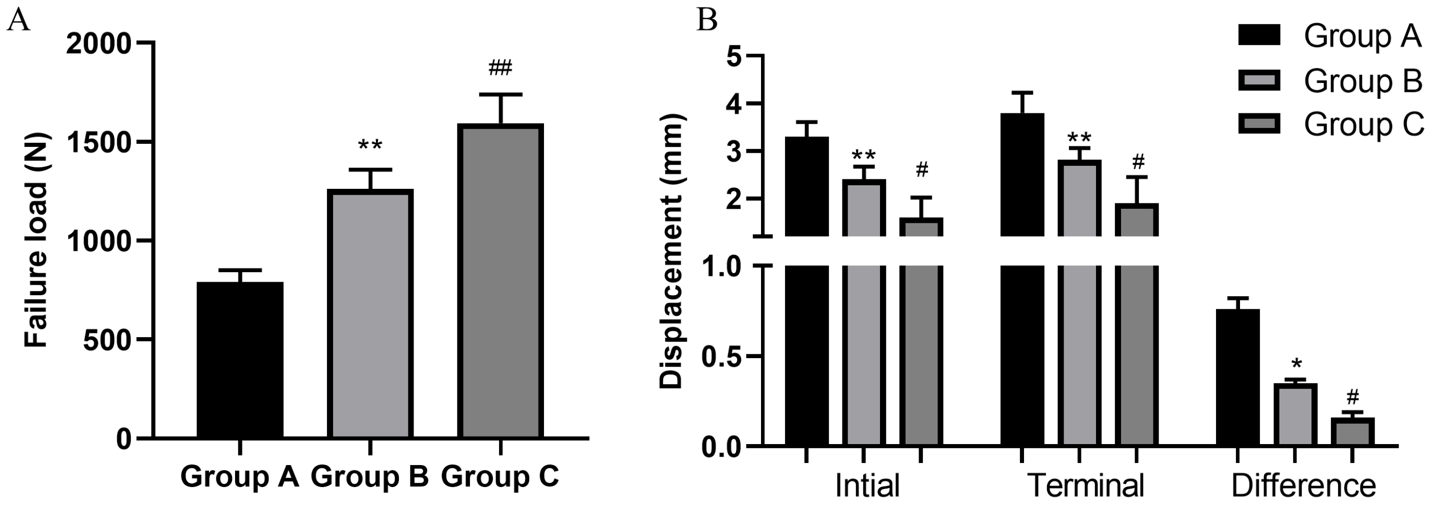

Figure 3

Failure model and fatigue test in vitro. A, Failure test analysis in vitro; B, Fatigue test analysis in vitro. *P<0.05, **P<0.01, Group B compared with Group A; #P<0.05, ##P<0.01, Group C compared with Group B

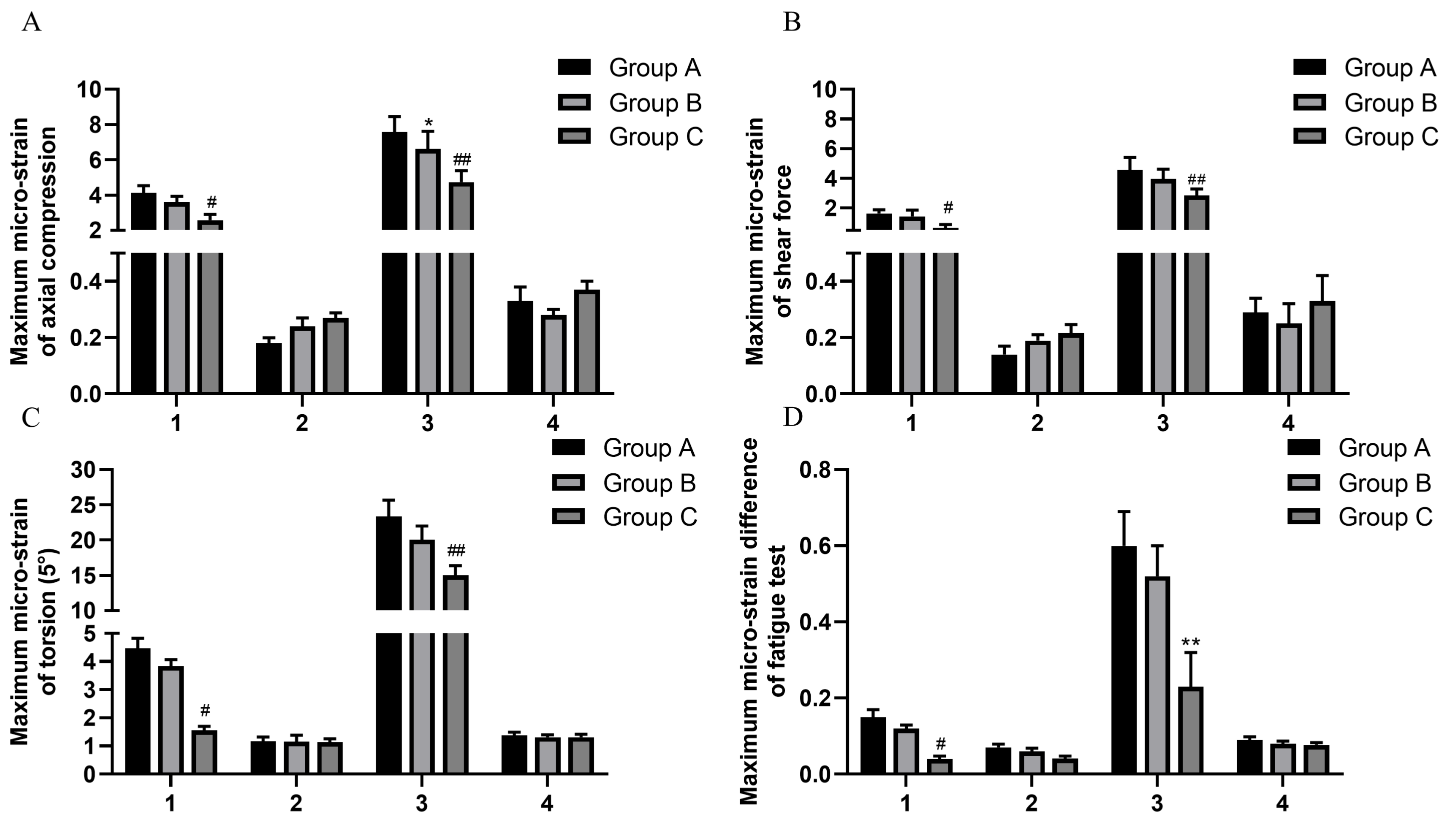

Figure 4

Resistance strain gauge test analysis in vitro. A, Maximum micro-strain of axial compression; B, Maximum micro-strain of shear force; C, Maximum micro-strain of torsion; D, Maximum micro-strain difference during the fatigue test. *P<0.05, **P<0.01, group B compared with group A; #P<0.05, ##P<0.01, group C compared with group B