Submitted: 19 August, 2024 Accepted: 26 September, 2024 Published: 03 September, 2024 DOI:10.22514/jocpd.2025.100

Journal of Clinical Pediatric Dentistry

ORIGINAL RESEARCH

# Comparison of biomechanics and clinical validation of torsion and swing tooth extraction methods

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## Abstract

**Background**: Adolescents often require extractions of premolar teeth with single flat or curved roots for orthodontic treatment of malocclusions. The torsion method is typically considered unsuitable for these teeth due to the risk of root fractures. However, clinical experience suggests that moderate torsion can safely and efficiently dislocate these teeth, particularly in younger patients with developing dental structures. Despite the widespread use of torsion and swing methods, comparative studies on their biomechanics and efficacy are lacking. **Methods**: Three-dimensional finite element analysis was used to compare biomechanical behaviors of the tooth-PDL (periodontal ligament)-alveolar bone complex during torsion and swinging loading. Clinical trials focused on the symmetrical extraction of premolar teeth required for orthodontic treatment in adolescents, comparing the two methods in terms of extraction time, alveolar socket expansion, surgical difficulty and patient satisfaction. **Results**: The torsion method exerted less stress on the single-rooted tooth and surrounding alveolar bone, proving superior to the swinging method in tearing the PDL. Clinical validation showed that the torsion method significantly reduced extraction time (averaging 12.10 $\pm$ 5.36 s, $p <$ 0.001), buccolingual expansion of the alveolar socket (0.53 $\pm$ 0.20 mm, $p < 0.001$), and volume expansion of the alveolar socket (1.22 $\pm$ 0.05 mm$^3$, $p < 0.001$). It also resulted in lower surgical difficulty and great postoperative patient evaluations. **Conclusions**: Both methods resulted in safe extraction, but the torsion method proved more advantageous by reducing the risk of root fracture, preserving the alveolar socket, and improving extraction efficiency. **Clinical Trial registration**: ChiCTR2400086715.

## Keywords

Tooth extraction; Biomechanics; Tooth socket; Oral surgery; Minimally invasive; Finite element analysis

## 1. Introduction

Irreparable dental problems resulting from various conditions, such as malocclusion and severe periodontitis, often necessitate extraction of the affected teeth [1, 2]. Premolar teeth, which usually have flat or curved roots, are often extracted in orthodontic treatment of adolescent malocclusion. Removing them completely and as minimally invasively as possible is crucial. Advances in precision medicine and minimally invasive principles [3] have made teeth extractions safer and more efficient. Proper force application during extraction can lead to minimal trauma to periodontal tissues, reduced procedure duration, improved patient experience, and fewer complications. Despite relatively simple extractions, such as removing a premolar for orthodontic treatment, careful handling is necessary to prevent alveolar bone or surrounding tissue damage [4, 5]. Preserving the alveolar bone is vital for subsequent tooth movement [6, 7] and soft tissue restoration [8, 9]. Dental forceps are commonly used for extraction through the torsion and swinging methods. In the swinging method, buccolingual movement dislocates the tooth, exerting pressure on the buccolingual alveolar bone wall and tearing the periodontal ligament (PDL). The twisting method *involves* repeatedly rotating the tooth around its long axis, which expands the alveolar socket and tears the PDL.

The torsion method is often deemed inappropriate for extracting single flat-rooted and curved-rooted teeth due to the risk of root fractures from improper twisting angles [10]. However, clinical experience with single-rooted teeth indicates that moderate torsion can facilitate efficient and safe dislocation. While both torsion and swing methods are widely used, comparative studies are lacking in regard to their biomechanical behavior and clinical effectiveness. It is possible for oral surgeons to choose the most efficient and minimally invasive extraction techniques by understanding these biomechanical responses, thereby reducing surgical trauma to periodontal tissues and establishing a scientific basis for dental education and extraction advancements.


  

This study investigated the biomechanical behavior and clinical efficacy of torsion versus swing methods for extracting single-rooted teeth. Through three-dimensional finite element analysis, we analyzed stress magnitudes and distributions in the tooth-PDL-alveolar bone complex during loading of representative single-rooted teeth. As well as symmetrical extractions of premolar teeth required for orthodontic treatment, clinical trials were conducted to examine extraction time, degree of alveolar socket expansion, surgical difficulty and patient satisfaction with both methods. Using biomechanical analysis and clinical efficacy, we provide strategies to optimize these extraction techniques. This study aimed to guide clinicians in selecting effective and minimally invasive extraction methods, enhancing treatment outcomes, and improving patient experience in adolescent dental care.

## 2. Materials and methods

The design of the theoretical analysis and clinical trial is illustrated in Fig. 1. The twisting process *involves* a rotational movement of the tooth along its long axis, while the swinging process entails buccolingual/palatal movement.

### 2.1 Establishment of the basic model

A 22-year-old female with healthy periodontal tissue, no impacted opsigenes, no extra teeth, and an intact and regular dentition were selected for this study. Cone Beam Computed Tomography (CBCT, KAVO, Biberach, BW, Germany, 120 kVp, 5 mA, 0.3 mm) was performed. Mimics (21.0, Materialise, Leuven, Belgium) and Geomagic Wrap (2017, 3D System, Santa Clara, CA, USA) were used to create individual three-dimensional solid models for the maxilla, mandible, and U1 (upper jaw incisor), L1 (lower jaw incisor), U3 (upper jaw canine), and U4 (upper jaw premolar) respectively. U1 and L1 represent single-round and single-flat-rooted teeth. U3 and U4 with an apical 1/3 curvature of 15° (Modeling through Unigraphics NX, 10.0, Siemens PLM Software, Munich, FB, Germany) represent single-round and single-flat-curved rooted teeth. SolidWorks (2017, Dassault Systemes, Paris, France) was employed to create PDL models with a thickness of 0.25 mm [11, 12] and Type II bone with a 1.5 mm thick external layer of cortical bone and an internal layer of trabecular bone [13, 14]. A geometric model was created by assembling the teeth, PDL, maxilla, and mandible separately without interference (Fig. 2A). To assign material properties through parameters, Ansys Workbench (19.0, Ansys, Canonsburg, PA, USA) was imported to set the teeth-PDL and PDL-alveolar bone as a bonded contact relationship (Table 1, Ref. [13–18]). Due to irregular shape of the model, the mesh was primarily composed of hexahedrons, supplemented by tetrahedrons. After an independence test of the mesh, using the sphere centered on the tooth axis, the mesh of the alveolar bone around the teeth was further refined to 0.7 mm.

### 2.2 Loading and boundary conditions

The torsion group and swinging group models were identical, with variations in load conditions. In torsion, the central axis of the teeth was the rotation axis, as the displacement load rotated the teeth, while in swing, the force was applied vertically to the buccal area of the teeth cervix (Fig. 2B). During torsion loading, the sub-step settings were set to ensure that the change in time and the torsion angle corresponded linearly in the

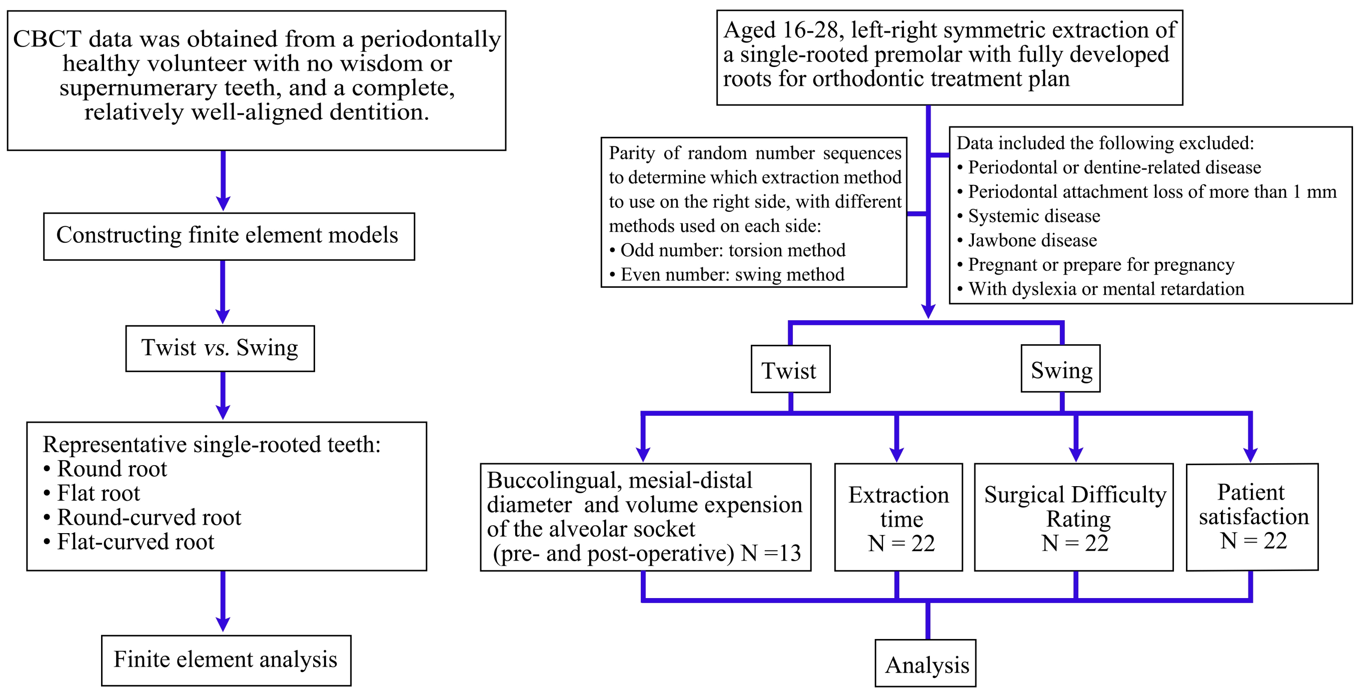


**FIGURE 1. Flow chart.** This flow chart outlines the design of the biomechanical analysis and the eligibility criteria, grouping, intervention, and indicators for the clinical validation part. We first analyzed the differences in biomechanical behavior between the torsion and swing methods using 3D modeling and finite element analysis, followed by clinical trials to further compare their effectiveness. CBCT: Cone Beam Computed Tomography.

**TABLE 1. Materials properties of the finite element model.**

| Material | Material model | Coefficients |
|---|---|---|
| Cortical bone [13, 15, 17] | Elastic | E = 13,700 MPa, ν = 0.26, ρ = 1400 kg/m$^3$ |
| Trabecular bone [14–16] | Elastic | E = 1370 MPa, ν = 0.30, ρ = 1400 kg/m$^3$ |
| Tooth [15, 17] | Elastic | E = 19,600 MPa, ν = 0.30, ρ = 2200 kg/m$^3$ |
| Periodontal ligament [17, 18] | Elastic | E = 0.667 MPa, ν = 0.45, ρ = 1100 kg/m$^3$ |

*Note: E: Elastic modulus; ν: Poisson's ratio; ρ: density.*

analysis process. Therefore, at any point in the torsion process, the stress value of the corresponding angle could be obtained.

During loading, the upper area of the maxillary model was fixed, and the mandible model was fixed from the surface of the condyle on one side along the ascending mandibular branch, the inferior border of the mandible, and the ascending mandibular branch of the contralateral side to the surface of the contralateral condyle to ensure that the jaws were stationary during tooth torsion (Fig. 2C).

PDLs were assumed to be totally torn when their minimum von Mises stress exceeded 0.026 MPa [14, 19, 20]. Meanwhile, we monitored the principal stresses in the tooth root area to ensure they did not exceed the ultimate tensile strength ($\sigma_{max}$) of 52.9 MPa and the ultimate compressive strength ($\sigma_{min}$) of 260 MPa [13, 19, 21, 22], respectively. Having met these conditions indicated a successful dislocation.

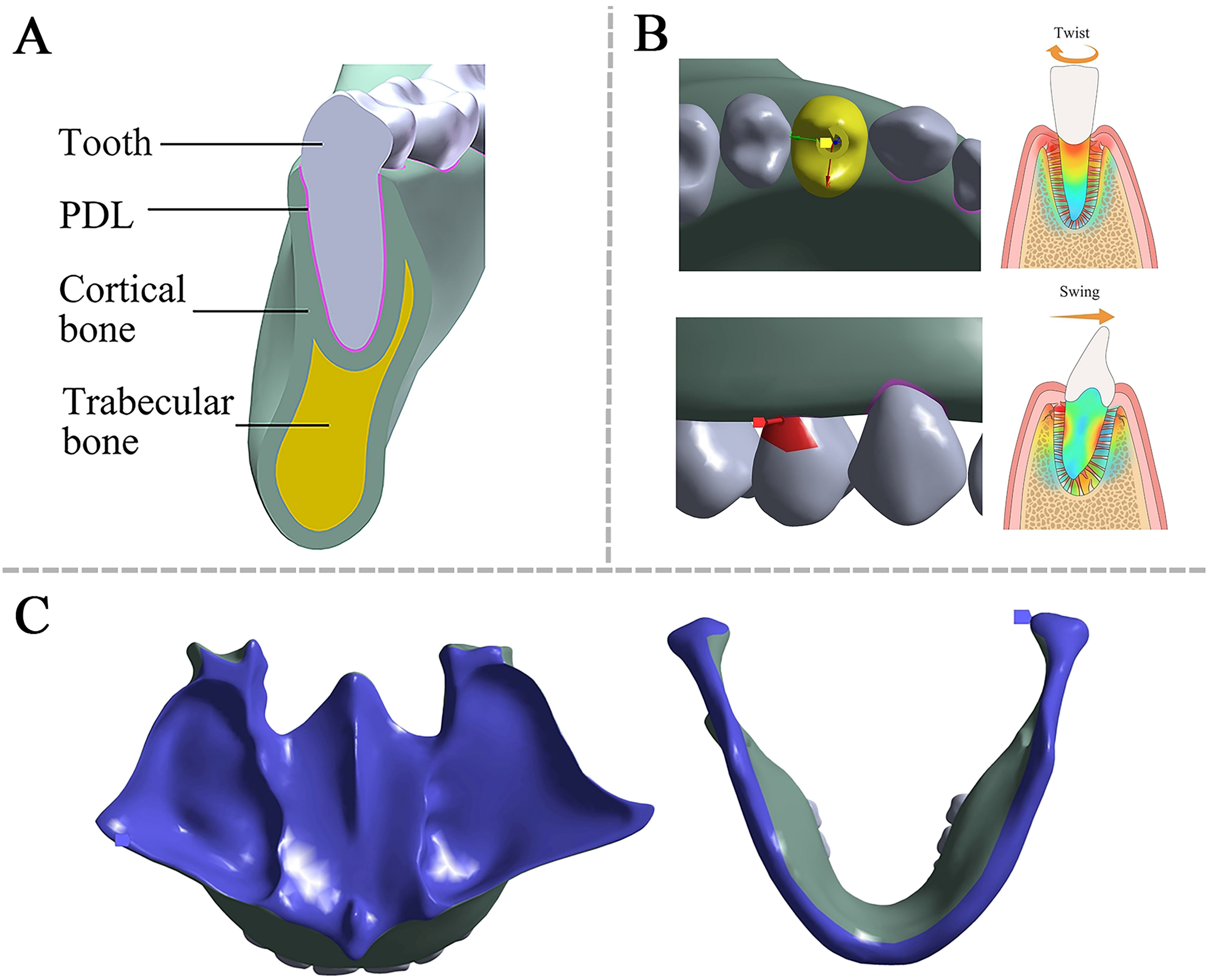


**FIGURE 2. Finite element model construction and conditions.** (A) The structure of the model, includes teeth, periodontal ligament, cortical and trabecular bone. (B) Schematic diagram of torsion and swing method. In torsion, the central axis of the teeth was the rotation axis, as the displacement load rotated the teeth, while in swing, the force was applied vertically to the buccal area of the teeth cervix. (C) Boundary conditions (blue region) which keep the jaws stationary during loading. PDL: periodontal ligament.

## 2.3 Sample size calculation

An own-pair design was used, with a Type I error (two-tailed) at 0.05 and a power ($1 - \beta$) of 0.9. 22 cases were included in this study (Lanzhou University Stomatology Hospital, Lanzhou, China, from 13 June to 13 July 2024), of which 13 consented to undergo postoperative CBCT scans to evaluate changes in preoperative and postoperative alveolar socket volume, as well as changes in buccolingual diameter of the top of the alveolar socket and mesial and distal diameters. An analysis of all patients was conducted to determine extraction time, surgeon-rated surgical difficulty, and patient satisfaction.

## 2.4 Eligibility criteria

This study enrolled 16–28-year-old patients who needed left-right symmetric extraction of a single-rooted premolar with fully developed roots for orthodontic treatment planning. Exclusion criteria were: (1) Affected teeth with any periodontal or dentine-related diseases (caries or apical periodontitis); (2) Periodontal attachment loss of more than 1 mm; (3) Patients with systemic diseases such as diabetes mellitus, hematologic disorders, or abnormal liver or kidney function; (4) Patients with jawbone disease or abnormal bone development; (5) Patients who are pregnant or preparing for pregnancy; (6) Patients taking medications that could affect study results; and (7) Patients who are dyslexic or mentally retarded and have difficulty understanding, reading, and signing the informed consent form.

## 2.5 Recruitment

Study participants were screened in advance. Upon reading, understanding, and signing the informed consent form, participants were informed about the study's goals, expected benefits, and possible risks.

An experienced physician with at least 10 years of clinical experience in alveolar surgery was randomly selected as the operator for this study. A clear understanding of the possible risks was provided to the operator before the surgical procedure. Data collection and analysis were not performed by the operator.

## 2.6 Randomization and blinding

To determine which extraction method would be used on the patient's right side, the operator used the parity of a computer-generated randomized sequence of numbers, generated in advance by members not *involved* in the clinical trial. Observed in both the left and right sides, odd numbers indicate the torsion method (group) and even numbers indicate the swing method (group). Patient was blinded to the extraction method used.

## 2.7 Data collection

(A) Preoperative and postoperative images were captures using CBCT (device information). Measurements of root width (mesial and distal diameters of the tooth cervix), root thickness (buccolingual diameter of the tooth cervix), root length (intrabony vertical distance from the cervical region to the apex), apical curvature angle (intersection of the apical 1/3 with the long axis of the tooth), alveolar socket volume, buccolingual diameter of the top of the alveolar socket, and mesial and distal diameters were conducted by three blinded examiners using repeated measurements with ImageJ (1.54f, National Institutes of Health, Bethesda, MD, USA), ensuring an intraclass correlation coefficient $>0.9$. We maximized agreement between measurements by using the same global image angle and repeatable anatomical landmarks.

(B) Another blinded examiner measured the extraction time from the time the operator placed the forceps on the tooth to when the tooth fully dislocated from the alveolar socket.

(C) The operator rated procedure difficulty according to the extraction procedure on both the right and left sides of the tooth as follows: (1) Easy, (2) Normal, (3) Hard (4) Very Hard.

(D) Patient satisfaction was collected by asking patients to rate their experiences with both the right and left sides of the extraction procedure as follows: (1) Poor, (2) Fair, (3) Good and (4) Excellent.

## 2.8 Statistical analyses

All variables were analyzed using descriptive statistics. Continuous variables such as root width-to-thickness ratio, root length, apical curvature angle, extraction time, and volume expansion ratio of alveolar socket based on pre- and post-operative information were presented as mean $\pm$ standard deviation and analyzed using the paired $t$-tests. Categorical variables such as root fracture, procedure difficulty, and patient satisfaction were presented as frequencies and percentages and analyzed using the paired Chi-Square Test. Data analysis was performed using GraphPad Prism (Prism10, GraphPad Software, Boston, MA, USA), with $p < 0.05$ indicates statistically significant differences.

# 3. Results

We selected 4 representative single-rooted teeth, each with a round root, round-curved root, flat root and flat-curved root for a comparative analysis of the torsion and swinging methods.

## 3.1 Tooth

For all representative teeth, stress concentrated at the tooth cervix and gradually decreased towards the root apex during torsion. In contrast, with the swinging method, stress concentration shifted downward, concentrating in the middle of the root and covering a wider range (Figs. 3,4). The maximum ($\sigma_{max}$) and minimum principal stresses ($\sigma_{min}$) on all teeth were lower during torsion than during swinging, with the differences being significant. As an example, $\sigma_{max}$ on tooth L1 during torsion loading was 6.09 MPa, whereas it reached 35.75 MPa with the swinging method (Fig. 5A,B).

## 3.2 Alveolar bone

A torsion method produced relatively uniform and less intense stress conditions the alveolar socket's inner wall. The swinging method, however, produced substantial stress concentrations and higher levels of stress at the buccal–lingual alveolar crest (Fig. 2). For example, the $\sigma_{max}$ on the alveolar bone of L1 was

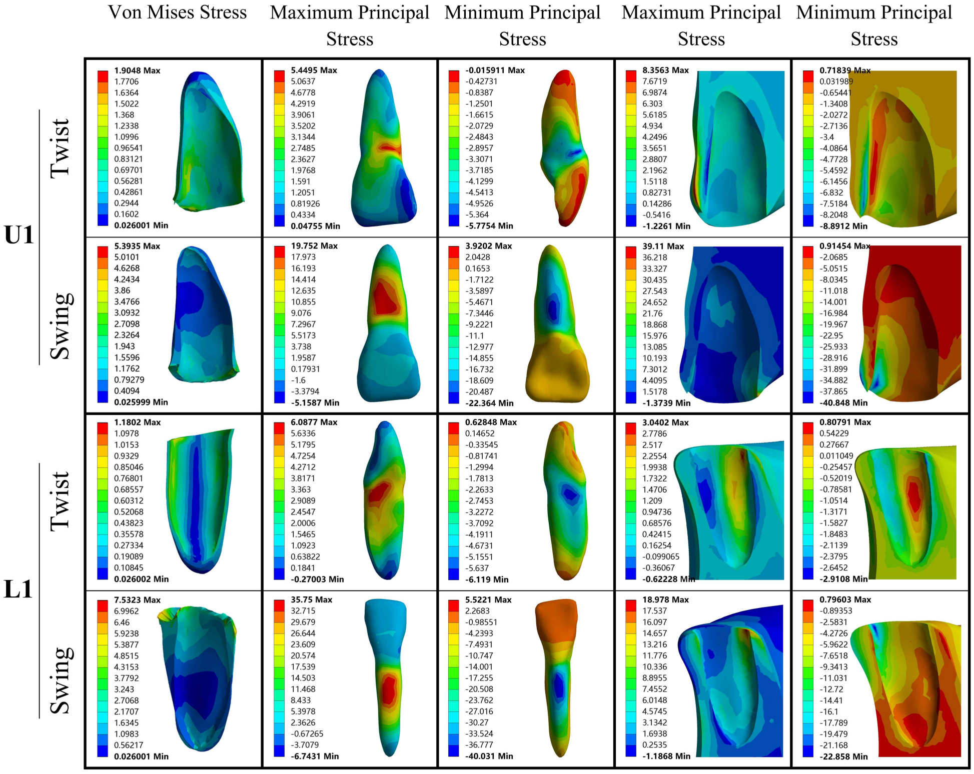


**FIGURE 3. Stress distribution in U1 and L1.** The figure illustrates the difference in stress distribution between the torsion and swing methods on the U1 and L1 tooth-PDL-alveolar bone complex. U1: upper jaw incisor; L1: lower jaw incisor; Max: maximum; Min: minimum.

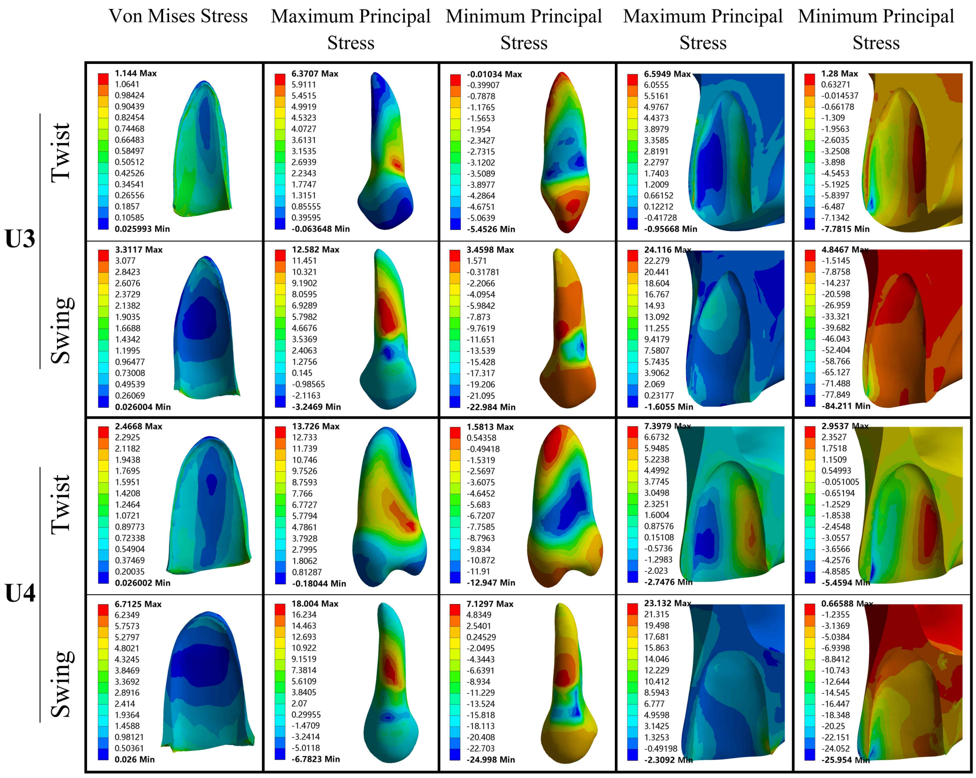


**FIGURE 4. Stress distribution in U3 and U4.** The figure illustrates the difference in stress distribution between the torsion and swing methods on the U3 and U4 tooth-PDL-alveolar bone complex. U3: upper jaw canine; U4: upper jaw premolar; Max: maximum; Min: minimum.

3.04 MPa during torsion loading, whereas it reached 18.978 MPa during swinging loading (Fig. 5C,D).

### 3.3 PDL

During torsion on single round-rooted teeth (U1, U3), von Mises stress in the PDL was primarily concentrated at the tooth cervix, decreasing toward the root apex. Swinging, on the other hand, exhibited stress concentration at the tooth cervix but maintained slightly higher stress levels near the root apex. Most PDL in the mid-root region experienced lower stress levels. Single flat-rooted teeth (U4, L1) with a narrow root width and surface depressions on the mesial and distal surfaces showed different stress distributions during torsion. A smaller stress was resulting from a more localized stress around the depressions and closer to the axis of rotation (Fig. 6).

### 3.4 PDL deformation

Total deformation refers to the displacement of a structure when subjected to a load. Even though swinging led to greater maximum tooth deformations, this deformation was mainly confined to the cervical and apical regions, with minimal deformations occurring in the mid-root area. By contrast, the torsion method induced a more uniform deformation across the tooth, progressively decreasing from the cervical to the apical region. Accordingly, the torsion method may be more effective at achieving a broader range of PDL tears (Fig. 4).

### 3.5 Clinical premolar extraction

22 cases were included in this study, of which 13 consented to undergo postoperative CBCT. There were no significant differences in root length, root width-to-thickness ratio, and root apical curvature between both groups. Statistically significant differences were observed in extraction time (Fig. 7A) and procedure difficulty. Despite torsion having no statistically significant difference in mesial-distal expansion of alveolar socket (Fig. 7B), buccolingual and volume expansion are statistically significantly less than swinging method (Fig. 7C,D). Furthermore, patients were relatively satisfied with both methods, with no statistical difference. Root fractures were not observed in any cases (Table 2).

## 4. Discussion

In previous studies on tooth extraction, researchers have primarily focused on measuring extraction forces in animal or human samples [23, 24], repairing post-extraction defects [25, 26], and developing new extraction devices [27, 28]. However, there is a lack of biomechanical analysis of the extraction process using traditional dental forceps. A deeper understanding

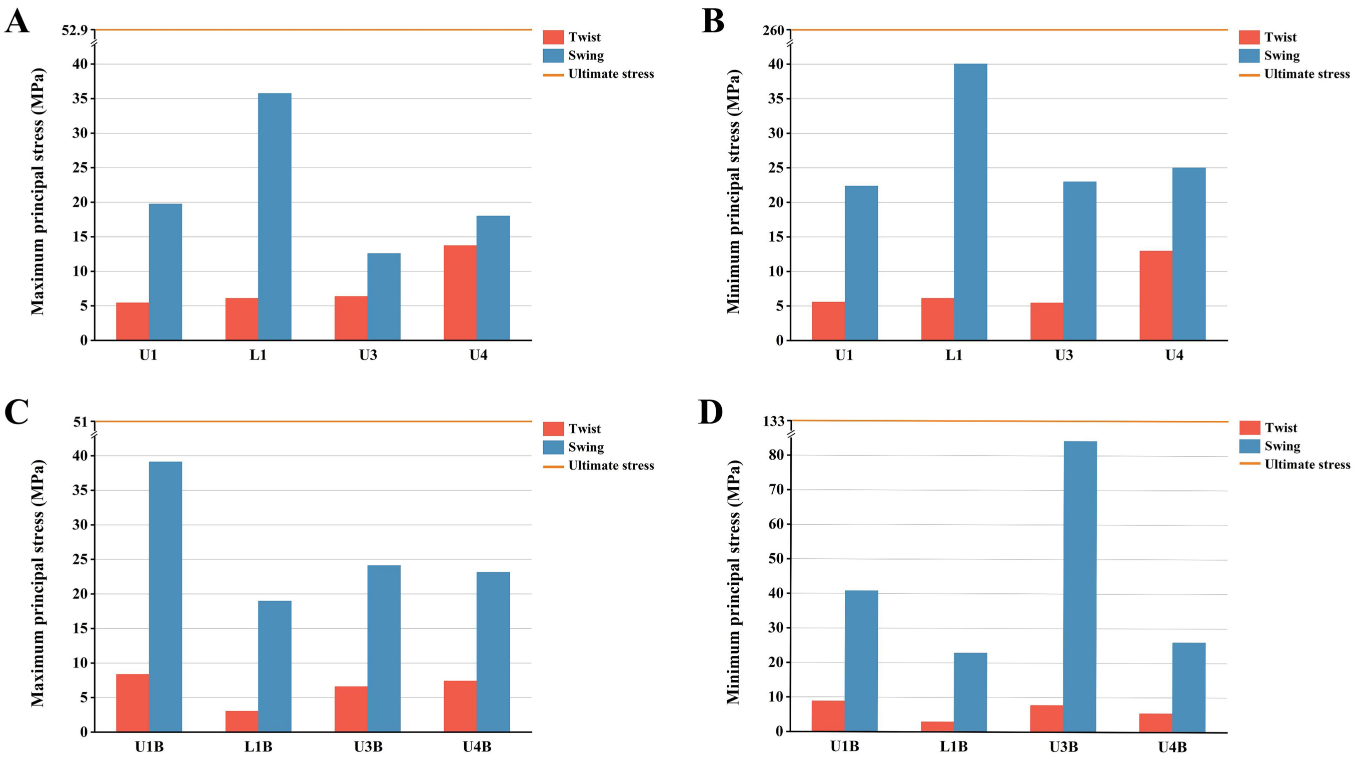


**FIGURE 5. Quantification of principal stresses.** (A) Comparative the maximum principal stresses on representative teeth. The torsion method generates lower maximum principal stress on the tooth when the PDL is completely torn. (B) Comparative the minimum principal stresses on representative teeth. The torsion method generates lower minimum principal stress on the tooth when the PDL is completely torn. (C) Comparative the maximum principal stresses on alveolar bone. The torsion method generates lower maximum principal stress on the alveolar bone when the PDL is completely torn. (D) Comparative the minimum principal stresses on alveolar bone. The torsion method generates lower minimum principal stress on the alveolar bone when the PDL is completely torn. U1: upper jaw incisor; L1: lower jaw incisor; U3: upper jaw canine; U4: upper jaw premolar.

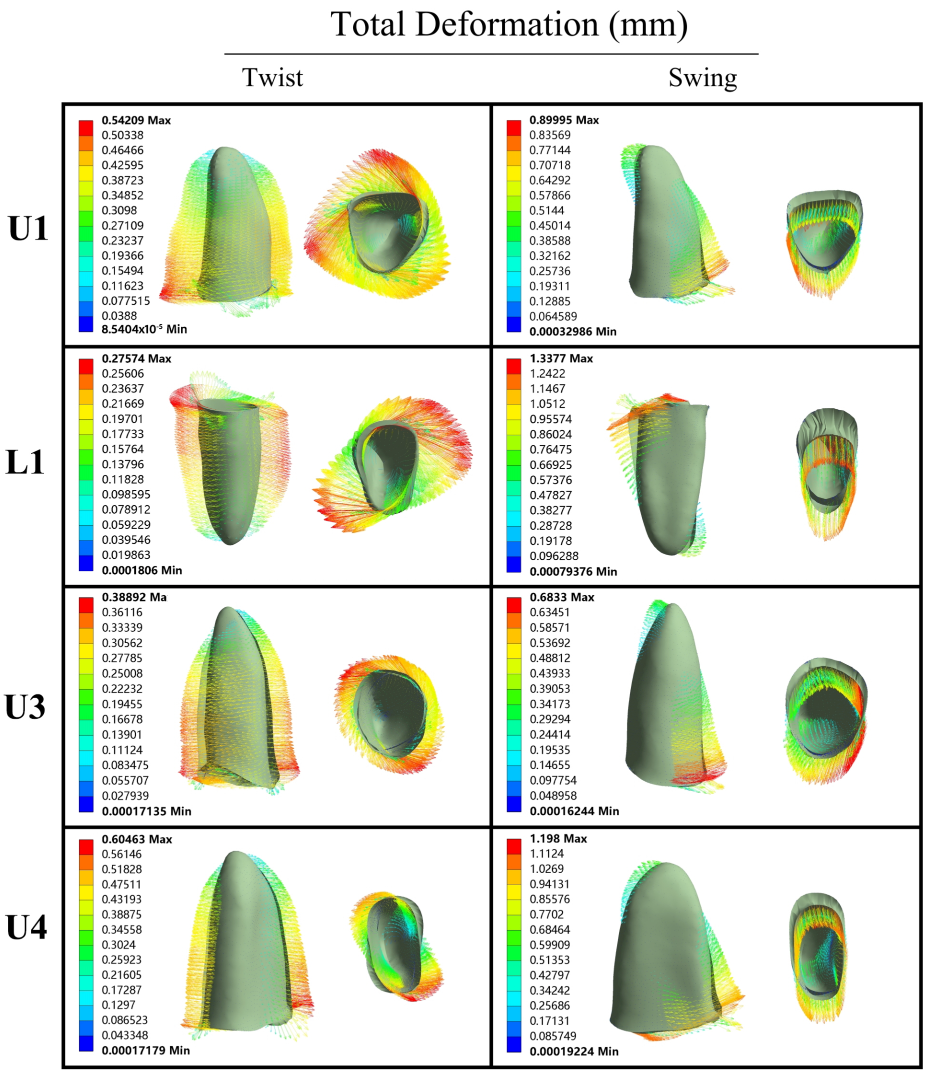


**FIGURE 6. Total deformation in the periodontal ligament.** The total deformation of the PDL was more uniform during torsional loading, while the swing method caused deformation primarily at the cervical and apex regions of the PDL. U1: upper jaw incisor; L1: lower jaw incisor; U3: upper jaw canine; U4: upper jaw premolar; Max: maximum; Min: minimum.

of the biomechanical behavior during force application can enhance precision in tooth extractions, making the procedure less invasive, while also offering insights for the development of improved extraction tools.

This study compared torsion and swinging methods of removing single round and flat-rooted teeth through biomechanical and clinical trials. Swing method dislocates the tooth by generating alternating tensile and compressive stresses between the root and alveolar bone, loosening the PDL [29]. Torsion, on the other hand, rotates the tooth along its long axis, effectively destroying the PDL through shear forces [30]. The study found that both methods were safe for extraction of flat, curved and round roots, with the main difference stress concentration and magnitude. A wider area and a greater value were observed with the swing method compared to the torsion method, where stress concentrations shifted from the cervical region to the middle of the root. The gradual narrowing of the tooth root from the cervical to the apical part reduces its ability to resist external forces, exposing the progressively weaker root to higher stresses and increasing the risk of root fracture. For teeth with different anatomical features, we found that flat-rooted teeth exhibit concave surfaces on the mesial and distal sides, where stress tends to concentrate during torsion. In curved-rooted teeth, stress concentration remains at the root cervix rather than the root apex. However, further research is needed to fully understand the stress distribution in teeth with larger curvature angles. Additionally, PDL deformation occurs during swinging, but it occurs mainly in the cervical and apical regions, with less effect on the main root portion. Torsion is more efficient at tearing the PDL by rotating the root as a whole, resulting in large and uniform deformations. Soft and hard tissue healing after tooth extraction are strongly influenced by the quantity and quality of the alveolar socket bone wall [25, 31]. Destruction of the alveolar ridge height affects site-preservation surgery and complicates esthetic zone restoration [32]. Therefore, it is crucial to preserve as much

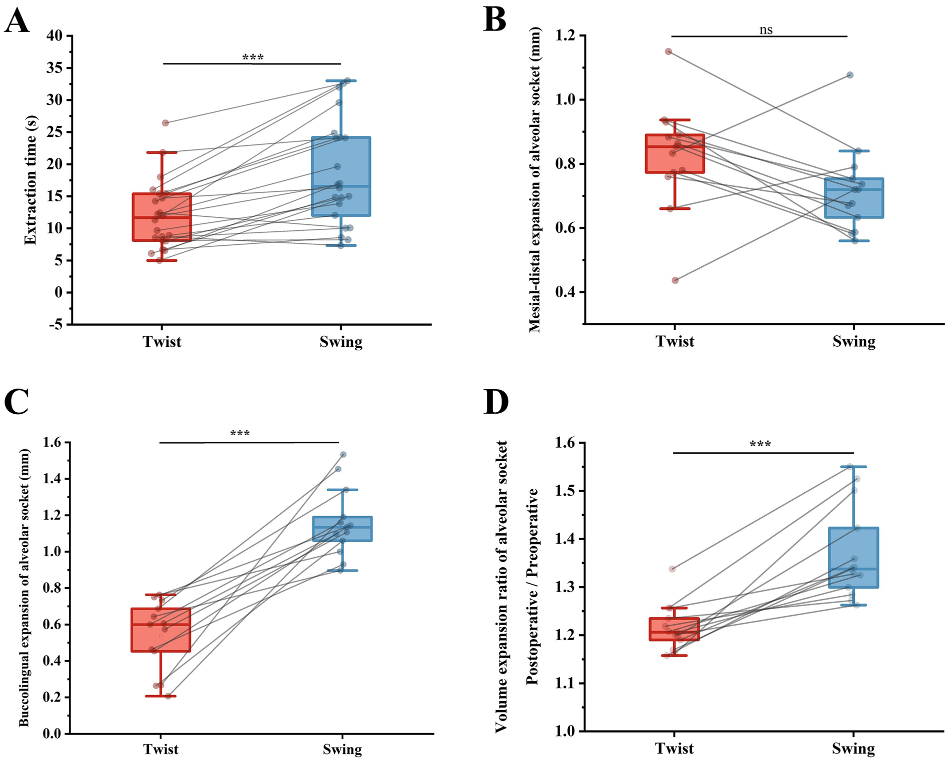


**FIGURE 7. Comparison of extraction time, mesial-distal, buccolingual and volume expansion of the alveolar socket preoperatively and postoperatively between torsion and swinging methods.** (A) Box plots depicting median time to extraction for two groups, the connecting line indicates the trend of the results of the two extraction methods in the same case. Twisting takes less time than swing method (n = 22, ***$p < 0.001$). (B) Box plots depicting median buccolingual expansion of alveolar socket, the connecting line indicates the trend of the results of the two extraction methods in the same case. Twisting takes less expansion than swing method (n = 13, ***$p < 0.001$). (C) Box plots depicting median mesial-distal expansion of alveolar socket, the connecting line indicates the trend of the results of the two extraction methods in the same case. Twisting takes more expansion than swing method (n = 13, ns: no statistical significance). (D) Box plots depicting median volume expansion of alveolar socket, the connecting line indicates the trend of the results of the two extraction methods in the same case. Twisting takes less expansion than swing method (n = 13, ***$p < 0.001$).

**TABLE 2. Comparison of two groups based on pre-and post-operative information.**

| | Group | | |
|---|---|---|---|
| Characteristic | Twist (%) | Swing (%) | *p* |
| Mean root length ± SD, mm | 11.86 ± 1.44 | 11.72 ± 1.14 | 0.723 |
| Mean root width-to-thickness ratio ± SD | 0.59 ± 0.09 | 0.58 ± 0.08 | 0.859 |
| Mean root apical curvature ± SD, ° | 16.53 ± 7.91 | 16.12 ± 8.42 | 0.867 |
| Mean buccolingual expansion of alveolar socket ± SD, mm | 0.53 ± 0.20 | 1.16 ± 0.20 | <0.001 |
| Mean mesial-distal expansion of alveolar socket ± SD, mm | 0.82 ± 0.17 | 0.72 ± 0.14 | 0.081 |
| Mean volume expansion ratio of alveolar socket ± SD | 1.22 ± 0.05 | 1.38 ± 0.10 | <0.001 |
| Mean extraction time ± SD, s | 12.10 ± 5.36 | 18.58 ± 8.27 | <0.001 |
| The difficulty of the procedure | | | |
| Easy | 18 (81.8) | 12 (45.5) | 0.031[a] |
| Normal | 4 (18.2) | 10 (54.5) | |
| Hard | 0 (0) | 0 (0) | |
| Very Hard | 0 (0) | 0 (0) | |
| Patient satisfaction | | | |
| Poor | 0 (0) | 0 (0) | 0.500[a] |
| Fair | 0 (0) | 0 (0) | |
| Good | 3 (13.6) | 5 (22.7) | |
| Excellent | 19 (86.4) | 17 (77.3) | |

[a]*Paired Chi-Square Test; others used paired t test. Statistically significant (p < 0.05). SD: Standard deviation.*

of the alveolar bone wall as possible during tooth extractions. When repeated swinging occurs, stress concentration occurs at the alveolar crest, potentially damaging the bone wall. Contrary to this, twisting ensures that the large PDL buffers and evenly disperses the extraction force, reducing the amount of stress generated in the alveolar socket, thereby reducing alveolar bone mechanical damage. As a result, the torsion method is more applicable to single-rooted teeth due to these advantages.

Moreover, clinical premolar extractions proved the feasibility of the torsion method for extraction of flat-rooted teeth. Premolar apical curvature angles varied from 4.87° to 39.85°, indicating that torsion may be applied to more curved-rooted teeth than expected. Additionally, the torsion method has advantages over the swing method in alveolar socket preservation, extraction efficiency, and procedure difficulty. Previous studies have compared different extraction methods in clinical practice and measured the extraction force. They found that the twisting method required less time on average, while the swinging method required greater force to extract the tooth, findings that are similar to our own [29, 33]. Postoperative alveolar socket morphology with the torsion method showed less overall volume expansion, particularly in buccolingual at the top. Despite greater mesial-distal expansion, the difference was not statistically significant. Thus, the torsion method better protects the alveolar socket, especially the buccolingual bone wall. Well-preserved alveolar bone is crucial for controlling tooth movement speed and direction. The integrity of the alveolar bone affects resistance to tooth movement, ensuring that orthodontic forces are effectively transmitted, allowing teeth to move as intended. An intact bone wall minimizes bone resorption post-extraction and supports effective orthodontic forces [34]. Extraction time and dentist evaluation indicate the torsion method is more efficient for extracting single-flat/curved rooted teeth, enhancing the patient experience. Maxillary premolars often have two roots. In our preliminary analysis of a double-rooted maxillary first premolar, we found that stress concentrated in the root bifurcation area, increasing the risk of root fracture. Therefore, we believed that double-rooted teeth should not be extracted using a single method. We excluded multi-rooted teeth from this study to focus on single-rooted teeth and compare the torsion and swinging methods, highlighting their biomechanical differences. Future studies will explore multi-rooted teeth and additional variables for more comprehensive insights.

Adolescent orthodontic treatment often requires extraction of affected teeth, which is why complete and minimally invasive extraction is important. This study investigated the differences in biomechanics and clinical efficacy between torsion and swinging methods of tooth extraction. However, several limitations exist. Anatomical diversity of teeth and periodontal tissues, along with variations in anatomical factors, may affect how stress is distributed. The torsion method needs to be evaluated for various anatomical structures and for the range of torsion angles suitable for diverse teeth. Further work is needed to quantify extraction forces and torsion angles accurately.

## 5. Conclusions

This study examines the biomechanical properties and clinical effectiveness of torsion and swing methods for extracting single-rooted teeth. Torsion method is superior in preserving alveolar bone integrity, reducing extraction time and stress on the tooth root. Its ability to evenly distribute stress and protect the alveolar socket makes it particularly beneficial in adolescent dental care, where maintaining bone structure is essential for future orthodontic treatment and optimal tooth movement. Despite the fact that both methods are effective, the torsion technique is significantly more efficient and has the potential to improve patient outcomes.

### ABBREVIATIONS

PDL, periodontal ligament; CBCT, cone beam computed tomography.

### AVAILABILITY OF DATA AND MATERIALS

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

### AUTHOR CONTRIBUTIONS

JWX—contributed to conception, design and drafted the manuscript. GZZ, MLS and HP—contributed to modeling and analysis. CDZ and YL—contributed to acquisition of data. KHL and ZH—contributed to interpretation of data. BPZ—contributed to critically revised the manuscript. EL—contributed to conception, design and critically revised the manuscript. All authors gave their final approval and agreed to be accountable for all aspects of the work.

### ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the Ethics Committee of Lanzhou University School of Stomatology (Approval No. LZUKQ-2024-046) and registered in the Chinese Clinical Trial Registry (ChiCTR2400086715). This study is in agreement with all relevant protocols, guidelines and resolutions. The written consent form was obtained from children and their parents.

### ACKNOWLEDGMENT

The authors would like to thank Jizeng Wang, Zhi-dong Zhang and Shi-fa Fan from Lanzhou University for their technical contributions to this study.

### FUNDING

This study was supported by Grants from the Research and Develop Program West China Hospital of Stomatology Sichuan University (LCYJ2019-20, RD-03-202102); the Natural Science Foundation of Sichuan Province (2024NSFSC1586).

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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**How to cite this article:** Jiawei Xing, Guangzeng Zhang, Mingliang Sun, Hao Pan, Congdi Zhang, Yao Liu, *et al*. Comparison of biomechanics and clinical validation of torsion and swing tooth extraction methods. Journal of Clinical Pediatric Dentistry. 2025; 49(5): 56-65. doi: 10.22514/jocpd.2025.100.