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# Biomechanical Comparison of Novel Dynamic Posterior Occipitocervical Rod and Rigid Rod in Craniocervical Junction Instability

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## Abstract

# Background Context:

Occipitocervical stabilization and fusion surgeries are the surgical treatment options for craniovertebral junction instability. Rigid occipitocervical fixation techniques can cause severe movement restrictions and complications. In the literature, motion-preserving occipitocervical fixation system has not yet been accomplished.

# Purpose

To improve functional outcomes by providing biomechanical stability with an occipitocervical dynamic rod in craniovertebral junction instability. Therefore, this study aimed to evaluate the biomechanical eligibility of occipitocervical dynamic rod.

# Study Design:

A biomechanical comparison study.

# Methods

The designed dynamic and rigid rods were compared from a biomechanical perspective using the same vertebrectomy model. Axial compression, dynamic and torsion tests were performed for biomechanical comparison with these models.

# Results

The test results also indicated that under the yield load and under static loading the new system was somewhat similar to the old one but was less stiff by comparison. The old system was found to be greatly superior to the new system especially when subjected to torsional loads. However, these torsion test results resulted from the dynamic properties of the rod system as it was expected before testing. The following results depict that our dynamic rod system has dynamic characteristics under the test conditions are useful under the test conditions.

# Conclusion

The novel dynamic rod that stabilizes the craniovertebral junction within the normal anatomical and biomechanical physiological limits and provides regional mobility is biomechanically successful.

However, these tests must be supported by controlled human studies; but this study provides the first basis for the use of dynamic rods in craniovertebral region surgeries.

# Clinical Significance:

The dynamic rod will improve functional results and quality of life in the patients required occipitocervical fixation surgery compared to standard rod.

## Introduction

The craniovertebral junction (CVJ) is a functionally stable unit comprising several bone and connective tissue structures that serve as a transition region from the skull to the spine. CVJ, the most mobile part of the spinal axis surrounded by important ligamentous structures and muscles, allows neck extension, flexion, and lateral bending and head axial rotation[1]. CVJ bone anomalies affect not only its bone structures but also the surrounding nervous and vascular system[2, 3]. In case of pathology causing CVJ instability, several surgical techniques have been applied and recommended to ensure stability from past to present[1, 4]. Nowadays, the widely used surgical treatment for patients with CVJ instability is the occipitocervical (OC) stabilization and fusion surgery[4, 5]. Neurological and functional outcomes have been significantly improved in patients with OC instability due to advancements in OC fixation techniques[4–6]. However, although current fixation techniques provide an improvement in instability, they cause serious movement restrictions in the cervical spine[7, 8]. In addition, dysphagia and dyspnea are important complications related to the instrumentation angle after the OC fusion surgery[7–10].

A dynamic rod has been designed considering the normal and pathological biomechanics of CVJ. Considering both the limitations on quality of life and complications of the OC fixation methods, the use of dynamic rods for CVJ is suggested to provide positive results in terms of long-term results. Therefore, this study aimed to evaluate the usability and applicability of the OC dynamic rod system biomechanically comparing with rigid rod system, which we designed for patients requiring OC fixation in case of instability due to CVJ pathologies.

## Materials and Methods

Ethics statement:The study’s protocol was reviewed and approved by the Institutional Review Board of Ankara University School of Medicine. It was reported that ethical approval and patient consent were not required for this in vitro study (IRB No: I6-298-19).

# Dynamic Occipitocervical Rod

The dynamic rod is used to fix the head and neck connection and to allow patients to move partially. The OC rod consists of three parts structurally: the short rod part fixed to the occipital bone, the joint part, and the long rod part fixed to the cervical region. After assembling the OC rod and turning it into a

product, the basic angle between the short and long rods is designed as 125° properly to the human anatomy

After assembling the OC rod and turning it into a product, the basic angle between the short and long rods is designed as 125° properly to the human anatomy. The standard OC rod lengths are as follows: 57.5 mm in the short rod section and 170 mm in the long rod section (Fig. 1).

The short rod (5), long rod (1), and locking nut (2), materials used to produce the dynamic rod, are made of titanium alloy (Ti6Al5V), and the bearing (4) and centering silicones (3) are made of biocompatible silicone (MED 4750)

The short rod part, a movable part of the dynamic rod, has a feature of making an angle of 15° in all directions. However, considering in terms of using together two dynamic rods, when the head and neck are fixed, the patient's movement is reduced. Namely, as the patient can move his neck 10° forward and backward, he can turn 5° to the right and left.

## Dynamic Occipitocervical Rod Experimental Model Constructions and Biomechanical Tests

In this study, vertebrectomy models were constructed with dynamic and rigid OC systems to test the system mechanically, and axial static compression, dynamic and torsion tests were performed for the biomechanical comparison in these models.

## Constructions of Vertebrectomy Models

To perform these tests in accordance with anatomical conditions, OC systems are fixed to the polyethylene material (ultra-high molecular weight polyethylene (UHMW-PE) 1000) representing the occipital and cervical parts according to American Society for Testing and Materials (ASTM) 2706-08 standard[11]. Rods were fixed to the system with a 125° OC angle in accordance with the design (Fig. 3a). Screw caps were tightened with torque wrench using a 5-Nm adjustable.

Figure 3a:*Vertebrectomy models according to ASTM2706-08 standard. Static and dynamic compression test set-up*

## ASTM2706-08 standard. Static and ASTM2706-08 standard. Static and

*dynamic compression test set-up, dynamic compression test set-up*,

*with dynamic rod. with Rigid rod.*

## Axial Static Compression Tests

Six vertebral models for each fixation system were tested using Instron 3300 (High Wycombe, UK). Axial compression was applied at a cross-head speed of 5 mm/min according to ASTM F 2706 standard[11] (Fig. 3b-c). During loading, load-displacement values were recorded. Yield load (N) and stiffness (N/mm) values were calculated. The yield point is the point where permanent deformation of the system begins. The knowledge under which conditions the materials will change shape permanently is very important for the design and use of the material. The material stiffness is calculated based on the slope of the elastic region of the load-displacement curve. The stiffness is defined as resistance to elastic deformation.

# Dynamic Compression Tests

Vertebrectomy models were placed in a electrodynamic testing frame according to the ASTM F 2706 standard[11] (Fig. 3b-c). The test setup is the same as in static tests; however, dynamic tests were performed with sinusoidal wave load with a load ratio of 10. 25%, 50%, and 75% of the yield load value obtained in the bending test was applied at 5 Hertz for 5,000,000 cycles. To determine the displacement amount before and after the test, distances between occipital and cervical PE blocks were measured.

## Torsion Tests

Six vertebrectomy models for each fixation system were prepared for torsion tests. Experiments were conducted with the help of the Instron 55MT static torsion test device at an angular speed of 2°/s

Figure 4. *Torsion test set-up of rigid rod system before(a) and after test(b)*

Experiments were continued until the failure occurred. Torque-angle graphs for each sample were obtained using the device software. The maximum torque, torsional stiffness, and yield torque were calculated from these graphs. The maximum torque is the highest torque value that withstands before it breaks. Torsional stiffness indicates its deformable characteristics under torsional loads. The yield torque is defined as the point which permanent deformation starts in the material.

# Data analysis

Data analysis has been performed using Statistical Package for The Social Sciences (SPSS, Windows, version 11.5). Between-group comparison was performed with the nonparametric Mann–Whitney test since the sample value was < 30. P-value was used to evaluate whether the data were statistically significant. If P-value is < 0.05 between the two groups, the difference was considered statistically significant.

## Results

# Static Compression Test Results

The mean yield load and stiffness values for static tests are provided in Table 1. The mean yield load values were 47.35 ± 8.91 N and 49.09 ± 9.62 N for the dynamic and rigid groups, respectively. The mean stiffness values were 7.58 ± 0.88 N/mm and 2.71 ± 0.17 N/mm for dynamic and rigid groups, respectively. The difference between the dynamic and rigid groups was not statistically significant for the yield load (P = 0.631), they have similar yield point. However, a significant difference was observed between groups for stiffness values (p = 0.004). The stiffness of the dynamic group is 64% higher than that of the rigid group.

Table 1
Static Compression Test Results

| **Dynamic Rod** | | | **Rigid Rod** | |
|---|---|---|---|---|
| **S.No** | **Yield Load (N)** | **Stiffness (N/mm)** | **Yield Load (N)** | **Stiffness (N/mm)** |
| **1** | 33.78 | 8 | 50.69 | 2.57 |
| **2** | 39.00 | 6.83 | 45.21 | 2.70 |
| **3** | 56.80 | 6.73 | 57.53 | 2.72 |
| **4** | 50.48 | 7.58 | 31.51 | 2.53 |
| **5** | 52.43 | 9.09 | 54.79 | 3.00 |
| **6** | 51.60 | 7.22 | 54.80 | 2.71 |
| **Mean** | 47.35 | 7.575 | 49.09 | 2.71 |
| **SD**[1] | 8.909 | 0.880 | 9.623 | 0.165 |

Table 1: *describes a comparison of* **displacement behavior** *under different loads for two types of rods*: **Dynamic Rod** *and* **Rigid Rod**. *It assesses how much each rod deforms (displacement) when subjected to specific loads.*

# Dynamic Compression Test Results

Under dynamic loading conditions, a dynamic load of 32 N was performed as 75% of the yield load. The difference between occipital and cervical parts before and after loading is 1.12 mm in the old system and 2.3 mm in the new system. A dynamic load of 25 N was performed as 50% of the yield load. The difference between occipital and cervical parts before and after loading is 0.85 mm and 2 mm in the old and new systems, respectively. Dynamic loading of 14 N was made as 25% of the yield load. The difference between the occipital and cervical parts before and after loading is 1 mm and 0.4 mm in the old and new systems, respectively

Table 2
Dynamic Compression Test Results

| Dynamic Rod | | | | Rigid Rod | | |
|---|---|---|---|---|---|---|
| Load (N) | Distance Before Loading (mm) | Distance After Loading (mm) | Displacement (mm) | Distance Before Loading (mm) | Distance After Loading (mm) | Displacement (mm) |
| 32 | 52.18 | 49.88 | 2.3 | 53.37 | 52.25 | 1.12 |
| 25 | 52 | 50 | 2 | 53.55 | 52.7 | 0.85 |
| 14 | 52.5 | 51.5 | 1 | 53.35 | 52.95 | 0.4 |

Table 2: *Evaluates the mechanical flexibility and stiffness of the two rods by measuring their deformation under increasing loads.*

# Torsion Test Results

Results of torsion tests are presented in Table 3. The mean maximum torques of the dynamic and rigid groups were 2.81 ± 0.95 Nm and 8.65 ± 0.37 Nm, respectively. The mean stiffness for torsion test was 0.14 ± 0.02 Nm/□ and 0.53 ± 0.19 Nm/□ in the dynamic and rigid groups, respectively. The mean yield torques for dynamic and rigid groups were 1.93 ± 0.29 Nm and 5.64 ± 1.30 Nm, respectively. The difference between the dynamic and rigid groups were statistically significant for maximum torque, torsional stiffness and yield torque parameters (p = 0.004 for all parameters).

Table 3
Torsion Test Results

| **Dynamic Rod** | | | | **Rigid Rod** | | |
|---|---|---|---|---|---|---|
| **S.No** | **Max Torque(Nm)** | **Stiffness (N/mm)** | **Yield Torque(Nm)** | **Max Torque(Nm)** | **Stiffness (N/mm)** | **Yield Torque(Nm)** |
| **1** | 2.79 | 0.146 | 2.49 | 8.83 | 0.625 | 3.91 |
| **2** | 4.67 | 0.145 | 1.78 | 8.89 | 0.452 | 7.86 |
| **3** | 2.54 | 0.16 | 1.69 | 8.07 | 0.87 | 4.96 |
| **4** | 2.62 | 0.15 | 1.86 | 8.42 | 0.41 | 5.97 |
| **5** | 2.09 | 0.11 | 1.80 | 8.59 | 0.41 | 5.54 |
| **6** | 2.13 | 0.12 | 1.95 | 9.09 | 0.42 | 5.62 |
| **Mean** | 2.81 | 0.14 | 1.93 | 8.65 | 0.53 | 5.64 |
| **SD**$^2$ | 0.954 | 0.019 | 0.288 | 0.368 | 0.185 | 1.304 |

Table 3: *The table compares the mechanical properties of two types of rods*—**Dynamic Rod** *and* **Rigid Rod** *—under Torsion Test The* **Dynamic Rod** *has lower torque capacity and stiffness, which suggests it is better suited for applications where flexibility or lower torque is required. The* **Rigid Rod** *is stronger and more consistent, making it ideal for applications requiring higher torque capacity and stiffness.*

# Discussion

Occipitocervical fixation is a method used for occipital bone and cervical spine fusion, causing prominent limitation in postsurgical head movements[6, 8, 9, 12, 13]. The OC junction that is a region with unique anatomical and functional features in the spine should be surgically stabilized when unstable secondary to various pathologies[3, 5, 6, 8, 10]. However, although the rigid stabilization of this unique region provides significant clinical results, it may result in various problems such as respiratory disorders, severe quality of life impairment due to movement restrictions, and adjacent segment diseases[7–10, 12]. These problems may not be negligible, although rigid OC stabilization has significant consequences on postsurgical improvement.

In the late 1980s, the standard method used to perform OC fixation included a contoured rod and wiring system, such as the Ransford loop system[4, 14]. In this method, rod is then fixed to the occipital bone using a titanium wire cable passing through the occipital holes and to cervical lamina through sublaminar wiring. The disadvantage of this technique includes increased sensitivity to axial compression loads that create a vertical collapse. This increased sensitivity may be caused by the rod sliding between the wires due to the loosened wire and by bone atrophy or erosion at the interface between the wire and bone[4, 15]. Structures containing wiring techniques attached to the rods are particularly susceptible to loosening with cyclic loading[15].

In 1989, Roy-Camille et al. reported the view of rigid OC fusion with skull base screws, plates, and lateral mass screws[16]. Later in 1991, Grob et al. reported that significant clinical results and bone fusion were obtained in 14 patients with occipital Y-plate and lateral mass screws[17]. The Olerud cervical system, launched in 1997, was the first rod and screw system used for OC fixation. Various monoaxial anchor screws in the cervical spine, such as subaxial lateral mass, transarticular and pedicle screws, C2 pedicle, C2 translaminar or C1-C2 transarticular screws, were connected to the shaped rod[12, 15]. Afterward, the rods are fixed to the occipital bone with occiput screws. Fortunately, new polyaxial screw systems allow easier connections between the rod and screw[6, 12].

Nowadays, spinal rigid instrumentation is used to stabilize and provide fusion during the surgical treatment for various spinal disorders[4, 6, 13, 15, 18]. Many rigid fixation systems have been produced, thanks to technological advancements providing immediate surgical stabilization until natural fusion develops[4, 13, 15, 18, 19]. Fusion surgery is known as the gold standard in the treatment of degenerative spine, spinal instability, and mechanical low back pain[5, 6, 12, 20, 21]. However, fusion surgery can bring together adjacent segment degeneration, mobility limitation, and some problems due to surgery[21–23].

Such complications observed after the fusion surgery have increased the search for dynamic stabilization[20, 21, 23].

Unlike fusion implants, motion-sparing implants intend to restore load sharing between spinal elements (discs, facet joints, vertebral bodies, and cartilaginous endplates) while allowing for controlled motions throughout the range of motion(ROM)[24]. In this context, motion protection strategies are generally classified into four categories: nucleus replacement, total disc replacement, interspinous spacers, and pedicle screw-based posterior dynamic stabilization (PDS)[24]. Each of these strategies target specific spinal elements to restore load sharing between the stabilizing structures of the spine[24]. Pedicle screw-based posterior dynamic stabilization allows a two-way approach: to mimic the kinematic signature of a healthy spine and to restore normal load sharing between the spinal elements. Dynamic stabilization devices aim to relieve pain by distributing the load between the front and back elements of the spine while trying to maintain joint motion[20–22, 24]. Several studies in the literature have reported that posterior dynamic stabilization can be superior to rigid stabilization by preventing adjacent segment degeneration, as it provides controlled motion, increases anterior load distribution, and protects motion[20–22, 24]. However, to conclude that a posterior dynamic device is better than fusion, results of many similarly designed, independently funded trials should be compiled and compared.

Several studies have been conducted to evaluate results of instrumentation techniques used for OC stabilization and fusion, and screw rod systems have been reported to be superior to other groups in OC fusion and achieved the most positive results in all disease processes[4, 6, 10, 18]. However, although current fixation techniques significantly improved instability, they cause severe movement restrictions in the cervical spine[6, 10, 19]. Posterior OC arthrodesis in children has been reported to significantly decrease cervical joint ROM compared to the control group. However, a 13° decrease in flexion–extension of each direction and 7° decrease in lateral bending have also been reported, with axial rotation as the most affected movement with an average decrease of 30°[8]. After OC arthrodesis, decreased visibility due to mobility is an important issue affecting the quality of life and increasing safety anxiety. Postoperative dysphagia and dyspnea are rare complications after OC fixation[7, 9, 10]. However, they cause serious daily life problems. Various mechanisms have been proposed for such complications, including cervical alignment changes, pharyngeal edema, and enlarged tongue. Several management methods have been proposed for postoperative dysphagia and dyspnea mechanisms after OC fixation. The angle of C0–C2, defined as the angle between the McGregor line and the lower end plate line of C2, has been reportedly important[7, 9]. Fixation with reduced lordotic C0–C2 angle was positively correlated with the narrowest sagittal diameter of the oropharyngeal air space, suggesting an induced dysphagia or dyspnea. In patients with RA with upper cervical spinal lesion, obstructive sleep apnea has been reportedly improved after OC fusion due to enlarged oropharyngeal cavity when the C0–C2 angle is fixed in a wider position[7].

When considering positive results of dynamic stabilization systems used especially in the lumbar region, the question “Can dynamic stabilization systems be used for this unique region in cases of instability due to OC region pathologies?” forms basis of the hypothesis. When evaluating the test results, the

dynamic rod has a similar feature with the rigid system as the yield load under static loading and is superior over the rigid system under these loading conditions in terms of rigidity. When exposed to torsional forces, the rigid system was found to be statistically significantly superior over the new system. However, torsion test results are due to the dynamic properties of the rod system as expected before the test. When differences between the occipital and cervical parts before and after loading were evaluated under dynamic loading conditions, these differences would not be clinically significant considering the craniometric properties of the CVJ[3]. Nagel et al. described the ideal fixation device as “stiff enough to limit displacement and strain, but strong enough so that it will not break and supple enough so that it will not cause breakdown at the bone–implant interface”[25]. We think that the best implant is the one that is closest to the normal anatomical and physiological characteristics, and meets the expectation of treatment with maximum patient compliance.In light of all this information, the dynamic OC rod system can be used to stabilize this region instability without ventral compression. The fusion implant should provide stabilization until the occurrence of fusion; however, this role should exist for life for dynamic stabilization systems. Therefore, laboratory and clinical studies required in using dynamic rod systems for the OC region should be continued.

## Conclusion

Dynamic OC rod, which provides CVJ stabilization with normal anatomical and biomechanical properties within physiological limits and with the ability to move to this region, is biomechanically successful. However, these tests can be used as a basis for the use of dynamic rods for surgeries in this region and must be supported by controlled human studies. The rod specifically designed for this purpose with successful test results forms the basis for other tests required in humans.

## Declarations

# Competing Interests

The study protocol was reviewed and approved by the Institutional Review Board of Ankara University School of Medicine (IRB No: I6-298-19). Ethical approval and patient consent were not required for this in vitro biomechanical study.

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# Author Contribution

Y.S.C. conceptualized and designed the study. T.D. and F.K.E.E. performed biomechanical modeling and data analysis. S.S., I.D., and K.E. contributed to the interpretation of results and manuscript revision. All authors reviewed and approved the final manuscript.

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# Data Availability

All data generated or analyzed during this study are included in this published article. Additional datasets are available from the corresponding author on reasonable request.

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# Footnotes

1. SD: Standart Deviation
2. SD: Standart Deviation

# Figures

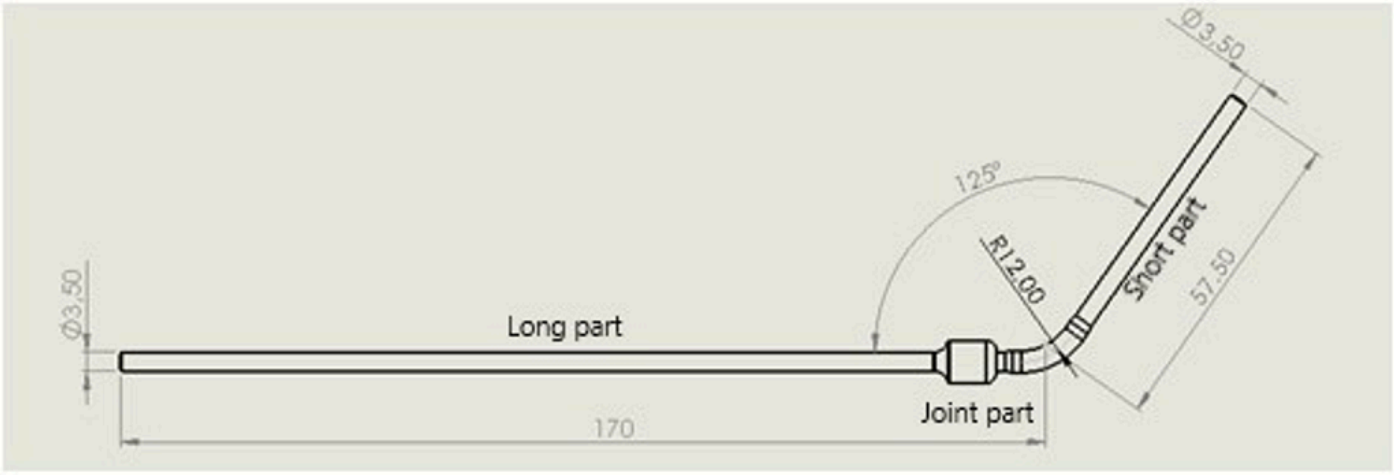



**Figure 1**

*Dimensions and angles of the basic parts of the posterior dynamic occipitocervical rod.*

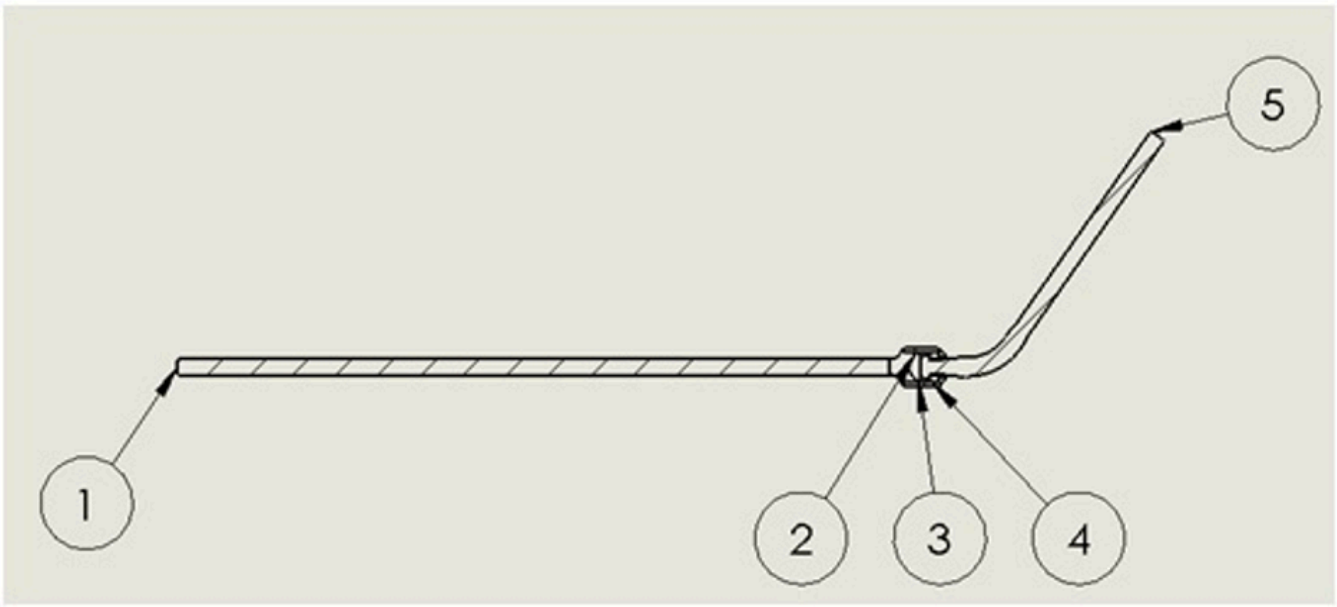



**Figure 2**

*Basic parts and design of the dynamic occipitocervical rod.*

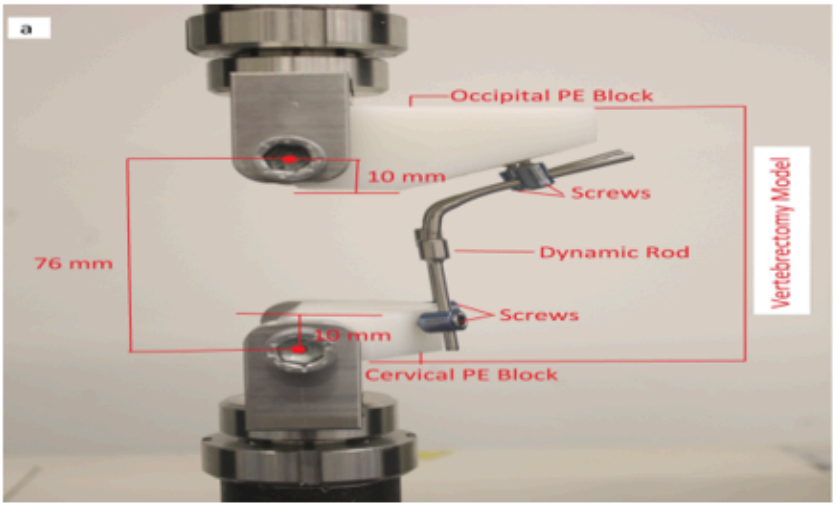



*Figure 3a:*

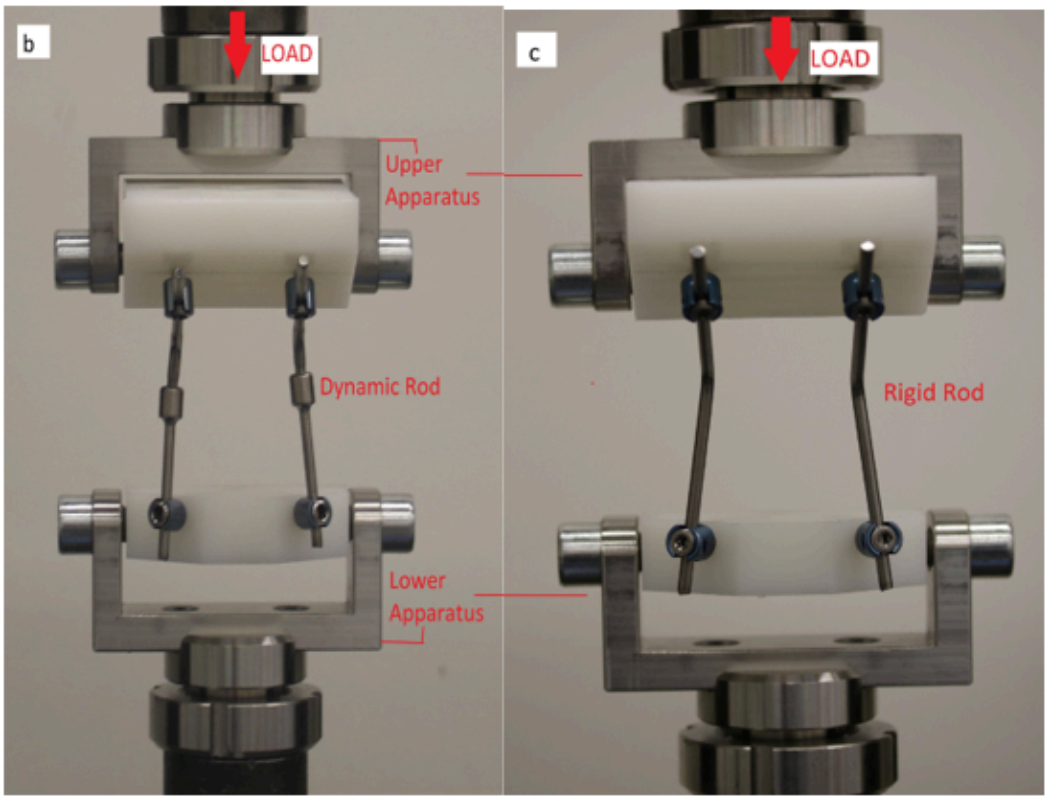



*Figure 3 b.*

*Figure 3 c.*

**Figure 3**

a: Vertebrectomy models according to ASTM2706-08 standard. Static and dynamic compression test set-up

b. Vertebrectomy models according to ASTM2706-08 standard. Static and dynamic compression test set-up, with dynamic rod.

c. Vertebrectomy models according to ASTM2706-08 standard. Static and dynamic compression test set-up, with Rigid rod.

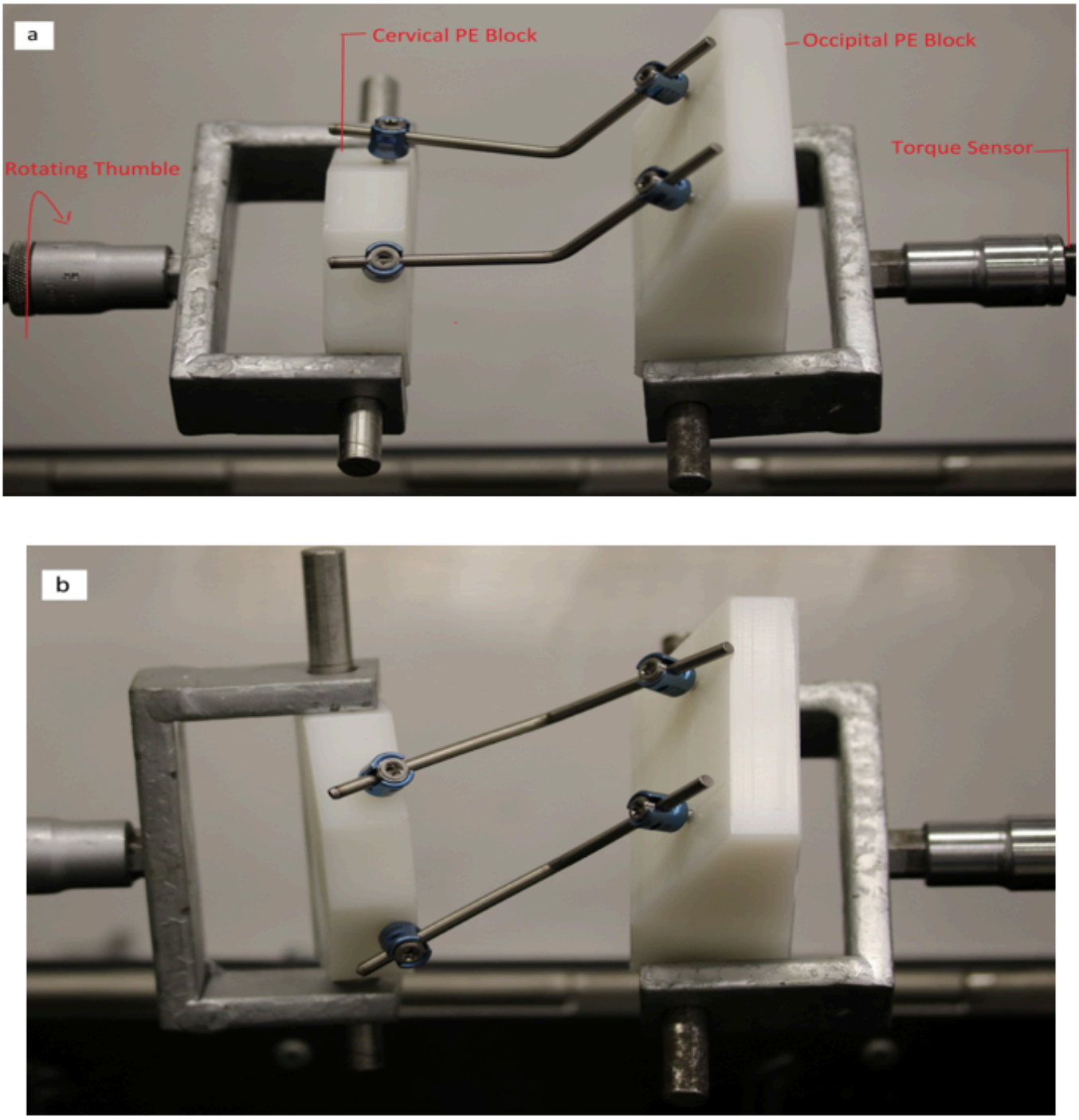



**Figure 4**

*Torsion test set-up of rigid rod system before(a) and after test(b)*

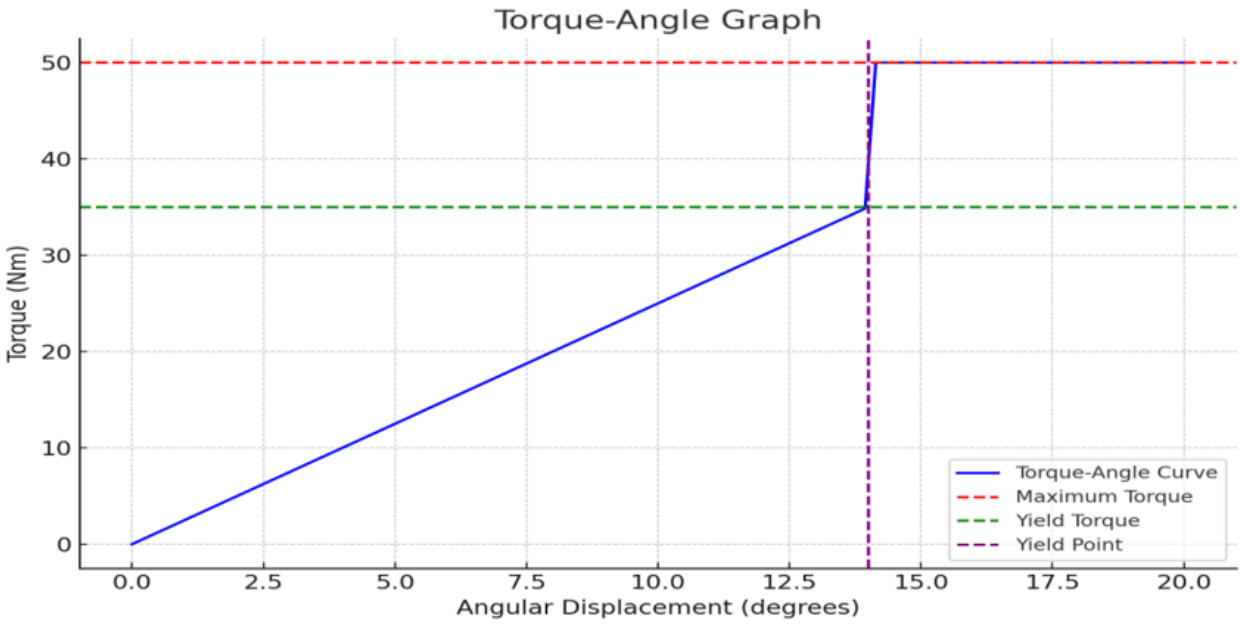



**Figure 5**

*Figure 4: . Torque-angle graphs for each sample*