Mechanical Evaluation of Aluminum Alloy Ring Fixator

Somboon Tosborvorn MD*, Sukrom Cheechareon MD*, Kittiput Ruttanuchun MD**, Suparerk Sirivedin PhD**, Chaitawat Rhienumporn MD**
* Orthopaedic Department, Rajavithi Hospital
** King Mongkut Institute of Technology

Objective: To test the homemade ring fixator as a tool for correction of bony deformity.

Material and Method: The authors developed an aluminum alloy ring fixator and tested it to find out the accuracy of manufacturing and strength of the ring systems under axial load with the Roundness Testing Machine and Lloyd Universal Testing Machine.

Results: The mean diameter of the twenty-five drill holes was 6.5843872 ± 0.0521594 mm (mean ± SD). Distance between particular drill holes, which reflected the precision of drilling, had a high accuracy with standard deviation from 0.1138 to 0.1870 mm. The roundness of the rings was 0.2421376 ± 0.12437977 mm (mean ± SD). The system structure had minimal permanent deformity at breaking point, mean yield strength of the system was 4786.9 ± 14.353 N (mean ± SD). This was caused by the failure of the wire. Mean stiffness of the system was 127 N./mm.

Conclusion: The aluminum alloy ring fixator was strong enough and well tolerated for clinical usage

Keywords: Ring fixator, Ilizarov, Aluminium alloy, Aluminium, External fixator

In 1952, Ilizarov invented his ring external fixator and described its construction, usage and applications. The system consisted of four or more rings with two or more cross Kirschner wires under tension per ring. The rings were connected to each other with threaded rod. In 1954, Ilizarov began his apparatus for lengthening extremities. After that, the apparatus was gradually accepted for clinical application and approved by the Food and Drug Administration for fracture fixation, pseudarthrosis of the long bones, limb lengthening by epiphyseal or metaphyseal distraction and correction of bone malformation.

Though the apparatus seemed to be useful, it was continuously improved materially. However, the price of the system is an obstacle for developing countries and low socioeconomic group of patients usually could not afford it. The authors developed a handmade aluminum alloy ring fixator that was used on one patient. Though the authors faced some problems on symmetry of the drill holes, the authors got good clinical results. However, the authors did not have supporting data in perspective of strength of this system.

The objectives of the present study were, first, to study the precision of manufacturing, second, to study the mechanical behavior of the aluminum alloy ring fixator under axial load, and to determine the strength of the system for clinical application.

Material and Method

An aluminum alloy square-end bar, the same dimension as the original one, was bent into a half ring with special bending tools. Mikron computer numerical control drilling tool (Mikron Agie Charmilles Group, Germany) was used to drill into the half rings at precise locations. The half rings were anodized for hardening its surface with a 15% sulphuric acid bath. Five drilled holes (Fig. 1) from five half rings, thus twenty-five holes were chosen for evaluation of the diameter with Optical Video Prob, OMIS 2 (Ram Optical Instrumentation Inc., California). Inner and outer diameter of the five half rings and roundness of the rings was measured...
with Coordinate Measuring System (Microval PFx, Brown & Sharpe, USA). Precision of the drilling sites was evaluated by measuring the distance between the center of the five selected drill holes (Fig. 1) on each of the five rings (variables were named as VAR 00001, VAR 00002, VAR 00003 and VAR 0004) with Co-ordinate Measuring System (Microval PFx, Brown & Sharpe, USA).

The presented ring fixator system was comprised of four full rings with two 1.8 mm Kirschner wires on each full ring. Rings at each end were 2.5 cm apart from each other. All rings were connected to each other with four threaded rods (Fig. 2).

Each Kirschner wire was pre-tensioned at 110 Kg. All of them were secured to the ring with a wire clamp and bolt by using a hand wrench simulating the real situation. For mechanical behavior test, polyvinylchloride tubes were used as long bone to ensure uniform and consistent material properties and pin tract responses. Three ring fixator systems were tested with Lloyd Universal Testing Machine (Fig. 3) with continuous load rate at 30 mm/min. Length of outer diameter of each ring and the gap between each pair of rings were recorded pre-test and post-test for comparison with a digital caliper.

For statistical analysis, descriptive statistics and the paired Student t-test used to determine the deformity of the ring configuration. This was determined at the outer diameter of each ring by measuring the gap between each pair of rings. Kolmogorov - Smirnov test was used to test goodness of fit of data that would further be analyzed with paired Student t-test. A p-value of less than 0.05 with two tailed was considered significance difference between.

![Fig. 2 System configuration](image2)

![Fig. 3 The ring fixator system under the testing machine](image3)

![Fig. 1 Five selected holes for evaluation](image1)
Results

Mean diameter of the twenty five selected drill holes was $6.5843872 \pm 0.0521594$ mm (mean ± SD).

The inner diameters of the five half rings were $197.99955 \pm 0.81985904$ mm (mean ± SD). The outer diameters of the five half rings were $228.24306 \pm 0.970154296$ mm (mean ± SD).

Mean consecutive distance between the five particular holes (VAR00001 - VAR00004) on five half rings is demonstrated in Table 1. Standard deviation of the consecutive distances ranged from 0.1135 to 0.1861 mm. The roundness of the rings was $0.2421376 \pm 0.12437977$ mm (mean ± SD).

The mean yield strength of the three-ring system was $4654.567 \pm 229.5704$ Newtons with displacement at $57.3067 \pm 1.1836$ mm (Fig. 4). The overall system still maintained its contour; there was no statistical significance of the ring diameter between pre and post test at 95% confidence (mean difference is -0.0225 ± 2.312818 mm (mean ± SD)) (Table 2). There was no statistical difference of the gap between ended rings pre and post test at 99% confidence (mean difference is 0.027917 ± 0.366226 mm (mean ± SD)) (Table 3). The extension or failure of the system was caused by plastic deformation of Kirschner wire and loosening of the wire clamps (Fig. 5).

Fig. 4 Load-Displacement (extension) Curve shows yield strength at 4300 N

Fig. 5 Shows the plastic deformation of K-wire, the ring fixator configuration still maintained (Post-test)
Mean load at 2 mm of displacement was 76.667 ± 8.0829 Newtons. Mean stiffness was 127 N/mm.

**Discussion**

Ring external fixator is accepted worldwide as a useful tool for orthopedic patients especially in difficult cases\(^1\). The first prototype was stainless steel\(^6\). Until now, there was evolution in material, from titanium\(^7\) to carbon-fiber composite\(^8,9\).

Aluminum alloy (Sp.gr 2.7) is lightweight material, weighting two to three times less than stainless steel (Sp.gr 7.9). From the authors’ limited experience, aluminum alloy ring worked well for clinical usage. Nevertheless, there was scarcely adequate scientific information about the strength of the aluminum alloy system. Pulate et al used an aluminum alloy ring cutting from aluminum tubes cast, but mechanical data is not available\(^10\).

In the present study, the material of the ring was hot treated aluminum alloy. This is stronger than aluminum tube cast. With a hand made bending tool, the mean inner diameter was 197.99 ± 0.819 mm, the mean outer diameter was 228.24 ± 0.970 mm. The mean roundness of the rings was 0.2421376 ± 0.12437977 mm (mean ± SD). The standard deviation of diameter and roundness was in an acceptable range for general hardware.
To avoid asymmetry of drilled holes on the half ring, a Computerized Control Machine was used to drill the holes at the precise location. From the data standpoint, the distance between drilled holes, which reflected the precision of the drill site, had high accuracy with standard deviation from 0.1138 to 0.1870 mm. The standard deviation of the drilled hole diameter was 0.0521594 mm, which is acceptable for bolt and screw.

The surface of pure aluminum alloy is abrasive and not hard enough. The authors anodized it with a 15% sulphuric acid bath. This would provide corrosive resistance, electrical insulation and abrasive resistance as well as improve paint adhesion. Properties such as porosity, abrasion resistance, color, and flexibility depend on the type, concentration, and temperature of the electrolyte, the strength of the electrical current, the processing time, and the type of metal.

In the present study, the original wire clamp, original Kirschner wire 1.8 mm and original thread rod were used. This eliminated confounding factors. To get results that could be repeated in real situation, all nuts and bolts of the system were tightened manually with maximal force.

Load-displacement behavior of the system under axial load was curvilinear (Fig. 4). Stiffness of the system at various point differed from each other. Overall, the stiffness was initially low and increased later on. Gasser proposed that the remarkable clinical results might come from this specific nonlinear behavior(11). It seemed that low stiffness at low load may stimulate bone healing, and high stiffness at high load may prevent over tolerance strain at the fracture site.

Comparing with other studies(4,12), stiffness of the presented aluminum alloy ring system (127 N/mm) was not different from the stainless steel ring system (103.91 N/mm) or titanium ring system. It probably meant that load-displacement behavior of the ring was affected from other common factors, Kirschner wire and wire clamp, not from the sort of material used for manufacturing the ring.

The ring fixator system could tolerate the load up to 4654.567 Newtons with displacement at 57.3067 mm. From Table 2 and Table 3, the ring gaps and ring diameters did not differ between pre and post test. This means that the system configuration had not changed after failure. From Fig. 5, the causes of displacement clearly were the elastic elongation of the Kirschner wire, loosening of the wire clamp and the less pretension force. Watson et al commented in his study that though the initial wire tension has an appreciable effect on the wire stiffness; it did not affect the elastic load range of the clamped-wire system(13). If the authors preferred more stiffness of the system, the authors needed to use a larger Kirschner wire, to apply more pre-tension force and to design a much more securing wire clamp(13,14).

At 2 mm of displacement in the present study, mean load was 76.667 Newtons, which did not differ from other studies(15,16). In a real situation, because of soft tissue filling the gap between fracture sites, the real load at 2 mm of displacement were usually much more than this figure.

Aluminum alloy ring fixator is strong enough for clinical usage and has a low system weight. This is an advantage over the stainless steel ring type.

**Conclusion**

Production quality of Aluminum Ring Fixator is acceptable and the fixator is strong enough for clinical application.

**Acknowledgement**

The present study was supported by a grant from the Medical Service Department, Ministry of Public Health.

**References**


การศึกษาความแข็งแรงของเครื่องยึดกระดูกแบบวงแหวน

สมบูรณ์ ทศบวร, สุกรม ชีเจริญ, กิตติภัฎ รัตนจันทร์, ศุภฤกษ์ ศิริเวทิน, ชัยธวัช เหรียญอัมพร

วัตถุประสงค์: เครื่องยึดกระดูกจากภายนอกแบบวงแหวนเป็นเครื่องมือที่มีประโยชน์ในการรักษาผู้ป่วยทางด้านโรคกระดูกและข้อเป็นอย่างมาก คณะผู้วิจัยได้พัฒนาเครื่องยึดกระดูกแบบวงแหวนโดยใช้อะลูมิเนียมอัลลอยด์ มาทำการขึ้นรูป

วัสดุและวิธีการ: ได้ทำการศึกษาถึงคุณภาพการผลิตและความแข็งแรงทางด้านโครงสร้างของเครื่องยึดกระดูกที่ได้ผลิตขึ้น

ผลการศึกษา: เส้นผ่าศูนย์กลางของรูที่ทำการเจาะมีค่า 6.5843872 +/- 0.0521594 มม. ระยะระหว่างรูที่กำหนดซึ่งสะท้อนถึงความแม่นยำของการเจาะมีค่าความแม่นยำสูงโดยมีค่าของความเบี่ยงเบนมาตรฐานระหว่าง 0.1138 และ 0.1870 มม. ความโค้งของวงแหวนมีค่า 0.2421376 +/- 0.12437977 มม. ไม่พบความแตกต่างอย่างมีนัยสำคัญของการเปลี่ยนแปลง ขนาดเส้นผ่าศูนย์กลาง ของวงแหวนก่อน และหลังทำการทดสอบที่ระดับความเชื่อมั่น 95% (ค่าเฉลี่ยความแตกต่างก่อนและหลังทำการทดสอบคือ -0.3175 +/- 0.9692 มม.) ไม่พบความแตกต่างอย่างมีนัยสำคัญในระยะระหว่างวงแหวนดูแล้วที่ระดับความเชื่อมั่น 99% (ค่าเฉลี่ยความแตกต่างก่อนและหลังทำการทดสอบคือ 0.027917 +/- 0.366226 มม.) โครงสร้างของเครื่องยึดกระดูกมีการผิดรูปอย่างมากที่จุดแตกหัก โดยมีความคลาดเคลื่อนโดยเฉลี่ย 4786.9 +/- 14.353 นิวตัน ซึ่งเกิดจากการกระแทกของวงแหวนและดัตช์ยึดจับลง เข้าความคลาดเคลื่อนนี้ไม่เกิน 127 นิวตันมม.

สรุป: เครื่องยึดกระดูกแบบวงแหวนที่ผลิตโดยใช้อะลูมิเนียมอัลลอยด์มีความแข็งแรงเพียงพอที่จะใช้ในทางคลินิกได้