The Clavicular Fracture : A Biomechanical Study of the Mechanism of Clavicular Fracture and Modes of the Fracture

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Abstract

A clavicle is an S-shaped long bone whose biomechanical behavior is unlike that of a straight tubular long bone. When a clavicle is under a compression load along the axis, the force produces a middle one-third clavicular fracture. The present study is a biomechanical study to confirm the clinical observations of the mechanism of the fracture and to discover the tension site and compression site of the fracture, using 12 fresh cadaveric clavicles, a universal testing machine and two special grips. One grip was constructed with a contour like a sternoclavicular articulation. The grip was mounted at the medial end of the clavicle. Another grip was constructed with a contour like an acromioclavicular articulation. The grip was mounted at the lateral end of the clavicle. A load was applied to the lateral clavicle like a force transmitting from the weight of the shoulder girdle. A load was also applied to the medial clavicle like a force from the sternocleidomastoid muscle. A compression load was applied along the axis of the testing clavicle through the upper grips by using a universal testing machine. The result found that the average load of the clavicular fracture was 1526.19 N. The fracture occurred at the middle one-third of the clavicle in the region of the curve of the lateral clavicle changing to the curve of the medial clavicle. While primatic cross section of the clavicle at the fracture site determined a tension and a compression site of the fracture, the fracture took the superoanterior aspect of the clavicle as a tension site and posteroinferior aspect as a compression site. The fracture had a ratio of length of the lateral fragment to the total length of the clavicle of 0.49. This study confirmed that a compression load along the axis of the clavicle produces a middle one-third clavicular fracture as in clinical observation and the fracture took the superoanterior aspect of the clavicle as a tension site.

Key word : Clavicular Fracture, Fracture Mechanism, Compression, Long Axis, Biomechanical Testing

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The clavicle is the most frequently broken bone in the body especially a middle one-third fracture[1]. However, there are two possible mechanisms of the injury including a fall on the outstretched hand and a direct blow on the shoulder which produce a compression force transmitting along the clavicular axis[1,2]. The clavicle links the shoulder to the axial bone and maintains the width of the shoulder under loads of the weight of the shoulder, pectoris major and sternocleidomastoid muscle[2,3]. Therefore, the clavicle is always under compression and tension. Because the clavicle is an S-shaped long bone and has a medial tubular shape changing to a lateral flat shape, this geometry makes the biomechnical response of the clavicle under loading different from a straight tubular long bone[4]. The aim of the study was to confirm clinical observation of the mechanism of clavicle fracture and determine the mode of the fracture, which may be useful in clavicular fracture fixation.

MATERIAL AND METHOD

Twelve fresh cadaveric clavicles consisted of 6 right sides and 6 left sides. The clavicles were obtained from cadavers with ages ranging from 18 to 25 years. The clavicles were prepared by removing soft tissues and preserved articular cartilage at both ends of the clavicles. The length of the clavicles was measured. Superoinferior and anteroposterior width of the clavicle at which curve of the medial clavicle changes to curve of the lateral clavicle being measured (Table 1). Two specially designed metal grips were prepared and used for an upper and a lower grip. The lower grip was constructed in a shape which could articulate with the sternal end of the clavicle. The upper grip was constructed in a shape which could articulate with the acromial end of the clavicle (Fig. 1). Two pulleys, 2 centimeters diameter, were prepared and used as an upper and a lower pulley. The upper pulley was installed beneath the cross-head metal of the universal testing machine (Fig. 1). The lower pulley was installed at the base of the universal testing machine (Fig. 1). The testing clavicle was adjusted in a vertical position with the long axis of the clavicle in line with the upper and lower grips. The acromial end of the clavicle was upwards and articulated with the upper grip functioning like an acromioclavicular joint. The sternal end was downwards and articulated with the lower grip, functioning like a sternoclavicular joint (Fig. 1). This position of the clavicle allowed direction of force to be along the clavicular long axis when a compression load was applied through the upper grip (Fig. 1). Two metal belts were prepared. One metal belt was applied at the lateral clavicle, 2.5 centimeters below the upper grip and was connected to a 5 kilograms metal weight through the upper pulley by a small metal sling. The direction of the

Table 1. Data of tested clavicles.

No.	Side (R/L)	Length (cm)	Thickness at junction of Two curve of the clavicle (cm) Anteroposterior	Superoanterior	Maximun load (N)	Length of the lateral fragment (cm)	Ratio of lateral fragment and length of the clavicle
1	R	16.25	1.53	1.10	2022.72	7.69	0.47
2	L	16.10	1.42	0.97	2814.56	8.00	0.49
3	R	16.90	1.30	1.06	1301.44	9.86	0.58
4	L	16.80	1.20	1.15	1403.36	8.50	0.51
5	R	15.20	1.23	1.02	1599.36	7.48	0.49
6	L	15.10	1.13	1.00	1356.32	7.58	0.50
7	R	16.50	1.16	1.06	627.20	8.00	0.48
8	L	15.89	1.33	1.10	1999.20	7.45	0.47
9	R	15.35	1.43	0.93	948.64	7.24	0.47
10	L	14.58	1.20	1.06	948.64	7.35	0.50
11	R	16.76	1.10	1.03	1560.16	7.75	0.46
12	L	16.79	1.00	0.98	1732.64	8.40	0.50
Average		16.02	1.25	1.04	1526.19	7.94	0.49
S.D.		0.79	0.15	0.06	583.80	0.72	0.03

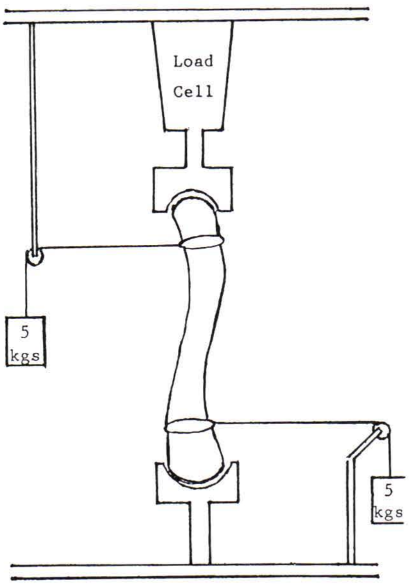

Fig. 1. **Diagram showing frontal view of the clavicle under the testing condition**

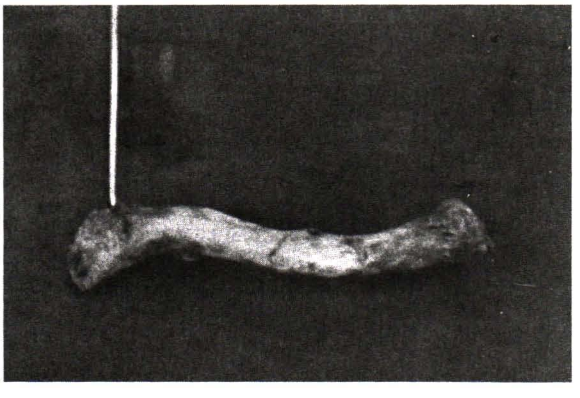

Fig. 2. **Showing a middle one-third clavicular fracture. The fracture tooks superoanterior aspect of the clavicle as a tension site.**

sling was at right angles with the clavicular axis and beneath the inferior aspect of the clavicle. The 5 kilograms functioned like a load from the weight of the shoulder transmitting to the lateral clavicle (Fig. 1). Another metal belt was applied at the medial clavicle, 2.5 centimeters above the lower grip and was connected to another 5 kilogram metal weight through the lower pulley by a small metal sling. The direction of the sling was at right angles with the clavicular axis and above the superior aspect of the clavicle. The 5 kilogram weight functioned like a force from the sternocleidomastoid muscle (Fig. 1). A compression load was applied at a rate of 10 millimeters per minute to the testing clavicle through the upper grip by using the universal testing machine (Shimadzu Tokyo Japan). Positions of the fracture were determined by measuring the length of the lateral fragment of the clavicle. Modes of deformation before the bone fractured were observed especially the tension and compression site. The maximal load of the clavicular fracture was recorded. The data was analyzed for normal distribution by using the Kolmogorov Smirnov Goodness of Fit test.

RESULTS

The fracture occurred at the junction of the curve of the medial clavicle changing to the curve of the lateral clavicle. Whereas, the primatic cross-section of the clavicle at the fracture site was a factor determining the modes of deformity especially tension and compression sites before the bone fracture, the fracture took the superoanterior aspect of the clavicle as a tension site and the inferoposterior as a compression site. At 10 millimeter per minute loading rate, there was no comminution of the fracture. The average maximal compression load of the clavicular fracture was 1526.19 N (SD, 583.80) (Table 1). The fracture had an average length of lateral fragment of 7.94 centimeter (SD, 0.72). Ratio of the lateral fragment to total length of the clavicle was 0.49 (S.D, 0.03) (Table 1). The statistical analysis showed that the data had normal distribution ($P>0.05$).

DISCUSSION

The experiment was set up so that the conditions of the testing clavicle were similar to the clavicle under load in the shoulder girdle, including the weight applied at the lateral and medial part of the testing clavicle presenting a force transmitted from the weight of the shoulder girdle and a force from the sternocleidomastoid muscle[5,6]. The grips were constructed as in the articulation of acromioclaviclar and sternoclavicular joints, so that the compression force was applied along the clavicular axis through the upper grip like the clinical observation of the mechanism of a middle one third clavicular fracture. Using a loading rate of 10 millimeter per minute on the testing clavicle was not a high speed force as in clinical observation such as in motorcycle accidents or falling from a running horse. So, the fractured middle one-third of the testing clavicle was a simple fracture with no comminution(4). However, using a 10 millimeter loading rate per minute an observation of the mode of the bone failure before the bone fracture facilitating the determination of the tension and compression site of the fracture. According to the results, it was found that the fracture took the inferoposterior aspect of the clavicle as the compression site and superoanterior aspect as the tension site. This explains why in the clinical observation in a X-ray film, comminuted fragments mostly occur at the inferior aspect of the clavicle(7) but the superior aspect of the clavicle breaks without comminution fragments(7). The experiment showed that the fracture occurs at the junction of the curve of the medial clavicle as it changes to the curve of the lateral clavicle. Because both curves of the clavicle have opposite direction of the curve, when a compression load is applied along the axis of the clavicle, a loading moment occurs at this junction of both curves of the clavicle(4). Due to deformity of the clavicle before bone fracture especially at the tension and compression site, the primatic cross section of the clavicle at the fracture site is one of the factors that plays a part in determination of the tension and compression sites of the fracture(4). This is because the primatic cross-section at the fracture site has a base at the superior aspect of the clavicle which is the tension site of the fracture and has an apex at the inferior aspect of the clavicle which is the compression site of the fracture(4,8). The results of the experiment comfirmed that a compression load applied at the lateral clavicle along the axis produces a middle one-third clavicular fracture. This corresponds to the clinical observation that a force is transmited from the shoulder when the shoulder hits on the ground. The out-stretched hand injury can possibly produce a middle one-third clavicular fracture when the upper extremity abducts more than 90 degrees. Because in this position a force transferring along the long axis of the upper extremity can be transmitted to the shoulder and continue the force to the clavicle as a compression force along the clavicular axis. In the case of an out-stretched hand injury, the upper extremity abducts less than 90 degrees and can produce a middle one-third clavicular fracture if the injury force continues and makes a smaller angle of shoulder abduction. This position results in the shoulder being likely to hit the ground.

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การทดสอบทางชีวกลศาสตร์ของกลไกการหักบริเวณส่วนกลางหนึ่งในสามของกระดูกไหปลาร้า

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กระดูกไหปลาร้า เป็นกระดูกรูปยาว แบบตัวอักษร S ซึ่งเมื่ออยู่ภายใต้แรงอัดตามแนวแกนจะมีพฤติกรรมทางชีวกลศาสตร์ แตกต่างจากกระดูกยาว ที่มีลักษณะเป็นทรงกระบอกตรง แรงกระทำที่ทำให้เกิดการหักที่ตำแหน่งส่วนกลางหนึ่งในสามของกระดูกไหปลาร้านั้นในทางคลินิกมักจะเป็นการบาดเจ็บที่มีแรงอัดตามแนวแกนของกระดูกไหปลาร้า การศึกษาครั้งนี้เป็นการทดลองทางชีวกลศาสตร์เพื่อแสดงให้เห็นชัด กลไกของการหักของกระดูกไหปลาร้าที่พบเป็นประจำในทางคลินิก การทดลองใช้กระดูกไหปลาร้าจาก cadavers จำนวน 12 คู่ universal testing machine และแท่งโลหะที่ออกแบบให้เข้ากับกระดูกที่ปลายทั้ง 2 ข้างของกระดูกไหปลาร้า ในลักษณะเป็นข้อต่อ กระดูกไหปลาร้าถูกจับให้ตั้งตรงในแนวดิ่งให้ส่วนปลาย clavicular อยู่บนและส่วนปลาย sternal อยู่ล่าง โดยกระดูกไหปลาร้านี้ถูกยึดติดกับ universal testing machine ด้วยแท่งโลหะคู่ที่ออกแบบไว้แล้ว กระดูกไหปลาร้าบริเวณเศษหนึ่งส่วนสามชิดทางส่วนปลาย clavicular และที่บริเวณเศษหนึ่งส่วนสามชิดทางส่วนปลาย sternal ถูกถ่วงด้วยน้ำหนัก ซึ่งประเมินให้คล้ายกับน้ำหนักหัวไหล่ และแรงของกล้ามเนื้อ sternoclidomastoid ที่มากระทำที่กระดูกไหปลาร้า จากนั้นเริ่มใช้แรงจาก universal testing machine กดกระดูกไหปลาร้าตามแนวแกน บันทึกแรงกดสูงสุดที่ทำให้กระดูกไหปลาร้าหัก ตำแหน่งของการหัก และลักษณะของการหักโดยดูเป็นด้าน tension และ compression ผลการทดลองพบว่า แรงกดสูงสุดมีค่าเฉลี่ยเท่ากับ 1526.19 N ตำแหน่งที่กระดูกหักอยู่บริเวณส่วนกลางหนึ่งในสามของกระดูกไหปลาร้ามีความยาวเฉลี่ยของกระดูกชิ้นนอก 7.94 เซนติเมตร ซึ่งคิดเป็นอัตราส่วนต่อความยาวของกระดูกไหปลาร้า มีค่าเฉลี่ยเท่ากับ 0.49 ลักษณะการหักใช้ด้าน superoanterior เป็นด้าน tension และ posteroinferior เป็นด้าน compression จากการศึกษาครั้งนี้ แสดงให้เห็นชัดว่ากลไกของการหักของส่วนกลางหนึ่งในสามของกระดูกไหปลาร้าเกิดจากแรงอัดตามแนวแกนของกระดูก ซึ่งตรงตามกลไกของการบาดเจ็บที่พบได้ทางคลินิก

คำสำคัญ : กระดูกไหปลาร้าหัก, กลไกการหัก, แรงอัด, แนวแกน, การทดสอบทางชีวะกลศาสตร์

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