A Standardized Formula to Analyse the Neurovascular Safety in Clavicular Plating; An Anatomical Study

Shruthi BN¹, Vivikta Venkatesh², Chandrakala C³, Akash Venkatesh⁴, Sarala HS⁵

¹Professor and Head, Department of Anatomy, Rajarajeswari Medical College & Hospital, Bengaluru-560074, India; ²UG Student, Rajarajeswari Medical College & Hospital, Bengaluru-560074, India; ³UG Student, Rajarajeswari Medical College & Hospital, Bengaluru-560074, India; ⁴Statistician, Department of Community Medicine, Rajarajeswari Medical College & Hospital, Bengaluru-560074, India; ⁵Assistant Professor, Department of Anatomy, Rajarajeswari Medical College & Hospital, Bengaluru-560074, India.

ABSTRACT

Introduction: Clavicle shaft fractures are common traumatic injuries that occur in the middle third of the clavicle, treatment is controversial but may be nonoperative or operative based on the degree of displacement and patient factors.

Objective: Our present study aims to determine a relationship between the length of the clavicle and the depth at which the neurovascular structures lie.

Methods: Our study was conducted on 30 cadavers (30 right upper limbs & 30 left upper limb). Measuring tape, vernier callipers and cay wires were used to determine the length and the depth of the clavicle.

Results: After the thorough statistical observation and analysis of the data set, we were able to apply the regression equation. By careful calculation, we derived the regression coefficient for this particular data set and were able to arrive at an accurate result.

Conclusion: Hence, by this equation, we could determine the depth of the neurovascular structures just by knowing the length of the clavicle. The present study could help orthopaedics intraoperatively in the precise selection of the screws which could minimize the risk of injury to subclavian vessels in the surgery and favour desirable outcomes.

Key Words: Clavicular fracture, Clavicular plating, Subclavian vessels, Clavicular length, Neurovascular bundle, Standardized formula

INTRODUCTION

The clavicle or the collar bone is one of the most peculiar bones in our body. It is the only long bone which lies horizontally and has two primary centres of ossification with a membranous development. This bone is responsible for the transmission of weight from the upper limb to the trunk. The clavicle is closely related to the neurovascular structures supplying the upper limb. Hence, breakage or fracture of the bone can have adverse effects on the day to day lifestyle of the affected individual. The clavicle has important anatomical relationships with subclavian vessels and brachial plexus, especially in its middle third, where the curvature is the reference point used for accessing these structures. In case of trauma or surgery in the middle third of the clavicle, fixation is done employing open surgery using synthetic material; these structures may become injured because of their anatomical proximity.¹,²

Plating of clavicle fractures has been thought a safe and reliable procedure but it is not without risks. There are 2 described locations for plate placement in clavicle fractures, superior and anterior. Those who advocate of superior plating claim less soft-tissue injury, stronger biomechanical profile, and easier surgical technique.³-⁵ Complications of superior plating include injuries to major neurovascular structures as subclavian vessels and brachial plexus.⁶ Iatrogenic neurovascular complications are fortunately rare. However, there are several case reports and small series of limb-threatening and even fatal neurovascular complications after clavicle
surgery. These injuries have been reported while drilling or screwing.\textsuperscript{8-10}

Given their rarity, we could find no high-level studies that looked specifically at neurovascular injuries but represents a potentially devastating outcome from an operation that is treating a problem that is neither life nor limb-threatening. If the screw applies pressure to the underlying structures or pierces it, it could lead to adverse effects since these underlying structures are responsible for the entire neurovascular supply of the upper limb. Several reports have advocated different techniques to avoid damaging these important infraclavicular structures but an excessive undesired soft-tissue dissection is required or a safe drilling angle should be calculated which is not easy during the trauma surgery.

This study aims to find the simple and effective method to avoid neurovascular complications in clavicle fractures plating by determining the relationship between the depth at which the neurovascular structures lie from the length of the clavicle. This helps the orthopaedic surgeons by choosing the right sized screw for clavicular plate fixture surgeries. This establishes neurovascular safety at the surgery of the middle third of the clavicle, employing dissection in cadavers.

**MATERIALS AND METHODS**

**Inclusion and Exclusion Criteria**

This study is cadaveric, 30 cadavers of an elderly age group between 55-70yrs, with a mean weight of 70kg, mean height 1.7m. Both sides of the cadaveric specimen were used and they were void of any congenital malformations, trauma or previous surgery in the shoulder region.

**Instruments**

Cay wires, bone drill, measuring tape, vernier callipers and instruments in the anatomical dissection kit were used which include scalpel, forceps and scissors.

**Procedure**

30 adult south Indian cadavers were dissected in the clavicular region bilaterally. The standard guidelines to expose the clavicular area were followed according to Cunningham’s manual of dissection, volume 1, 16\textsuperscript{th} edition\textsuperscript{11}. Deep dissection was performed on either side of the cadavers to expose the clavicle and the neurovascular structures beneath it. The following structures were identified: subclavian vein, upper trunk of brachial plexus and supraclavicular nerves. The subclavian vein is marked to measure the distance from the most proximal point of the middle third of clavicle (Figure 1).

The regression equation is as follows:

$$Y - y = bYX (X - x)$$

$Y$ is the depth of the subclavian vessels from the clavicle

$X$ is the length of the clavicle for which you would calculate the depth
Statistical Analysis

Based on the regression equation our research has arrived at a formula which can determine the depth at which the subclavian vessels are situated concerning the clavicle measuring from its superior surface by knowing the length of the clavicle. The regression equation helps us in determining a dependent variable based on an independent variable. In this case, the independent variable would be the length of the clavicle and the dependent variable would be the depth of the neurovascular structures from the clavicle.

The regression equation of Y on X

To estimate the depth of subclavian vessels are situated based on length of clavicle both on Right side and Left side

\[ Y = \bar{y} + b_{yx} (X - \bar{x}) \]

Here,
- \( Y \) is the depth of the subclavian vessels from the clavicle
- \( \bar{y} \) is the mean of the depth of the clavicle
- \( b_{yx} \) is the regression coefficient
- \( X \) is the length of the clavicle for which you would calculate the depth
- \( \bar{x} \) is the mean of the length of the clavicles

The regression coefficient can be calculated as follows:

\[ b_{yx} = \frac{n \sum xy - \sum x \sum y}{n \sum x^2 - (\sum x)^2} \]

Here,
- \( \sum xy \) is the sum of the product of the length of the clavicle and underlying depth.
- \( \sum x \) is the sum of the lengths of the clavicles
- \( \sum y \) is the sum of the underlying depths of the structures
- \( \sum x^2 \) is the sum of the squares of the lengths of the clavicle
- \((\sum x)^2\) is the square of the sum of the lengths of the clavicle
- \( N \) is the number of specimens

RESULTS

The anatomical distance from the midpoint of the clavicle to the subclavian vein was measured in all the specimens with the arm held in anatomical position. The mean values of all the specimens are tabulated in table 1 and 2. A data set was formed with the following information, length of the clavicle, mid-point of where the hole was drilled and the depth of the neurovascular structures.

The mean length of clavicular length on right 14.81 cm and left side 14.84 cm, and from the middle of the clavicle to the subclavian vein, the mean depth is 1.33 cm & 1.43 cm on right and left sides respectively.

The standard deviation of the clavicular length on the right and left side is 1.53 cm on both right and left side. The SD of the depth at which the vessels lie is 0.24 cm and 0.20 cm on right and left sides respectively.

RIGHT SIDE

Calculating for the right side Regression Coefficient,

\[ \sum x = 444.2 \]
\[ \sum y = 39.86 \]
\[ \sum x^2 = 589.74 \]
\[ (\sum x)^2 = 6644.58 \]

\[ X = 14.81 \]
\[ Y = 1.33 \]

Substituting the above values in the equation for the regression coefficient formula we get,

Regression coefficient \( b_{yx} = \frac{n \sum xy - \sum x \sum y}{n \sum x^2 - (\sum x)^2} \)

\[ = \frac{30 \times 596.35 - (444.2) (39.86)}{30 \times 6644.58 - 197313.6} \]

\[ b_{yx} = -0.0067 \]

Therefore, regression coefficient \( b_{yx} \) for the right side = -0.0067

Y on X Regression equation is fitted, to find the depth of subclavian vessels is situated based on length of clavicle on Right side.

For example to estimate depth when length of clavicle on right side is \( x = 12.4 \)

\[ Y = y + b_{yx} (X - x) \]

\[ Y = 1.33 + (-0.0067) (12.4 - 14.81) \]

\[ = 1.33 - 0.0067 (12.4) = 1.4292 - 0.0830 \]

\[ Y (12.4) = 1.3462 \]

LEFT SIDE

\[ \sum xy = 634.2 \]
\[ \sum x = 445.3 \]
\[ \sum y = 42.9 \]
\[ \sum x^2 = 6677.51 \]

\[ (\sum x)^2 = 198292.1 \]
\[ X = 14.84 \]
\[ Y = 1.43 \]
Substituting the above values in the equation for the regression coefficient formula we get,

Regression coefficient \((b_{xy}) = \frac{n \sum xy - \sum x \sum y}{\sum x^2 - (\sum x)^2}\)

\[ = 30 \times 634.2 - 445.3 \times 42.9 = 198292.1 \]

\[ b_{xy} = -0.0381 \]

Therefore, regression coefficient \((b_{xy})\) for the left side is \(-0.038\)

Y on X Regression equation is fitted, to find the depths of subclavian vessels are situated based on length of clavicle on Left Side.

For example to estimate depth when length of clavicle on left side is \(x = 12.3\)

\[ Y = y + b_{xy} (X - x) = 1.43 + (-0.0381) (12.3 - 14.84) = 1.43 - 0.0381 \times 12.3 = 1.5268 \]

Z test: (To know is there any significant difference in length of Clavicle considering in right and left side)

To analyse the significant difference between Right and Left side Length of Clavicle

The Null Hypothesis:

\(H_0: \) There is no significant difference between Right and Left side Length of Clavicle

\(H_1: \) There is a significant difference between Right and Left side Length of Clavicle

Under \(H_0\), the test statistic is

\[ Z = \frac{X_1 - X_2}{\sqrt{s_1^2 + s_2^2/n_1/n_2}} \approx N(0,1) \]

\[ = -0.093, \text{ (The P-value is 0.9259, 0.9259 >0.05 therefore it is not significant)} \]

Here the test is the two-tail test at 5% level of significance, the critical values are -1.96 and 1.96

Since the value lie within this region, therefore, \(H_0\) is accepted.

That is there is no significant difference between Right and Left side Length of Clavicle

Z test: (To know is there any significant difference in depth of Clavicle considering in right and left side)

To analyse the significant difference between Right and Left side depth of Clavicle

The Null Hypothesis:

\(H_0: \) There is no significant difference between the Right and Left side depth of Clavicle

\(H_1: \) There is a significant difference between the Right and Left side depth of Clavicle

Under \(H_0\), the test statistic is

\[ Z = \frac{X_1 - X_2}{\sqrt{s_1^2 + s_2^2/n_1/n_2}} \approx N(0,1) \]

\[ = -1.758, \text{ (The P-value is 0.0787, 0.0787 >0.05 therefore it is not significant)} \]

Here the test is the two-tail test at 5% level of significance, the critical values are -1.96 and 1.96

Since the value lie within this region, therefore, \(H_0\) is accepted.

Correlation Analysis is used to find the correlation between length and depth of Right and left side Clavicle (Figure 3)

![Figure 3: Correlation between length and depth of clavicle in right limbs. \(r = -0.0419, P\)-value 0.829, It is not significant. Calculations and digits are expressed in centimeter.](image-url)
Correlation Analysis is used to find the correlation between length and depth of Right and left side Clavicle (Figure 4)

![Figure 4: Correlation between length and depth of the clavicle in left limbs. r = -0.2905, P-value 0.12, It is not significant. Calculations and digits are expressed in centimeter.](image)

After the data set were grouped & thorough statistical analysis we came to know that:

- There is no significant difference between Right and Left side Length of Clavicle
- There is no significant difference between the Right and Left side depth of Clavicle.
- Z test: (To know there is any significant difference in depth of Clavicle considering in right and left side)
  
  \[ Z = -1.758 \]  
  
  (The P-value is 0.0787, 0.0787 >0.05 therefore it is not significant)
- Here the test is the two-tail test at 5% level of significance, the critical values are -1.96 and 1.96
- Since the value lie within this region, therefore, \( H_0 \) is accepted
- Correlation between Right length and depth of clavicle : \( r = -0.0419 \), P value 0.829, It is not significant.
- Correlation between Left length and depth of clavicle : \( r = -0.2905 \), P value 0.12, It is not significant.

**DISCUSSION**

Clavicular fractures at midshaft (at the junction of medial 2/3rd and lateral 1/3rd) are very common. The most common and current treatment of choice is the internal fixation with superior plating. Though there are many options available for surgical fixation, like clavicular plating and intramedullary(IM) fixation they pose highest risk. IM fixation has the potential advantages of a smaller incision and less dissection and soft tissue exposure. For the last two decades, the use of rockwood and hagie pins represented the most popular form of IM implants. The use of alternate IM implants, such as Kirschner wires, titanium elastic nails, and cannulated screws, also has been described in limited case series. However, concerns persist regarding the complications associated with the use of these implants.

Though there are several studies which have reported regarding the morphometry of clavicle, there is less number of studies which report a method which aids in the accurate selection of screws to avoid these iatrogenic injuries. The present study establishes the interrelationship between the length of the clavicle to that of the depth at which the subclavian vein lies to reduce the complications caused due to IM devices.

The 3-dimensional study by Sinha\(^1\) have reported that the subclavian vein is closely related to the clavicle in the medial half, drills and screws should be aimed superior to inferior in the medial third and anterior to posterior in the middle third of the clavicle. Caution must be employed if the measured screw length is >16 mm. This is derived from the narrowest reported clavicle thickness (11 mm) and the closest reported distance of the vessels to the middle third of the clavicle (5 mm). If the screw is longer than this or is markedly longer than the adjacent screws, the surgeon must pay close attention to the trajectory of the screw and the degree of prominence to ensure they are within the safe range. The maximum allowable is 4 mm, based on the closest reported distance of the vessels to the middle third of the clavicle (5 mm).

A cadaveric study by Robinson\(^3\) has found out that the closest structure to the clavicular cortex is a subclavian vein which lies about 4.8mm. Unlike other surgical approaches, palpation or visualization of the deep neurovascular structures at risk is difficult to be performed by a single approach and performing additional incisions is not part of the routine approach.

The minimum screw prominence resulting in a vascular injury was 8 mm. It is alarming that this length is less than the reported mean distances between the clavicle and the arteries (17-26 mm)\(^6,15\). It has been proposed that the injury occurs when the vessels are brought closer to the metalware during arm movement.\(^9\) The distance from the superior surface of the clavicle to the superior surface of the subclavian vein in cadavers has been reported as 22-34 mm.\(^14\) A magnetic resonance imaging (MRI) study reported the distance from the anterior surface of the clavicle to the sheath of the neurovascular bundle as 11-22 mm in the medial third and 16-64 mm in the middle third.\(^6\)

Screws that protrude from the posterior and posteroinferior aspects of the clavicle are at risk of injuring these vascular structures. Despite this, vascular injuries have, fortunately, been rare, and several large series of clavicle fixation cases have reported no vascular complications.\(^15\) The length that a screw can safely protrude from the far cortex of the clavicle has not been reported. Regarding safe drilling, Alajmo\(^16\)
evaluated the effect of using sharp versus blunt drill bits and their analysis showed that plunging by 5 and 20 mm occurred using sharp and blunt drill bits, respectively.

According to the relationship of the clavicle to the axillary artery and vein in the cephalad-caudal plane, Galley\textsuperscript{14} advocated the use of an 18-mm drill stop but, in our opinion, a fixed 18-mm drill could be too large in some cases and too short in others.

Collinge\textsuperscript{16} suggested that, to avoid neurovascular complications, drilling should be applied in a posterior and superior direction, whereas Venkatachalam\textsuperscript{17} recommended that it should be performed from anterior to posterior. Though there are various surgical methods for fixing fractures with unstable variation of lateral clavicle fracture, the gold standard treatment option is debatable and challenging. But in a study by Ashwin Chauhan, \textit{have found out that,} the functional outcome after using a pre-contoured locking plate for distal end of clavicular fractures is beneficial and satisfactory.\textsuperscript{18}

It seems to be clear that knowing accurately the clavicle anatomy and its relation to the subclavian neurovascular bundle, iatrogenic injury can be avoided by controlling the drilling direction as advocated by Qin\textsuperscript{19} but from our point of view, keeping in mind a safety drilling angles, the neurovascular structure closest to the middle third of the clavicle is subclavian vein and most susceptible to injury. During our dissection, it was observed that the subclavious muscle provided anterosuperior protection for the adjacent neurovascular structures and that it could be used as an anatomical reference point for delimiting a safety zone.

Our technique aimed to minimize the neurovascular complication during its use. This can be used by less experienced surgeons who can be more confident during surgery. The main advantage of our technique is its simplicity, accessibility, and cost-effectiveness as the no-special device is required and easy to assess intraoperatively.

If there is any doubt about the degree of screw prominence, an intraoperative assessment must be performed. Subperiosteal dissection can be used to identify the screw tips. Intraoperative fluoroscopy can be used in this situation but maybe unreliable if the imaging plane is not perpendicular to the screws. The present study will be supported with radiographic studies by comparing the cadaveric measurements with that of CT measurements.

**CONCLUSIONS**

Although rare, limb or life-threatening neurovascular complications from clavicle surgery have potentially devastating implications for young & active patients. The subclavian vein remains in closest proximity to the clavicle and it is the vital structure most likely to be inadvertently injured. The distances measured are accurate as the arms are placed in anatomical position. An understanding, appreciation of the proximity and relationship of the vessels concerning the clavicle will hopefully enable surgeons to choose the exact size of the screw needed, further minimise the risk of vascular injury during plating of the clavicle. We believe that a simple procedure as limiting the drill length according to the cephalad-caudal length of the clavicle measured in the preoperative x-ray and confirmed intra-operative is a valid option to help mainly young surgeons to avoid these major complications in clavicle fractures plating. The present study findings are expected to help orthopaedic surgeons in accurately choosing the clavicular screw.

**ACKNOWLEDGEMENTS**

Authors acknowledge the immense support and encouragement received from the management of Rajarajeswari Medical College and Hospital, Bengaluru, Karnataka, India to conduct this study. We extend our thanks to Dr. Prasanna Assistant professor of Orthopedics at RRMCH for his guidance.

**Conflicts of interest:** Nil

**Source of funding:** Nil

**REFERENCES**


