Original article

Humeral fractures by arm wrestling in adult: a biomechanical study

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Abstract. Humeral shaft fractures may occur as a result of arm wrestling. We discuss the biomechanics of this rare injury mechanism. Using Strength of materials concepts, Computerized Tomography and Bone Density Scans we studied the biomechanical and anatomical conditions that predispose to this particular fracture. An unfavorable ratio between inner-outer diameter and a low bone mineral concentration in the distal third of humerus compared to other sections of bone were seen as critical aspects. The biomechanical study observed the primary importance of these factors to explain the typical shape and location of this fracture. These results indicate that each arm wrestler should be conscious of the risks of practicing this activity. (www.actabiomedica.it)

Key words: adult, wrestling injuries, humeral fractures, male, biomechanics

Introduction

Arm wrestling is a rapidly growing sport all over the world with an increasing number of athletes. During the match, two players, sitting at a table in front of each other, try to turn the opponent's arm down to a specified level. These torsional efforts, combined with other factors such as poor posture (1), inadequate athletic training (2-4), hypertrophy of muscles (5) and inefficient "motor control mechanisms" (3, 6) may cause a significant trauma. We observed five patients at the Department of Orthopedic Surgery (Fig. 1) who had suffered this injury due to an arm wrestling match and all cases presented a spiroid fracture at the mid-distal humerus. The following document will assess the biomechanical and anatomical causes behind this particular fracture.

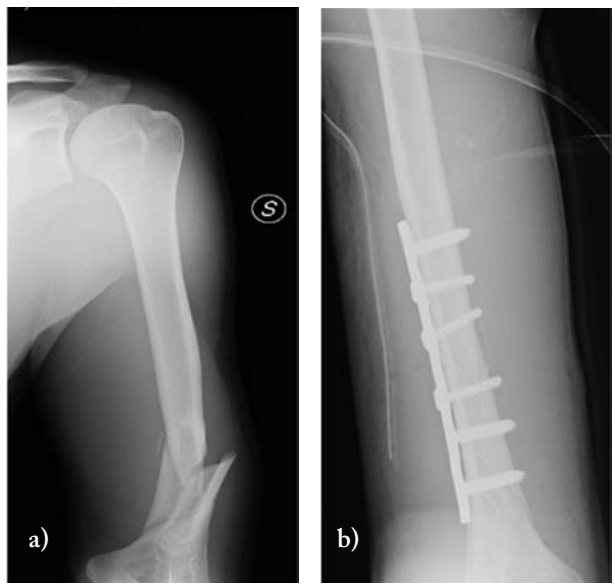

Figure 1. a, b) Anteroposterior X-rays of the Spiral fracture of the humerus and his treatment whit plating

Materials and methods

One humerus of a human cadaver taken from an healthy adult male subject was examined. The humerus was investigated using High Resolution Computerized Tomography (H.R.C.T.) and Bone Mineral Density (B.M.D.) scans. The high-resolution C.T. uses thick tops thinner and allows to obtain more detailed images than those provided by conventional C.T. This method of investigation has permitted us to determine the cortical bone thickness distribution (the inner and outer diameters) of various sections of our humerus. The B.M.D. technique is a medical diagnostic technique used to determine the status of bone mineralization, revealing the degeneration of the structure. For the implementation of this technique has been positioned, under the humerus, a bag containing five liters of physiological saline.

The biomechanical study was performed using Strength of materials concepts in association with the Department of Industrial Engineering. Strength of materials deals with the mechanics of structures under load and describes the internal stresses due to the structural static and dynamic behavior using mathematical-physical models to formulate and solve problems of structural strength (7).

Results

The M.O.C. study showed that the humerus, at the level of the distal third, has a lower bone mineral density than the other portions (Fig. 2). Bone density is here assumed as a proxy measurement for bone strength, which is the resistance to fracture and the truly significant characteristic. Furthermore, the C.T. revealed that, always at the level of the distal third, the ratio between the outer diameter and the inner is less than the other portions of the bone (Fig. 3) in agreement with observations from the literature (Fig. 4), (10). Arm wrestling puts a high torque action on the humerus bone to a degree seen in few other physical activities. Since normally the humerus bone is not significantly stressed in this direction, injuries can occur surprisingly easily. The humeral fracture by arm-wrestling occur in the distal third of the humerus with

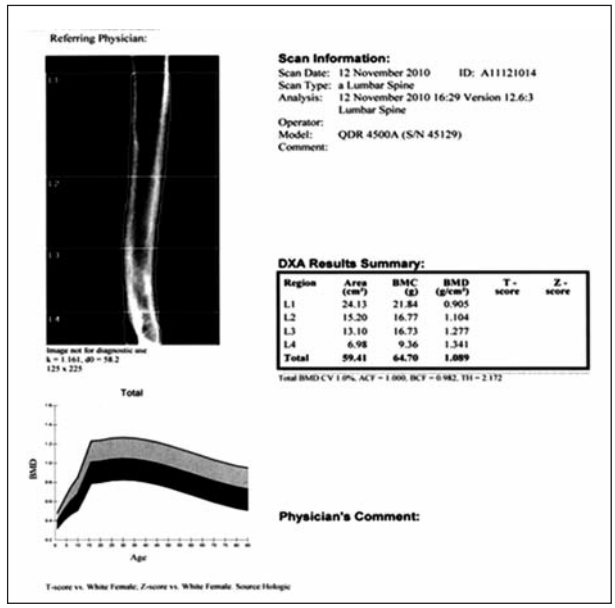

Figure 2. Our B.M.D. study

a typically spiral line fracture. The interpretation of the fracture appearance is obtained considering the scheme of Fig. 5a, where a hollow cylinder is subjected to torque. The shear stress depends on the magnitude of the applied torque to the bone section. The equation that relates the shear stress τ to the torque T is:

$$\tau = \frac{Tr}{I}$$

where r is the distance from the axis of rotation to the point where the shear stress is calculated and I is the moment of inertia of the section. In the case of the hollow cylindrical structure of Fig. 3, resembling a bone section, the moment of inertia is:

$$I = \pi \frac{(D^4 - d^4)}{32}$$

where *D* and *d* are the outer and inner diameter, respectively. The maximum shear stress develops at the surface.

$$\tau_{max} = \frac{16TD}{\pi (D^4 - d^4)}$$

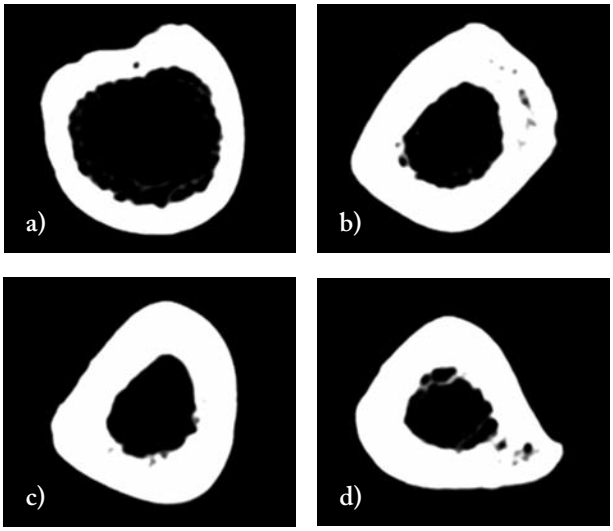

Figure 3. a, b, c, d) The hollow section of the humeral bone at the proximal, medial and distal ends. Our T.C. study

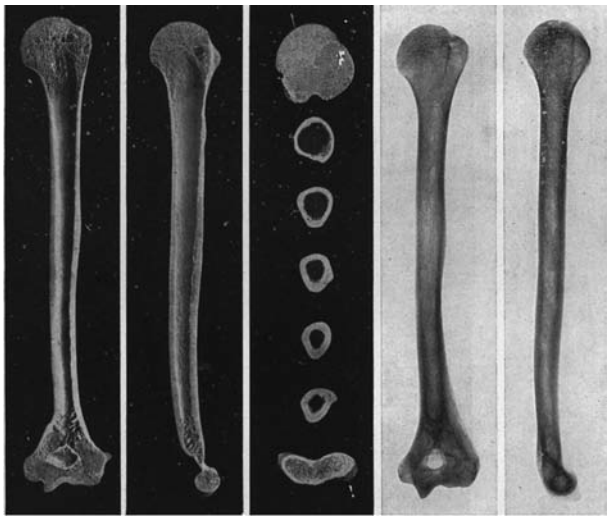

Figure 4. Front section, sagittal, seven transverse sections, anteroposterior and lateral location photography. Taken from "technique of fracture treatment", Dr. Lorenz Bohler (10)

By equilibrium consideration, the 45° direction with respect to the axis subjected to either tensile stress $\sigma = \tau$ or compression $(-\sigma = -\tau)$ depending on the torque direction (Fig. 5) (8). The cortical bone material is known to have a relatively high compressive strength (about 170 MPa) but poor tensile strength of 104–121 MPa, meaning it resists pushing forces well,

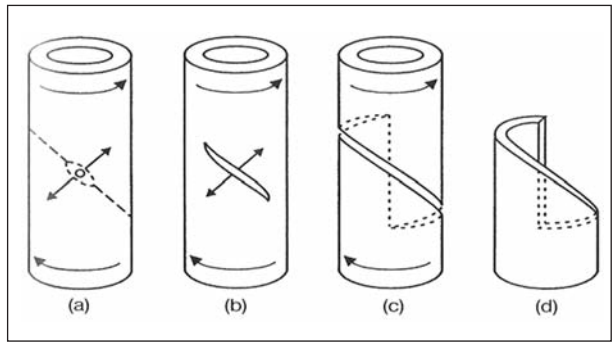

Figure 5. Evolution of the breaking line in a hollow cylinder subjected to torsion (8)

but not pulling forces. Therefore when the limiting torque T for that bone section is reached, fracture occurs as shown schematically in Fig. 5 b 5c. It is seen experimentally that the torsional strength of a humerus is 40-60 MPa (3).

Discussion

We treated five fractures of the humerus sustained during arm wrestling. All patients were healthy young males between 22 and 29 years and had no underlying bone disease. Based on these cases we have tried to understand the causes of this uncommon fracture in collaboration with Department of Biomedical Sciences and Internal Medicine, section of Diagnostic Imaging (Department of Clinical Sciences) and Department of Industrial Engineering. The practice of arm wrestling is cause of a particular type of a spiral humeral fracture that occurs typically under the humerus third distal. During the match the shoulder joint is actively internally rotated against the opponent while the elbow is fixed in flexion, resulting in enormous violent torque forces across the humeral shaft (11). In literature, the most frequent injuries caused by arm wrestling are the fracture of the medial epicondyle (in adolescents) (5, 12-14), the rupture of the subscapularis tendon and the spiral fracture of the distal third of the humerus with a very clear prevalence of the latter (12). EMG studies have shown that the pectoralis major muscle and the flexor carpi ulnaris are mainly used as agonists participate in simulated arm

wrestling while the biceps and the pronator teres muscle appear to play secondary functions (Figure) (15). The players who suffer this injury are typically young males between 20 and 40 years and are not regular arm wrestler [6, 12, 16, 18, 21, 22]. In fact, sports characterized by fast movements at high intensity, such as sprinting short distances, fencing and tennis, cause a significant increase in bone mass (4, 21, 23). Clinically, it shows a deformity of the arm and the presence of preternatural motility associated with pain. Several authors have already shown that it is not possible to obtain a humeral fracture during arm wrestling in normal conditions (1, 3). However, there are many situations that predispose to fracture as reported: an unbalance between muscular strength and thickness of the humeral cortex caused by anabolic steroid (24), an alteration of motor control mechanism induced by alcohol, drugs or excessive tiredness and by using poor posture that creating considerable efforts of torque and bending due to the increased thrust and the erroneous thrust centers assumptions (1, 25).

Conclusions

We have shown, through the study M.O.C. and C.T., how humeral bone presents a very particular anatomy that makes it more vulnerable to fractures in the distal third.

The biomechanical study has shown that the humerus breaking during arm wrestling is mainly determined by the intensity of the torque (which depends on the type of exercise), by the outer and inner wall's bone diameter (which depend on the characteristics of the section of the bone) and the tensile strength of the bone (depending on the consistency of bone). This allowed us to explain that fractures occur at the mid-distal humerus because there the humerus presents the most unfavorable outside-inner diameter ratio and reduced bone concentration.

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