ECRONICON OPEN ACCESS

ORTHOPAEDICS
Review Article

The Biomechanical Forces that Act on the Elbow Joint

Shahid MK[1]*, Fletcher M[2], Robati S[3] and Pemmaraju G[2]

[1]*Department of Trauma Orthopaedics, Queen Elizabeth Hospital, United Kingdom*

[2]*Department of Trauma Orthopaedics, New Cross Hospital, United Kingdom*

[3]*Department of Trauma Orthopaedics, Darrent Valley Hospital, United Kingdom*

***Corresponding Author:** Mohammad Kamran Shahid, Department of Orthopaedics, Queen Elizabeth Hospital, 46, Pereira Road, Harborne, Birmingham, B17 9 JN. United Kingdom.

Received: January 20, 2015; **Published:** March 31, 2015

Abstract

There is a wide range of stabilizing and active factors required for the use of the elbow in activities of daily living. These then reflect on understanding in the management of elbow disorders, of which elbow prostheses are looked at here. The joint is maintained by the integrity of the capsuloligament and the muscles proximal and distal to the joint. Studying biomechanics includes looking at the forces acting through the elbow joint, the kinematics and the maintenance of elbow stability through action of active and passive stabilizers.

Each force exerts a moment through a moment arm, which can be represented by a free body diagram (Figure 1). Elbow flexion and extension occurs around an instant center of rotation involving an area of 2 to 3 mm in diameter at the trochlea. Pronation and supination are important for function, and the axis of movement is a longitudinal axis from the centre of the radial head to the centre of the ulna head. Active stability is maintained through action of muscles providing joint compressive forces. Passive stability arises from the humerus articulating very congruently with the ulna and the role of surrounding soft tissue stabilizers to include the lateral and medial collateral ligament complexes.

This review paper evaluates the current literature regarding elbow biomechanics.

Keywords: *Elbow; Elbow biomechanics; Elbow prosthesis; Elbow joint replacement; Elbow kinematics*

Introduction

The elbow joint is a complex structure that acts as an important mechanical link in the upper extremity between the shoulder and wrist [1]. It is dynamic, allowing movement at the joint to facilitate arm movement [2], it is static, providing an anchor for movements [3] and a high level of understanding is required when disrupted, allowing physicians and patients to appreciate how important the joint is to everyday function [4,5]. This in turn allows research into complex solutions in elbow treatment and rehabilitation [6,7].

The elbow joint comprises of 3 parts: the radio humeral joint - allows movement between the radius and humerus, the ulnohumeral joint - between the ulna and humerus, and the superior radioulnar joint - between the radius and ulna, which are all contained within the same joint capsule [8].

The main movements occurring at the elbow joint are flexion, extension, pronation and supination [9]. The ulnohumeral and radio humeral joints act as a 'modified hinge joint' [8,10] allowing range of motion from 0° to approximately 145° in the normal patient [11]. Flexion here is due to the action of biceps, brachialis and brachioradialis muscles. Extension is achieved from the action of the triceps muscle located in the posterior aspect of the arm [12]. Supination and pronation occurs at the superior radioulnar joint which acts as a 'pivot' joint [13] and normal values quoted are approximately 75° pronation and 80° supination [11]. Supination is achieved through action of biceps and supinator muscles whereas pronation requires the use of pronator teres, pronator quadratus, and flexor carpi radialis muscles [8]. The forearm is angled slightly away from the long axis of the humerus in full extension. This is known as the 'carrying angle' and has a mean angle of 12.7 degrees +/-3.8 degrees [14].

The biomechanics of the elbow joint are all affected by the bones, muscles and ligaments involved [15]. Weakness in muscle or injury to ligaments can result in abnormal forces in the elbow, which can ultimately over time cause degeneration of the articular cartilage of bone [13].

Excessive movement or force applied to the elbow can injure these structures. Loftice., *et al*. [10] describes biomechanics as the 'science that examines forces acting upon and within a biological structure and effects produced by such forces.' This review attempts to explore the literature regarding the biomechanical forces that act on this elbow joint, which in combination with anatomy is essential for the optimum management of elbow disorders.

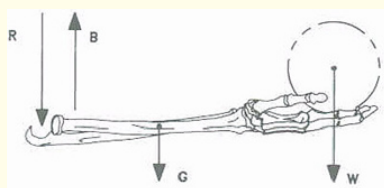

Figure 1: *Free body diagram showing forearm holding a ball [16]. The biomechanical forces that act on the elbow joint.*

Materials and Methods

The review of literature was performed through the PubMed database and used key words including: 'Elbow', 'elbow biomechanics', 'elbow prosthesis', 'elbow joint replacement', 'elbow kinematics'.

The exclusion criteria included: articles not in English and where there was no mention of elbow biomechanics within the article.

Materials also accessed were referenced online tools for information and clinical and anatomical textbooks.

Results and Discussion

The review of literature was performed through the PubMed database and used key words including: 'Elbow', 'elbow biomechanics', 'elbow prosthesis', 'elbow joint replacement', 'elbow kinematics'.

Static Analysis of the Elbow Joint

One can apply the basic principles of statics to the elbow joint to analyze the effects created by acting forces and moments. Lucas., *et al.* [17] suggests a free- body diagram can be useful (Figure 2). On the diagram, it is assumed that the wrist, hand and finger joints are all rigidly fixed. Forces have shown acting on the free body including the joint reaction force R acting between the ulna and the humerus, and the force acting through the biceps muscle B.

Capo., *et al*. [18] has explored three dimensional analysis of soft tissue footprints and anatomy through nine cadaveric dissections providing mean quantitive data E.g. medial collateral ligament mean origin (humeral) footprint area of 216 mm^2. This can provide useful information to the surgeon in helping to restore normal elbow biomechanics and preserve range of motion.

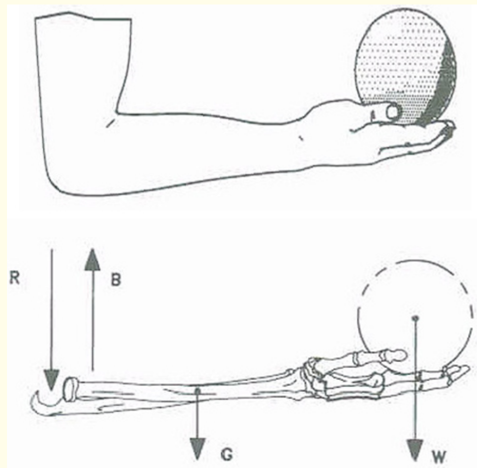

Figure 2: *A: Arm flexed at 90° at the elbow, with wrist and fingers rigid, holding a ball in palm of hand.*
B: Free body diagram showing forearm holding a ball [16].

In the free body diagram, G is the weight of the forearm acting vertically downwards, B is the biceps force, and R is the joint reaction force. To generate an idea of what possible force prosthesis needs to sustain, it is important to know: the relationship between forces acting through biceps and gravitational force through the hand as well as joint reaction force. Lucas., *et al*. [17] describes using a similar model to that above of the elbow that the force in the biceps is roughly 10 times that held in the hand.

This was calculated by taking moments about the elbow, taking into account that the joint reaction force has a moment arm of zero and so creates no moment about the joint axis.

i.e., Moments about Elbow joint = 0 = $(B \times D1) - (G \times D2) - (W \times D3)$
D1, D2, D3 are perpendicular measured distances from the elbow joint.
G is the weight of the humerus.
W is the weight of a mass in the hand.

Using the force through the biceps, one can then take moment in the 'y-axis' direction where the sum of the moments are equal to zero.

i.e., sum of moments in 'y direction = 0 = $- R + B - G - W$

From the above equation, we can calculate R from the known values of B, G and W. Lucas., *et al*. [17] describes that using weights and flexing at the elbow, the forces passing across the articulating surface of the elbow will be approximately 8.5 times the weights in his hand. This occurs from taking moments of all forces acting about the forearm taking account of the distances from the elbow joint where they all act. Morrey., *et al*. [19] described that 60% of the axial load at the elbow joint will be transmitted through the radio humeral joint, which compares with 40% through the ulnohumeral articulation.

Dynamic Loads at the Elbow

Significant compressive and shear forces occur at the elbow joint [20-22]. The joint reaction forces vary with elbow position [23], it has been shown that the force transmission is greatest between 0 and 30 degrees of flexion and is greater in pronation than supination [22]. With the elbow extended, the overall force on the ulno-humeral joint is concentrated on the coronoid. In flexion, this force moves towards the olecranon.

Some studies have shown that the greatest amount of force is generated with the initiation of flexion [24]. Calculations suggest that about three times the body weight may be transmitted across the elbow joint when it is flexed at 90 degrees [24]. The forces involved, and the reaction to the action may contribute to the degeneration seen in arthritis.

Assessment of physiological patterns at a frequency to potentially simulate daily movements of the elbow via testing machine [25] and via three-dimensional video analysis [26] may have a role in assessing implants for use in joint reconstruction.

This may include in the choice and angulation of plates for injuries around the joint. This is turn may affect the success or otherwise of rehabilitation and maintenance of function [27].

Knowledge of the changes in extremes of load at the elbow also has a role in the prevention and treatment of injuries in athletes [28]. The patterns afforded by the analysis of stiffness around the joint changing with task may allow prediction of the injury sustained by repeated force such as in throwers, confirmed with clinical and radiological assessment [29]. In these cases, valgus and extension loads may be the culprits, with requirements of return to function higher than the normal elbow injury [30].

Flexion and Extension

McRae [11] has reported that the normal elbow joint allows flexion and extension from 0° to 140° and the functional range of motion to perform activities of daily living is described by Morrey., *et al*. [15] to be in the 30° to 130° range. It has been shown that elbow flexion and extension occurs around an 'instant center of rotation involving an area of 2-3 mm in diameter at the trochlea' [1]. Morrey., *et al*. [31] has shown that the ulnohumeral joint also has 6° axial rotation due to the obliquity of the trochlea groove. These findings are important in consideration for designing elbow implants to try to restore anatomy and biomechanical properties as close as possible to the original joint.

Willing., *et al*. [32] described the use of computational models to predict the range of elbow motion calculated from computed tomography image data. This data could be useful in assisting surgeons in improving the outcomes of surgical treatment of patients with elbow contractures.

Allied to this, is the physiotherapy side of rehabilitation and the knowledge of the extremes of movement, while aware of the degree of motion required nominally may improve outcome further down the line of recovery [33,34].

Pronation and Supination

Pronation and supination of the elbow also needs to be considered. The axis of movement for pronation and supination is a longitudinal axis from the centre of the radial head to the centre of the ulna head [35]. According to Naig [36], the radius and ulna lie in parallel, but in supination, the radius crosses over the ulna and during pronation, its head does move distally and dorsally. There is movement of the ulna proximally and medially and of the radius proximally in pronation and distally in supination [37].

It is reported that [38], with an approximate degree of pronation of 80 to 90 degrees and approximate supination of 90 degrees, the average rotation is 180 degrees [39]. Supination is an elbow driven movement, and the substitution allowed through shoulder abduction in pronation does not exist for supination [40].

Ibanez-Gabeno., *et al*. [41], looking at the role of pronator teres and the forces through it, found that the maximal efficiency is the highest in full elbow flexion and close to forearm neutral position for each elbow angle. The vertical component of pronator teres is the highest among all components and is greater in pronation and elbow extension, as well as there being effects from movement further down the forearm to wrist [42].

According to Laksanachareon and Wongsiri [43] we find that the average torque created at the elbow joint is 7 kg-m in male and 3.5 kg-m in female with the elbow at 90 degrees flexion. However, in extension, the torque is less and noted to be 800-900 g-m in male, 350-500 g-m in females. Measurement of torque is changing with assessment of the analysis processes [44]. Morrey., *et al*. [45] describes that at 0° to 30° flexion the forces through the radial head were of greatest magnitude and much greater in pronation (Figure 3). This occurs because the direction of the joint reaction force changes with the angle of flexion, becoming more posterior with elbow flexion and anterior with elbow extension [1]. Figure 4 demonstrates that force vectors acting at the elbow change with flexion angle.

Figure 3: *Magnitude of force across radial head is higher with pronation, suggesting radial head moves more proximally with pronation [19].*

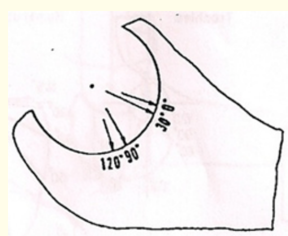

Figure 4: *Force vectors change with flexion angle [55].*

Elbow stability

The biomechanical stability of the elbow joint is maintained through action of both active and passive stabilizing structures [1].

Active stability is achieved through action of muscles providing joint compressive forces [46]. A number of muscles cross the elbow joint [8], which on contraction can create forces in the region of the humerus, radius and ulna inside the joint. Alcid., *et al*. [47] has reported that the congruity of the articulations as well as well as the medial and lateral collateral ligament complexes account for the majority of the joint stability [48]. The muscles have an important dynamic role in stabilising the joint.

Amis and Miller [49] describe that at near full extension of the elbow, the forces were observed to be greatest axially at the distal humerus and such forces decrease with increasing elbow flexion. Amis., *et al*. [50] has shown the joint compressive forces in the sagittal plane acting on the distal humerus in both flexion and extension. Figure 5 has shown the size and direction of such forces acting at the distal humerus.

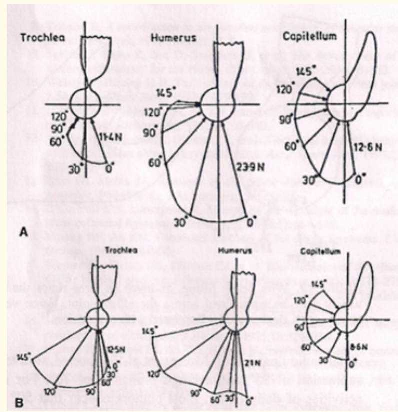

Figure 5: *A: Magnitude and direction of forces at distal humerus during flexion.*
B: Magnitude and direction of forces at distal humerus during extension [19].

Passive stability arises from the humerus articulating very congruently with the ulna and the role of surrounding soft tissue stabilisers e.g. collateral ligaments. The ulna has a very important role and has been shown by An., *et al*. [51] that by removing increasing segments of the proximal ulna, a linear decrease in stability is observed both in flexion and extension (Figure 6).

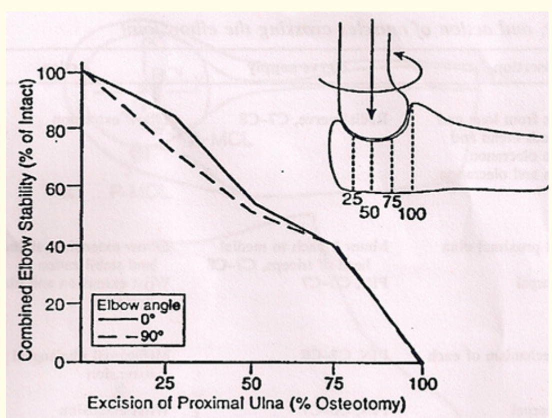

Figure 6: *Removing segments of ulna demonstrates linear decrease in elbow stability in both extension and 90° flexion [1].*

Schueller-Weidekamm and Kainberger [52] describe that the pattern of injury that occurs in specific sport activities are related to movement overload that results in tensile forces and or compression and shear stress. Acute symptoms were described to arise from degeneration of the tendons and ligamentous structures due to repetitive microtrauma from overuse syndrome [53,54].

Fornalski., *et al*. [1] describes that in both extension and flexion, that the proximal half of the sigmoid notch could absorb 75-80 percent of valgus stress. This contrasts to the distal half of the sigmoid notch (coronoid) which resists 60 percent of varus stress in flexion and 67 % in extension [51]. Instability at the elbow increases with the removal of increasing segment lengths of coronoid. Removal of the radial head leads to such instability being more pronounced with less removal of coronoid and is visible in Figure 7.

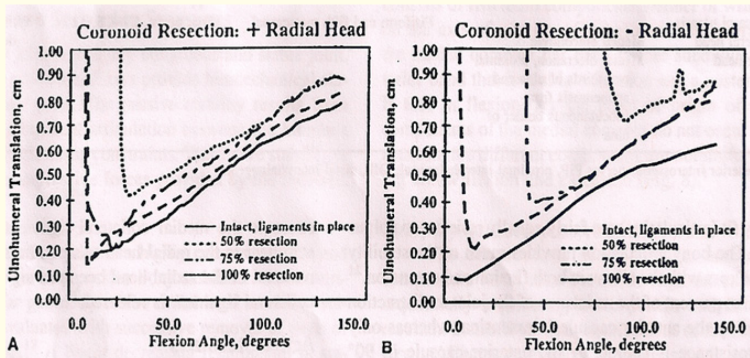

Figure 7: *A: Ulnohumeral instability rises with increasing coronoid removal and the protective role of radial head until almost full extension.*
B: Post removal of radial head, ulnohumeral instability present with less coronoid removal [1].

Passive stability is also achieved through action of soft tissues stabilising the joint to include the medial and lateral collateral ligament complexes and the anterior capsule [55]. Peimer [56] describes that stability against varus stress occurs through action of the lateral ulnar collateral ligament. The lateral collateral ligament complex also comprises of the annular ligament, accessory lateral collateral ligament, and the radial collateral ligament [19]. The site of origin of both the medial and lateral collateral ligament complex is different where the lateral collateral ligament arises from the lateral condyle at the point of axis of rotation of the elbow and the medial complex away from the axis of rotation [57,58]. Hence, the lateral collateral ligament is in equal tension along its length, throughout range of motion of the elbow. However, the medial collateral ligament which comprises of 2 components, has an anterior band which undergoes tension in extension, and a posterior band with tension in flexion [59]. Fornalski., *et al*. [1] explains that as the 2 components of the medial complex do not originating from the axis of elbow rotation, there is not equal tension throughout their length during flexion and extension [60].

The anconeus muscle has an important role in elbow stability [61]. Pereira [62] describes the function of the posterior and deep anconeus as an elbow extensor decreasing in influence with increasing elbow flexion angle. The anterior superficial aspect, which is adjacent and parallel to the lateral collateral ligaments, would most likely work in unison to provide constraint to the posterolateral stability of the elbow [63].

Elbow prosthesis

Elbow joint replacement involves replacing the bones that make up the elbow joint with artificial prosthetic components. Amis., *et al*. [50] describes how an elbow joint prosthesis may be loosened by a combination of tensile and torsion forces. They also add that one can ignore tensile force at the elbow, except when a relaxed limb is given a sudden pull. Hence, tensile forces do not occur through voluntary movements such as lifting a book. This was demonstrated through saggital sections of the hand gripping a handle where tension in the finger flexor tendons creates a palmar flexion moment on the wrist, which is counteracted by the actions of the extensor carpi muscles. The overall result is to compress both the radial head and coronoid process against the humerus.

There are different types of elbow prosthesis in use today. Broadly, these can be divided into unconstrained, semi-constrained and fully constrained varieties. There are various indications for their use but the most important group is of rheumatoid arthritis. Kincaid., et al. [63] does report that total elbow arthrosplasty can improve patients clinically, but long-term survival rates have historically lagged behind those reported for hips and knees. Clinical complications associated with implant wear, osteolysis, stem loosening and device failure have been implicated as reasons for limited long-term survivorship [64]. There is limited published information on the biomechanics and method for preclinical evaluation of total elbow prostheses that could provide direct insight into the mechanisms of failure. Complex fractures round the elbow have been an important indication for elbow arthroplasty. Sorensen., *et al*. [65] reported that TEA in complex fractures of the distal humerus in elderly patients can result in acceptable short- to medium term outcome [66].

Sahu., *et al*. [67] investigated the role of anatomically designed radial head implants on elbow biomechanics compared with non-anatomical implants by determining the radiocapitellar contact pressures. The study showed that geometry was important as the anatomically designed radial head component had a lower and more evenly distributed contact pressures than the non-anatomic implants [68].

Amis., *et al*. [50] describes that failure of the humeral component of the prosthesis has been caused by inward rotational effects of the humerus, when pressure on the palm of the hand leads to a large torque on the elbow joint as a result of the lever arm of the forearm. It is important to understand that joint mechanics does not have a role if the integrity of the medial collateral ligament is lost as the torque will be resisted entirely by the humeral component. When forces act into the hand, we find that small muscles stabilise the wrist, so that the elbow is not acted upon by a great extent by the forearm muscles. Figure 8 shows the forces acting on the forearm during an inward rotation effort where tension in the medial collateral ligament can be approximately two times the body weight and a compression of up to three times the body weight acting on the radial head [50].

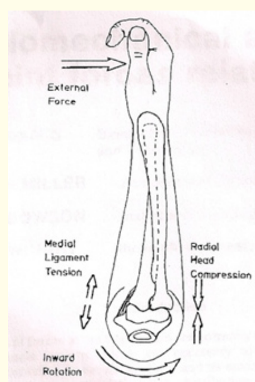

Figure 8: *Forces on the forearm during an inward rotational effort [50].*

We have mentioned earlier the large forces acting on the radial head. The radial head is routinely removed during elbow replacement and analysis of the literature has shown that this is controversial. Amis., *et al*. [50] describes that this procedure was successful for suitable patients not imposing large forces on the arm e.g. arthritic patients. Resection of the radial head leads to transfer of the axial load onto the ulna, which then results in significant tension in the medial ligament to overcome a valgus deformity at the elbow. This tension can contribute to a significant increase in the ulno-humeral force, which is concentrated over the lateral edge of the coronoid process, giving a force of up to 9 times the body weight [54]. Hence, it is important that in a young, active person a radial head replacement is vital for a total elbow replacement.

Conclusions

This review of the literature available looks primarily at the forces acting on the elbow. The available studies have furthered understanding and contributed to the progression of treatment of elbow disorders, of which elbow prosthesis was covered.

The forces, not inconsiderable, across the elbow, as well as the protective functions of muscle and ligament must be considered when enabling re-stabilisation of the elbow. This allows better return to a normal biomechanical balance of the elbow.

Bibliography

1. Fornalski S., *et al*. "Anatomy and biomechanics of the Elbow joint". *Techniques in Hand Upper Extremity Surgery* 11.1 (2003): 1-9.
2. Ibáñez-Gimeno P., *et al*. "Analysis of the forearm rotational efficiency in extant hominoids: New insights into the functional implications of upper limb skeletal structure". *Journal of Human Evolution* 76 (2014): 165-176.
3. Rao ZT., *et al*. "Effect of elbow flexion angles on stress distribution of the proximal ulnar and radius bones under a vertical load: measurement using resistance strain gauges". *Journal of Orthopaedic Surgery and Research* 9.1 (2014): 60.
4. Koontz AM, *et al*. "Upper limb kinetic analysis of three sitting pivot wheelchair transfer techniques". *Clinical biomechanics* (*Bristol, Avon*) 26.9 (2011): 923-929.
5. Tsai CY., *et al*. "The relationship between independent transfer skills and upper limb kinetics in wheel chair users". *BioMed Research International* (2014): 984526.
6. AbdRazak NA., *et al*. "Biomechanics principle of elbow joint for trans humeral prostheses: comparison of normal hand, body-powered, myoelectric & air splint prostheses". *Biomed Eng Online* 13 (2014): 134.
7. Nicol AC., *et al*. "A biomechanical analysis of elbow joint function". *Joint Replacement in the Upper Limb* (1977): 45-51.
8. Moore KL and Dalley AF. "Clinically Oriented Anatomy". Fifth edition, USA (2006): Lippincott Williams and Wilkins, 860-865.
9. Chou PH., *et al*. "Elbow load during different types of bench, press exercise". *Biomedical Engineering- Applications, Basis and Communications* 20.3 (2008): 185-189.
10. Loftice J., *et al*. "Biomechanics of the elbow in sports". *Clinics in Sports Medicine* 23.4 (2004): 519-530.
11. McRae R. "Pocket book of Orthopaedics and Fractures". London: (1999) Churchill Livingstone.
12. An KN., *et al*. "Muscles across the elbow joint: A biomechanical analysis". *Journal of Biomechanics* 14 (1981): 659-669.
13. Joint Pain Info. "Basic Elbow Biomechanics. (2008)
14. Zampagni ML., *et al*. "Estimating the elbow carrying angle with an electrogoniometero: acquisition of data and reliability of measurements". *Orthopaedics* 31.4 (2008): 370.
15. Morrey BF., *et al*. "A biomechanical study of normal functional elbow motion". *Journal of Bone and Joint Surgery* 63.6 (1981): 872-877.
16. Paul SC and Collins GM. "Engineering Biomechanics/ Statics". (2003).
17. Lucas GL., *et al*. "A Primer of Biomechanics. Germany: (1998): Springer Verlag.
18. Capo JT., *et al*. "Three-dimensional analysis of elbow soft tissue footprints and anatomy". *Journal of shoulder and elbow Surgery* 23.11 (2014): 1618-1623.
19. Morrey BF. "The elbow and its disorders. Philadelphia: (2000): WB Saunders.
20. Szekeres M. "A biomechanical analysis of static progressive elbow flexion splinting". *Journal of Hand Therapy* 19.1 (2006): 34-38.
21. Vilimek M. "An artificial neural network approach and sensitivity analysis in predicting skeletal muscle forces". *Acta of bioengineering and biomechanics* 16.3 (2014): 119-127.
22. Fornalski S., *et al*. "Anatomy and biomechanics of the elbow joint". *Techniques in Hand Up Extremity Surgery* 7.4 (2003): 168-178.
23. Halls AA and Travill A. "Transmission of pressure across the elbow joint". *Anatomical Record* 15 (1964): 243-248.
24. Delee J., *et al*. "Orthopaedic Sports Medicine: Principles and Practice". (2010): Philadelphia, PA Saunders.
25. Kiene J., *et al*. "A physiological dynamic testing machine for the elbow joint". *Open Orthopaedics Journal* 7 (2013): 78-85.
26. Søgaard K., *et al*. "Dynamic loads on the upper extremities during two different floor cleaning methods". *Clinical Biomechanics* 16.10 (2001): 866-879.
27. Penzkofer R., *et al*. "Anatomical plate configuration affects mechanical performance in distal humerus fractures". Clinical Biomechanics 25.10 (2010): 972-978.
28. Patel RM., *et al*. "The thrower's elbow". *Orthopedic Clinics of North America* 45.3 (2014): 355-376.
29. Kancherla VK., *et al*. "Elbow injuries in the throwing athlete". *Orthopedic Clinics of North America* 45.4 (2014): 571-585.
30. Cain EL., *et al*. "Elbow injuries in throwing athletes: a current concepts review". *American Journal of Sports Medicine* 31.4 (2003): 621-635.

31. Morrey BF and Chao EY. “Passive motion of the elbow joint”. *Journal of Bone and Joint Surgery* 58.4 (1976): 501- 508.
32. Willing RT., *et al*. “Evaluation of a computational model to predict elbow range of motion”. *Computer Aided Surgery* 19 (2014):1-7.
33. Ellenbecker TS., *et al*. “Rehabilitation of the elbow following sports injury”. *Clinical Sports Medicine* 29.1 (2010): 33-60.
34. Ellenbecker TS., *et al*. “Current concepts in examination and treatment of elbow tendon injury”. *Sports Health* 5.2 (2013): 186-194.
35. Hollister AM., *et al*. “The relation- ship of the interosseous membrane to the axis of rotation of the forearm”. *Clinical Orthopaedics and Related Research* 298(1994): 272-276.
36. Naig S. “Biomechanics of Elbow Complex”. (2008): [Online].
37. Palmer AK and Werner FW. “Biomechanics of the distal radioulnar joint”. *Clinical Orthopaedics & Related Research* 187 (1984): 26-35.
38. Bryce CD and Armstrong AD. “Anatomy and Biomechanics of the Elbow”. *Orthopedic Clinics of North America* 39.2 (2008) 141-154.
39. Boone DC and Azen SP. “Normal range of motion of joints in male subjects”. *Journal of Bone and Joint Surgery* 61.5 (1979): 756-759.
40. Kapandji A. “Biomechanics of pronation and supination of the forearm”. *Hand Clinics* 17.1 (2001): 111-122.
41. Ibanez-Gimeno P., *et al*. “Biomechanics of forearm rotation: force and efficiency of pronator teres”. *Plos One* 9.2 (2014): e90319.
42. Otoshi K., *et al*. “Ultrasonographic assessment of the flexor pronator muscles as a dynamic stabilizer of the elbow against valgus force”. *Fukushima Journal of Medical Science* 60.2 (2014): 123-128.
43. Laksanachareon S and Wongsiri S. “Design of Apparatus to study human elbow motion”. *Biomedical Engineering* (2003): 236-237.
44. Koirala K., *et al*. “Using the Electromyogram to Anticipate Torques about the Elbow”. *Transactions on Neural Systems & Rehabilitation Engineering* (2014): [Epub ahead of print].
45. Morrey BF., *et al*. “Force transmission through the radial head”. *Journal of Bone and Joint Surgery* 70.2 (1988): 250-256.
46. Dunning CE, *et al*. “Muscle forces and pronation stabilize the lateral ligament deficient elbow”. *Clinical Orthopaedics and Related Research* 388 (2001): 118-124.
47. Alcid JG., *et al*. “Elbow anatomy and structural biomechanics”. *Clinical Sports Medicine* 23.4 (2004): 503-517.
48. Spratley EM and Wayne JS. “Computational model of the human elbow and forearm: application to complex varus instability”. *Annals of Biomedical Engineering* 39.3 (2011): 1084-1091.
49. Amis AA and Miller JH. “Design, development, and clinical trial of a modular elbow replacement incorporating cement-free fixation”. *Engineering in Medicine* 13.4 (1984): 175-179.
50. Amis AA., *et al*. “Biomechanical aspect of the elbow: Joint forces related to prosthesis design”. *Engineering in Medicine* 10.2 (1981): 65-68.
51. An KN., *et al*. “The effect of partial removal of proximal ulna on elbow constraint”. *Clinical Orthopaedics and Related Research* 209 (1986): 270-279.
52. Schueller-Weidekamm C and Kainberger F. “The elbow joint- a diagnostic challenge: anatomy, biomechanics, and pathology”. *Der Radiologe* 48.12 (2008): 1173-1185.
53. Field LD and Savoie FH. “Common elbow injuries in sport”. *Sports Medicine* 26.3 (1998): 193-205.
54. Siewe J., *et al*. “Injuries and overuse syndromes in competitive and elite body building”. *International Journal of Sports Medicine* 35.11 (2014): 943-948.
55. Morrey BF and An KN. “Articular and ligamentous contributions to the stability of the elbow joint”. *American Journal of Sports Medicine* 11.5 (1983): 315-319.
56. Peimer CA. “Surgery of the hand and upper extremity”. *New York* (1996): McGraw-Hill.
57. Josefsson PO., *et al*. “Surgical versus non-surgical treatment of ligamentous injuries following dislocation of the elbow joint: a prospective randomized study”. *Journal of Bone and Joint Surgery* 69.4 (1987): 605-608.
58. Josefsson PO, *et al*. “Ligamentous injuries in dislocations of the elbow joint”. *Clinical Orthopaedics and Related Research* 221 (1987): 221-225.

59. Eygendaal D., *et al*. "Posterolateral dislocation of the elbow joint: relation- ship to medial instability". *Journal of Bone and Joint Surgery* 82.4 (2000): 555-560.
60. Armstrong AD., *et al*. "The medial collateral ligament of the elbow is not isometric: An in vitro biomechanical study". *American Journal of Sports Medicine* 32.1 (2004): 85-90.
61. Molinier F., *et al*. "The anconeus, an active lateral ligament of the elbow: new anatomical arguments". *Surgical and Radiologic Anatomy* 33.7 (2011): 617-621.
62. Pereira BP. "Revisiting the anatomy and biomechanics of the anconeus muscle and its role in elbow stability". *Annals of Anatomy* 195.4 (2013): 365-370.
63. Bruce JR and Andrews JR. "Ulnar collateral ligament injuries in the throwing athlete". *Journal of the American Academy of Orthopaedic Surgeons* 22.5 (2014): 315-325.
64. Kincaid Bl. and An KN. "Elbow biomechanics for preclinical evaluation of total elbow prostheses". *Journal of Biomechanics* 46.14 (2013): 2331-2341.
65. Sorensen BW., *et al*. "Primary total elbow arthroplasty in complex fractures of the distal humerus". *World Journal of Orthopaedics* 5.3 (2014): 368-372.
66. Ducrot G., *et al*. "Complex fractures of the distal humerus in the elderly: is primary total elbow arthroplasty a valid treatment alternative? A series of 20 cases". *Orthopaedics & Traumatology: Surgery & Research* 99.1 (2013): 10-20.
67. Sahu., *et al.* "Influence of radial head prosthetic design on radiocapitellar joint contact mechanics". *Journal of Shoulder and Elbow Surgery* 23.4 (2014): 456-462.
68. Gray AB., *et al*. "The effect of a coronoid prosthesis on restoring stability to the coronoid-deficient elbow: a biomechanical study". *Journal of Hand Surgery* 38.9 (2013): 1753-1761.

Volume 1 Issue 1 March 2015