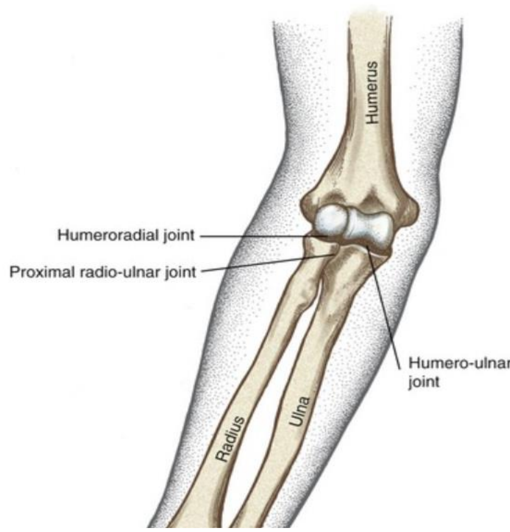
Biomechanics of the Elbow

1. Structure of the Elbow

The **elbow joint** connects the arm and forearm and provides both **mobility** and **stability** during daily and functional activities. Although often described as a **hinge joint**, the elbow is more precisely a **trochoginglymus joint**, consisting of **three articulations** within one capsule:

- **Humeroulnar joint**
- **Humeroradial joint**
- **Proximal radioulnar joint**

These articulations are supported by strong **ulnar** and **radial collateral ligaments** that maintain stability during motion. Fig.1 The elbow joint.



1.1 Humeroulnar Joint

The **humeroulnar joint** is the true **hinge joint** of the elbow, where the **trochlea of the humerus** articulates with the **trochlear fossa of the ulna**.

Its primary movements are **flexion** and **extension**, although some individuals may allow a small amount of **hyperextension**.

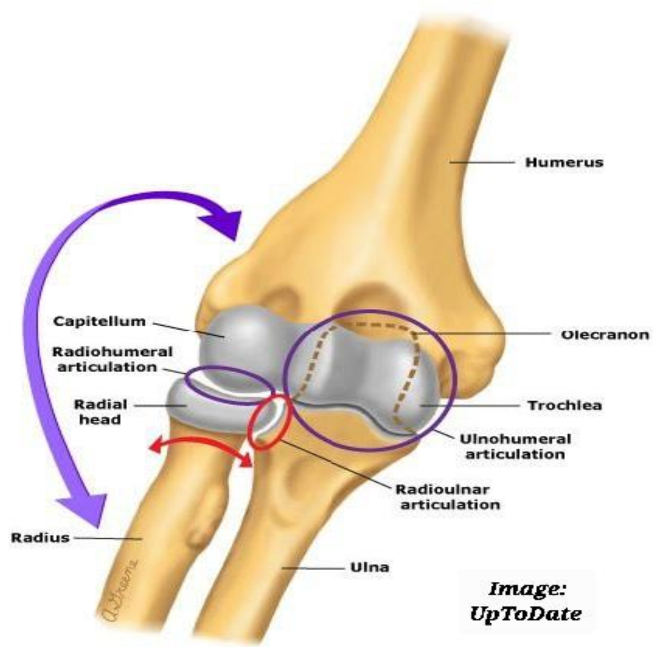
The joint is most stable in the **close-packed position of extension**.

1.2 Humeroradial Joint

The **humeroradial joint**, located immediately lateral to the humeroulnar joint, is formed between the **capitellum of the humerus** and the **head of the radius**.

Although it is classified as a **gliding joint**, motion is restricted to the **sagittal plane** because of its connection to the humeroulnar articulation.

The **close-packed position** occurs when the elbow is **flexed at 90°** and the forearm **supinated about 5°**. Fig.2 The elbow joint structure.



1.3 Proximal Radioulnar Joint

The **proximal radioulnar joint** is a **pivot joint** formed by the **head of the radius** bound by the **annular ligament** to the **radial notch of the ulna**.

This articulation permits **pronation** and **supination** of the forearm. The **close-packed position** is at approximately **5° of supination**.

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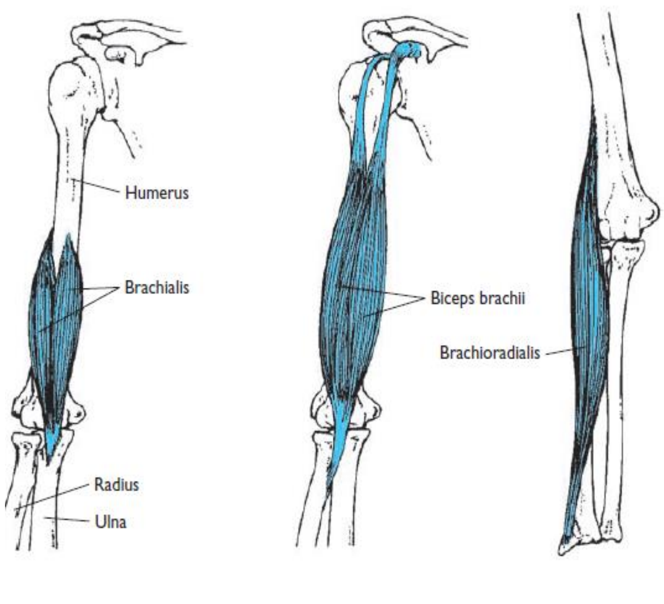
1.4 Carrying Angle

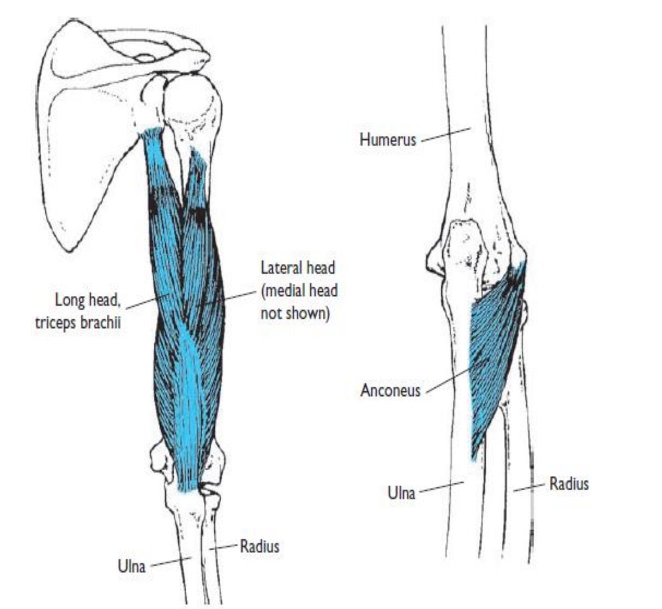
When the arm is in anatomical position, the **axes of the humerus and ulna** form an angle known as the **carrying angle**, usually **10–15° in adults** and typically **greater in females**.
This angle changes with growth and is slightly larger on the dominant side.

2. Movements at the Elbow

Flexion is mainly produced by the **brachialis**, **biceps brachii**, and **brachioradialis**, while extension is achieved through the **triceps brachii** assisted by the **anconeus** (Fig. 3).



The major flexor muscles of the elbow.



The major extensor muscles of the elbow.

3. Loads on the Elbow

Because of the shape of the olecranon process, the triceps moment arm also varies with the position of the elbow. As shown in Fig 4, the triceps moment arm is larger when the arm is fully extended than when it is flexed past 90°.

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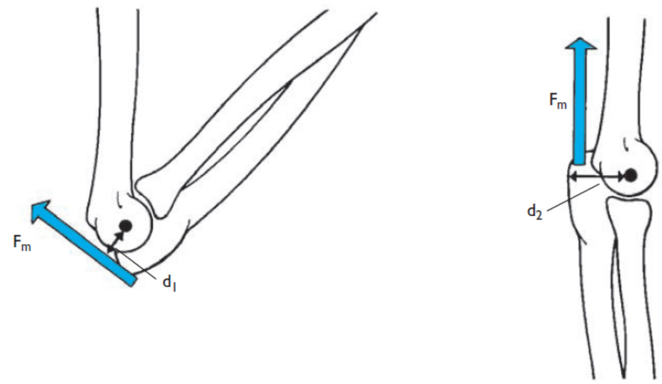
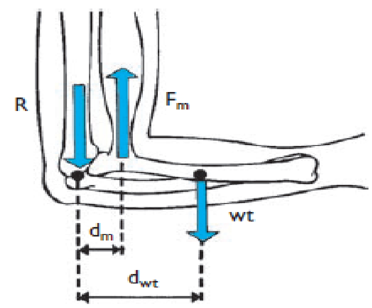


SAMPLE PROBLEM.1

How much force must be produced by the brachioradialis and biceps (F_m) to maintain the 15 N forearm and hand in the position shown below, given moment arms of 5 cm for the muscles and 15 cm for the forearm/hand weight? What is the magnitude of the joint reaction force?

Known

$$wt = 15\text{ N}$$
$$d_{wt} = 15\text{ cm}$$
$$d_m = 5\text{ cm}$$



Solution

The torque at the elbow created by the muscle force must equal the torque at the elbow created by forearm/hand weight, yielding a net elbow torque of zero.

$$\sum T_e = 0$$
$$\sum T_e = (F_m)(d_m) - (wt)(d_{wt})$$
$$0 = (F_m)(5\text{ cm}) - (15\text{ N})(15\text{ cm})$$
$$F_m = \frac{(15\text{ N})(15\text{ cm})}{5\text{ cm}}$$
$$F_m = 45\text{ N}$$

Since the arm is stationary, the sum of all of the acting vertical forces must be equal to zero. In writing the force equation, it is convenient to regard upward as the positive direction.

$$\sum F_v = 0$$
$$\sum F_v = F_m - wt - R$$
$$\sum F_v = 45\text{ N} - 15\text{ N} - R$$
$$R = 30\text{ N}$$

Biomechanics of the Wrist

1. Structure of the Wrist

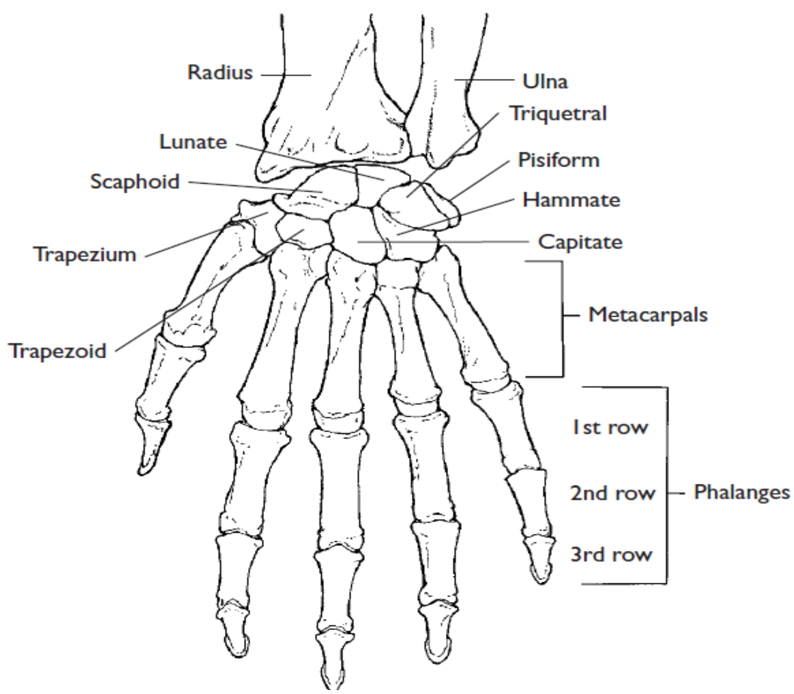
The **wrist joint complex** consists of the **radiocarpal** and **intercarpal joints**, which together allow smooth and coordinated motion between the **forearm** and **hand**.

1.1 Radiocarpal Joint

The **radiocarpal joint** is a **condyloid articulation** formed by the **distal end of the radius** and the **proximal row of carpal bones** the **scaphoid**, **lunate**, and **triquetrum**.

A **fibrocartilaginous articular disc** separates the **ulna** from the carpals, helping with **shock absorption** and smooth movement.

This joint allows **flexion**, **extension**, **radial deviation**, **ulnar deviation**, and **circumduction**. Its **close-packed position** occurs in **extension with radial deviation**. Fig.5 Bones of the wrist and hand.



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1.2 Intercarpal Joints

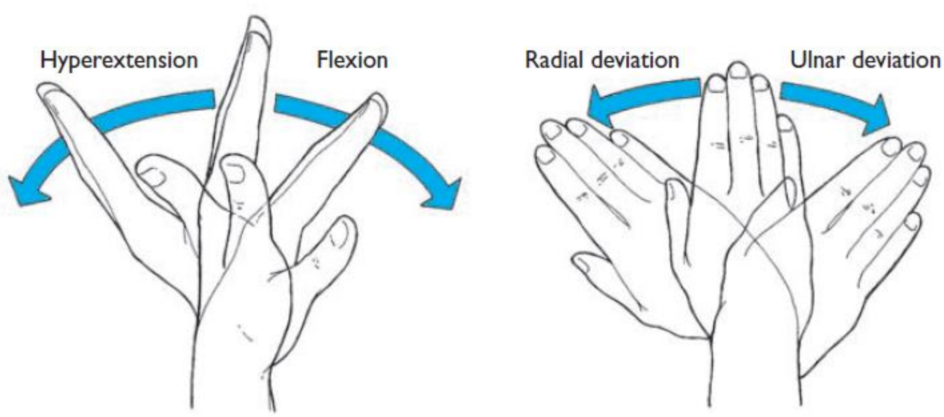
The **intercarpal joints** are **gliding articulations** between adjacent carpal bones. Although each joint has limited movement, together they allow the wrist to adapt its shape and position during motion, increasing overall **flexibility** and **shock absorption**. They also help distribute **load** across the wrist during gripping or pushing tasks.

2. Movements of the Wrist

The wrist moves in two main planes:

- **Flexion and extension** (sagittal plane)
- **Radial and ulnar deviation** (frontal plane)

These can combine to produce **circumduction**, a circular motion of the hand. Fig.6 Movements occurring at the wrist.



Typical range of motion values:

- **Flexion:** 70°–90°
- **Extension:** 65°–85°
- **Radial deviation:** 15°–20°
- **Ulnar deviation:** 25°–40°

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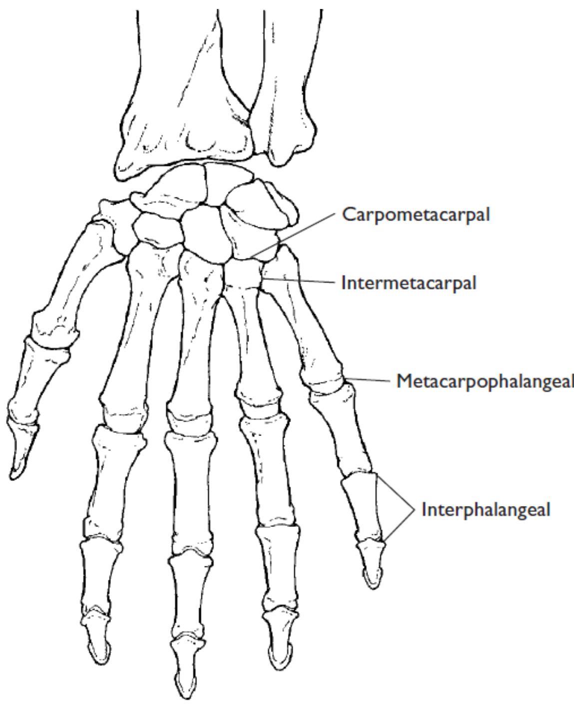
Biomechanics of the Hand

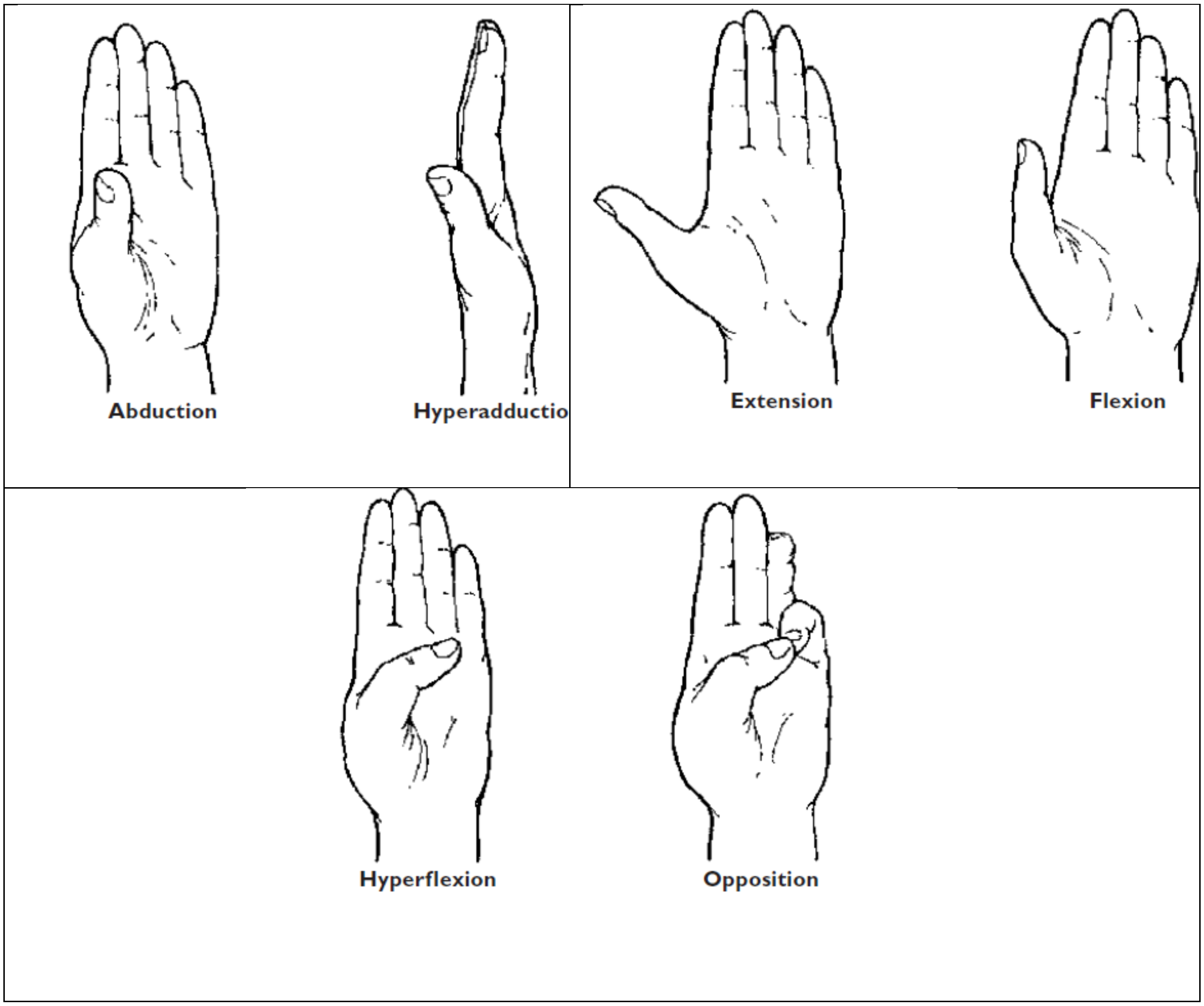
1. Structure of the Hand

The **hand** contains **27 bones** organized into **carpals**, **metacarpals**, and **phalanges**. Its structure allows both **strength** and **precision**, enabling grasp, manipulation, and sensory feedback. Fig. 7: Skeletal structure of the hand.



1.1 Carpometacarpal (CMC) Joints

The **carpometacarpal joints** connect the **distal carpal bones** with the **bases of the metacarpals**.
All except the **thumb joint** are **gliding joints** with very limited motion. The **thumb carpometacarpal joint** is a **saddle joint** between the **trapezium** and the **first metacarpal**, allowing **flexion**, **extension**, **abduction**, **adduction**, and **opposition** a key function for grasp and manipulation. Fig. 8 for thumb joint movement.



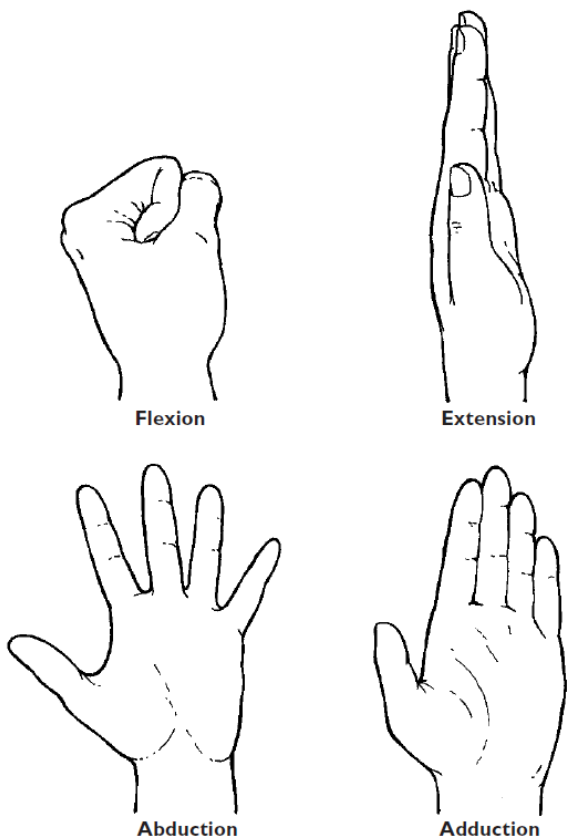
1.2 Metacarpophalangeal (MCP) Joints

The **metacarpophalangeal joints**, or **knuckle joints**, are **condyloid articulations** between the **metacarpal heads** and the **bases of the proximal phalanges**. They permit **flexion**, **extension**, **abduction**, **adduction**, and **circumduction**.

The **close-packed position** occurs in **full flexion**. Strong **collateral ligaments** and a **volar plate** stabilize the joint and limit hyperextension.

1.3 Interphalangeal (IP) Joints

The **interphalangeal joints** are **hinge joints** that allow **flexion and extension** of the fingers.
These joints are critical for **gripping and releasing objects**. Fig.9 Movements of the fingers.



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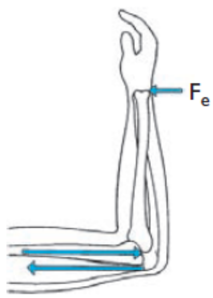
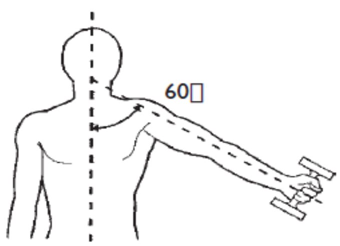
PROBLEMS

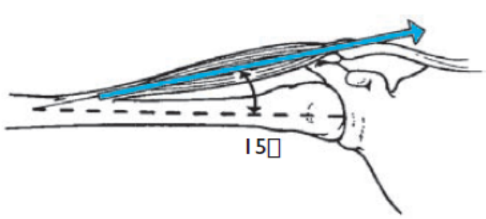
1. How much tension (F_m) must be supplied by the triceps to stabilize the arm against an external force (F_e) of 200 N, given d_m = 2 cm and d_e = 25 cm? What is the magnitude of the joint reaction force (R)? (Since the forearm is vertical, its weight does not produce torque at the elbow.) (Answer: F_m = 2500 N, R = 2700 N)



2. What is the length of the moment arm between the dumbbell and the shoulder when the extended 50 cm arm is positioned at a 60° angle? (Answer: 43.3 cm)



3. The medial deltoid attaches to the humerus at an angle of 15°. What are the sizes of the rotary and stabilizing components of muscle force when the total muscle force is 500 N? (Answer: rotary component = 129 N, stabilizing component = 483 N)



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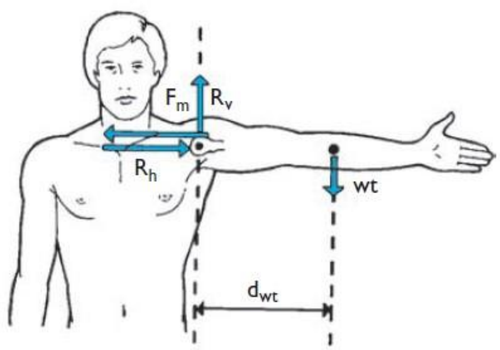
4. Using the diagram in Figure below as a model, calculate the tension required in the deltoid with a moment arm of 3 cm from the shoulder, given the following weights and moment arms for the upper arm (u), forearm (f), and hand (h) segments: $wt_u = 19$ N, $wt_f = 11$ N, $wt_h = 4$ N, $d_u = 12$ cm, $d_f = 40$ cm, $d_h = 64$ cm. (Answer: 308 N)



5. Solve the Problem in Figure below the addition of a 10 kg bowling ball held in the hand at a distance of 35 cm from the elbow. (Remember that kg is a unit of mass, not weight!) (Answer: F_m = 732 N, R5619 N)