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Intuitionistic fuzzy evaluations of the elbow joint range of motion in the sagittal plane

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Abstract: In this paper, a new technique is proposed for evaluating the functional capacity of the elbow joint. The method is based on intuitionistic fuzzy sets and interval valued intuitionistic fuzzy sets. The fact that in decision making, particularly in the case of orthopedic physical assessment, there is a fair chance of the existence of a non-zero hesitation part at each moment of evaluation means that the deterministic (hesitation) part has an important role here since it is not always possible to estimate satisfactory membership and non-membership values.
Keywords: Elbow joint, Interval-valued intuitionistic fuzzy set, Intuitionistic fuzzy set, Range of motion.
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1 Biological motivation

The elbow is the anatomic area that joints the arm or “brachium” with the forearm or “antebrachium”. The bony structures of the elbow are the distal part of the humerus and the proximal ends of the forearm bones (radius and ulna). The distal end of the humerus is formed by the pulley-shaped trochlea medially and the convex capitulum laterally. The trochlea of the humerus articulates with the deep trochlear notch found on the proximal end of the ulna. The superior surface of the head of the radius is concave for articulation with the capitulum, with the raised margin articulating with the capitulutrochlear groove. Structurally, the joint is classed as a synovial joint, and functionally as a hinge joint. Like all synovial joints the elbow joint has a capsule enclosing the joint. The elbow joint capsule wraps all three bones and both functional joints. Within the elbow complex there are three separate synovial articulations: humeroulnar joint, humeroradial joint and the proximal radioulnar joint. The humeroulnar joint is the articulation between the trochlea of the humerus and the trochlear notch of the ulna. The bones of this joint are shaped so that the axis of movement is not horizontal but instead passes downward and medially, going through an arc of movement. This position leads to carrying angle at the elbow. Typically the normal range of the carrying angle is between 10 and 15 degrees [6]. The humeroradial joint is a uniaxial hinge joint and consist of the spheroidal capitulum of the humerus and the proximal surface of the head of the radius. The proximal radioulnar joint is the articulation between the head of the radius and the radial notch of the proximal ulna. This joint is classed as a uniaxial cone-shaped pivot joint. Stability of the elbow complex is provided mainly by the ligamentous apparatus surrounding the joint and the interlocking mechanism of the articulating surfaces. The elbow complex allows two degrees of freedom in the sagittal plane: flexion-extension and pronation-supination.

For the purpose of the present study, we will briefly discuss only the flexion-extension movements of the elbow joint. Elbow flexion and extension are accomplished through the humeroulnar and the humeroradial joints. Motion occurs in the sagittal plane around a medial-lateral axis (fig.1). More specifically, the flexion-extension axis of the elbow joint runs through the epicondyles of the humerus and passes through the center of the trochlea. The range of flexion and extension can be predicted from the angular characteristics of the involved bony components. The angular value of the articulate surface of the trochlea of the humerus is 330 degrees, while that of the trochlear fossa of the ulna is 190 degrees. The difference is 140 degrees, a value very close to the possible active range of motion. Similarly, 140 degrees is the difference between the angular value of the articulate surface of the capitellum (180 degrees) and that of the proximal radial head (40 degrees). The normal flexion-extension arc of the intact elbow ranges from -10 degrees to 160 degrees. Active range of elbow flexion ranges from 135 degrees to 145 degrees [5, 7]. Movement is usually stopped by the contact of muscular masses of the upper arm and forearm, along with contraction of the triceps. Passive range of elbow flexion ranges from 150 degrees to 160 degrees [7]. Factors limiting the passive range of elbow flexion include the impact of the head of the radius against the radial fossa, the impact of the coronoid process against the coronoid fossa and tension from the capsule and triceps. Normal active elbow extension is considered to 0 degrees although individual variations can be few degrees positive or negative. Up to 10 degrees of hyperextension may be exhibited, especially in women and children. Extension is mainly limited by the olecranon abutting against the posterior aspect of the humerus in the olecranon fossa and by stretching of the anterior part of the joint capsule.

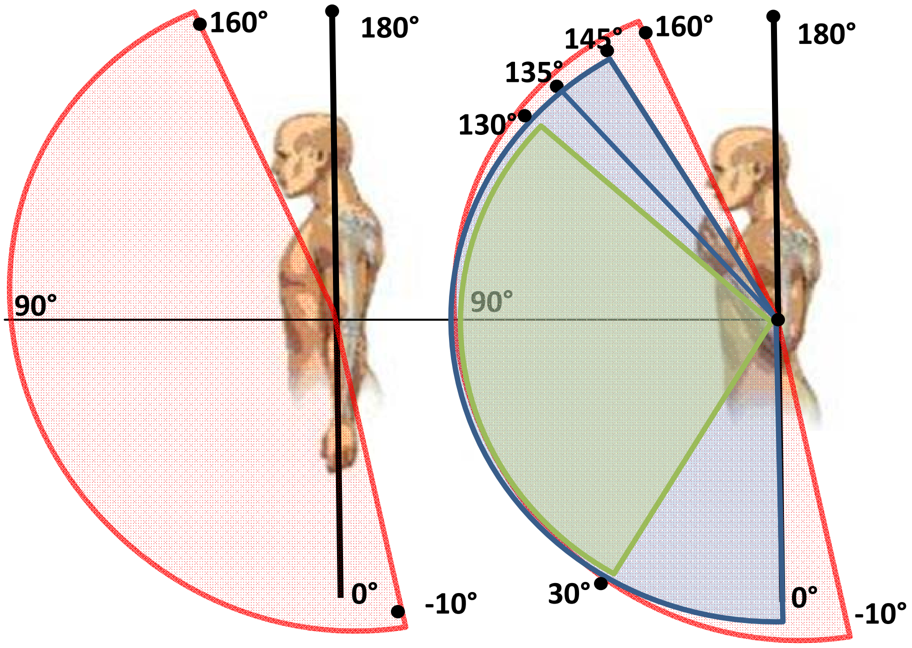

Figure 1. Range of motion of the elbow joint. In red passive range of motion (-10 to 160), in blue active range of motion (from 0 to 135/145) in green functional range of motion (from 30 to 130).

Elbow range of flexion-extension motion includes evaluation of both passive and active motion. Usually the degrees of motion are recorded as the deviation from the reference position in either direction from the anatomical position in a standardized format. The most common system of recording the range of motion values is the sagittal, frontal, transverse, rotation (SFTR) system [4].

Since the motion is measured in degrees, the measurements are reported with a beginning and end measurement. The normal values of elbow flexion extension movements in the sagittal plane(S) recorded by the SFTR system are:

Active range of motion **S: 0° – 0° – 145°**

Passive range of motion **S: 10° – 0° – 160°**

where, the first number refers to extension, the second is the neutral-0 position and the third is the final position in opposition to that of the first movement.

Elbow motion serves to position the hand in space. For a normal upper extremity functioning is required a freely mobile and stable elbow joint. Even with a limited range of motion in the shoulder for example, most activities in daily life can be performed with a mobile elbow. Inability to move the elbow joint gives a fixed linear position of the hand relative to the body, resulting in the inability of movement of the hand away and toward the body. Loss of elbow motion in the sagittal plane can impact most of the activities of daily living such as eating, shaving, washing, carrying etc. As we already mentioned above the normal active range of motion of the elbow ranges from 135 degrees to 145 degrees. However, many daily activities are performed with less than these ranges. Morrey et al. [8] found the functional arc of elbow motion during activities of daily living to be 100° for both flexion and extension

(30° to 130°). Feeding activities such as drinking from a cup, eating using a fork or a spoon, cutting with a knife may be performed within an arc of movement from about 46 degrees to 136 degrees of flexion [3]. The purpose of the present study is to give a possible example for evaluation of the elbow flexion extension movements in the sagittal plane using IFD and IVIFSs.

2 Intuitionistic fuzzy evaluations

In intuitionistic fuzzy logic (IFL) [1, 2], if p is a variable then its truth-value is represented by the ordered couple

$$V(p) = \langle M(p), N(p) \rangle, \quad (1)$$

so that $M(p)$, $N(p)$, $M(p) + N(p) \in [0, 1]$, and $M(p)$ and $N(p)$ are respectively degrees of validity and of non-validity of p. These values can be obtained applying different formula depending on the problem considered. If we like to use Interval-Valued IF (IVIF) values, then (1) obtains the same form, but now

$$M(p) = [\inf M(p), \sup M(p)] \subset [0, 1],$$

$$N(p) = [\inf N(p), \sup N(p)] \subset [0, 1],$$

and

$$\sup M(p) + \sup N(p) \leq 1.$$

Now, we shall give an IF estimation of the functional capacity in the elbow joint during the movement in the sagittal plane. The approach presented in our study involves the following steps:

- Determination of the normal barriers of the elbow joint movement (Fig. 2).

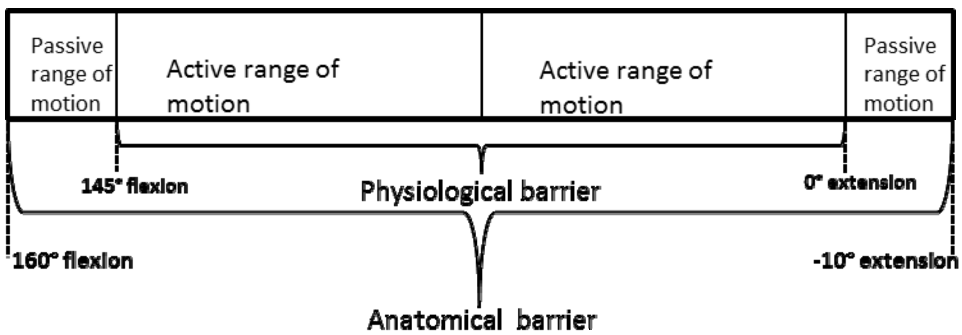

Figure 2. Diagram of normal range motion of the elbow joint

The normal active range of motion of the elbow in the sagittal plane occurs within the physiological barriers of this joint, in our case we assume that the physiological barrier of the elbow joint is S: 0 – 0 – 145. However, movement can be introduced passively beyond the physiological barrier, stretching the supporting soft tissues and closing the bony structures.

This is the 'anatomical barrier'. We assume that the anatomical barrier of the elbow joint is S: -10 – 0 – 160.

Let $\beta = 145^{o}$ and $\alpha = 0^{o}$. Then

$$\omega = \beta - \alpha = 145^{o}.$$

Therefore,

$$M(p) = \frac{\beta - \alpha}{170^{\circ}} = \frac{145^{\circ}}{170^{\circ}}.$$

On the other hand,

$$\varphi = 170^{o} - (\beta - \alpha) = 25^{o}$$

and

$$N(p) = 1 - \frac{\beta - \alpha}{170^{\circ}} = \frac{35^{\circ}}{170^{\circ}}.$$

- Determination of abnormal motion of the elbow joint (Fig. 3)

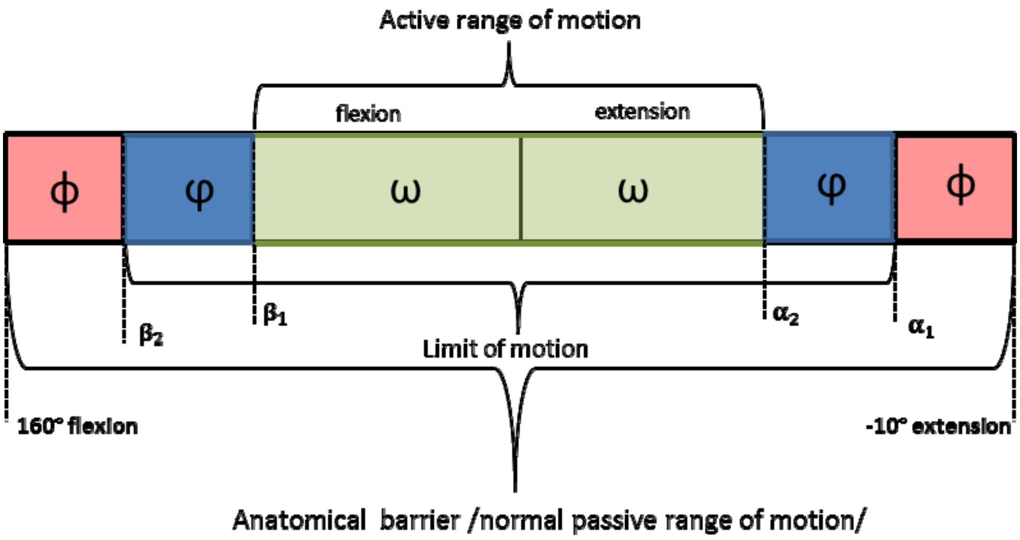

Figure 3. Diagram of limited range of motion of the elbow joint

The active range of motion during the physical examination of a person *p* is:

$$\omega = \beta_1 - \alpha_2 < 145^{o}.$$

Therefore,

$$M(p) = \frac{\beta_1 - \alpha_2}{170^{\circ}} < \frac{145^{\circ}}{170^{\circ}}.$$

The restricted range of motion which will not be accomplished even with an additional passive force applied is:

$$\varphi = 170^{o} - (\beta_2 - \alpha_1) > 25^{o}$$

and

$$N(p) = 1 - \frac{\beta - \alpha}{170^{\circ}} > \frac{35^{\circ}}{170^{\circ}}.$$

So, for patient p we determine his/her personal IF estimation is the form $\langle M(p), N(p)\rangle$. If we like to give an IVIF-estimation, it will have the form

$$\langle M(p), N(p)\rangle = \langle [\alpha_1, \alpha_2], [\beta_1, \beta_2]\rangle,$$

where α_1, α_2, β_1, β_2 are above described estimations for patient p.

3 Conclusion

Somatic dysfunction of the elbow joint occurs when there is a restriction of motion occurring within the normal range of movement. A thorough and accurate assessment of a subject's elbow joint range of motion is essential for correct diagnosis, treatment and determination of rehabilitation potential. However, all assessment and testing in clinical practice is based on the assumption of uncertainty. By employing IF evaluations we can express a hesitation concerning examined objects. The method proposed in this article, assigning IF values and numeric grades, will significantly improve the overall assessment of the elbow joint range of motion. Future research will focus on improving the overall assessment method by considering the possibility of assigning relative weight coefficients for all movement values since for some joint dysfunctions some particular joint motions are more important than others.

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