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Pronation and supination of the hand: Anatomy and biomechanics

Pronation–supination de la main : anatomie et biomécanique

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Abstract

Proper functioning of the hand relies on its capacity to rotate and point the palm upward (i.e. supination) or downward (i.e. pronation) when standing up with the elbow in 90° flexion. Hand rotation is possible because of forearm rotation and also rotation of the whole upper limb at the shoulder. Two distinct mechanisms contribute to hand rotation: one in which the ulna is immobile and another in which the ulna is mobile. In this review, we first summarize how evolution of the human species has led to the progressive development of specific forearm anatomy that allows for pronation and supination. Then we analyze how the three joints of the forearm (i.e. proximal, middle and distal radioulnar joints), in association with the characteristic shape of both forearm bones, allow the forearm to rotate around a single axis. Lastly, we describe the neuromuscular anatomy that controls these complex rotational movements. The anatomical and biomechanical points developed in this paper are analyzed while considering clinical applications.

Keywords: Forearm rotation; Pronation; Supination; Interosseous membrane; Anatomy; Proximal radioulnar joint; Middle radioulnar joint; Distal radioulnar joint

Résumé

Le fonctionnement correct de la main repose sur sa capacité à tourner et diriger la paume vers le haut (supination) ou vers le bas (pronation) lorsque le sujet est debout avec le coude fléchi à 90°. La rotation de la main est rendue possible par la rotation de l'avant-bras, qui est elle-même complétée par la rotation de l'ensemble du membre supérieur au niveau de l'épaule. Il est ainsi possible de distinguer deux mécanismes aboutissant à la rotation de la main: une rotation à ulna fixe et une autre à ulna mobile. Dans cet article, nous résumons les grandes étapes évolutives de l'espèce humaine qui ont conduit au développement d'une anatomie spécifique de l'avant-bras permettant la pronation–supination. Puis nous analysons comment les trois articulations de l'avant-bras (radio-ulnaires proximale, moyenne et distale) associées aux géométries caractéristiques des deux os de l'avant-bras permettent la rotation de l'avant-bras autour d'un axe unique. Enfin, nous décrivons l'anatomie neuromusculaire qui motorise ces mouvements complexes de rotation. Les aspects anatomiques et biomécaniques développés dans cet article sont envisagés à la lumière de leurs applications cliniques.

Mots clés : Rotation de l'avant-bras ; Pronation ; Supination ; Membrane interosseuse ; Anatomie ; Articulation radio-ulnaire proximale ; Articulation radio-ulnaire moyenne ; Articulation radio-ulnaire distale

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1. Introduction

An essential prerequisite for proper functioning of the hand is its positioning in space, in terms of location and orientation. The hand's orientation relies on its capacity to rotate and tilt. Forearm rotation makes it possible to point the palm upward (i.e. supination) or downward (i.e. pronation) and is inseparable from the radius' own orientation, given the strong attachments between both of these structures.

Forearm rotation can be viewed as rotation of the ''hand–radius'' unit around the ulna (Fig. 1). However, the entire forearm (i.e. ''radius + ulna'') can also rotate because of movements of the upper limb and trunk. Therefore, one must distinguish between the forearm's rotation around an immobile ulna and the forearm's rotation with a mobile ulna. This conceptual distinction is artificial as daily movements use both these mechanisms in synergy, but it will simplify the biomechanical analysis of these complex motions.

The goal of this review is to outline the anatomical and biomechanical bases of these mechanisms.

2. Evolutionary view

According to the taxonomic classification of species (Retrieved May 23, 2016, from the Integrated Taxonomic Information System – http://www.itis.gov.) derived from works of Carl Linnaeus (1707–1778) [1], Homo sapiens belongs to the phylum Chordata, class Mammalia, order Primates, family Hominidae, and genus Homo.

Human upper limbs have a similar structure to the forelimbs of the other pentadactylous tetrapods given that they are composed of four separate segments: the stylopodium (with the humerus), the zeugopodium (with the radius and ulna), the mesopodium (with the carpal bones) and the autopodium (with the hand skeleton) [2,3] (Fig. 2).

In several classes of the phylum Chordata including Mammalians, Reptilians, and Amphibians, the upper limb/forelimb is composed of a humerus, a radius and an ulna. The oldest known specimen with this forelimb pattern is Eusthenopteron, a lobe-finned fish that lived 380 million years ago [4]. The forelimb evolved because of changes in the behavior of our ancestors. The common ancestor of the Primates lived about 56 million years ago. He was an arboreal animal who grasped branches to move in and between trees. With the progressive appearance of bipedalism, the upper limb has gradually gained the ability to interact with the surrounding environment (grasping, manipulating, modifying, interacting with objects, animals, vegetals) as well as with its own body (feeding, hygiene, self-care). The upper limb needed to be very precise in order to position the autopodium (the hand) to manipulate objects and hang from branches. Pronation and supination developed gradually due to an increase in mobility between the radius and ulna. Conversely, the hind limb was tasked with providing support and propulsion — activities that require considerable stability — thereby explaining why there is very little motion between the bones in the lower leg (i.e. tibia and fibula).

Consequences of this differential evolution between species are now visible when various mammalians are compared. In purely quadruped mammalians like elephants, horses or rhinoceros, the radioulnar mobility is almost non-existent. The two forearm bones are joined by a short, strong and wide ligament that allows very little range of motion and, moreover, undergoes ossification with advancing age. In mainly quadruped mammalians that have the ability to temporarily stand on their hind limbs (i.e. transitory bipedalism) like rodents or

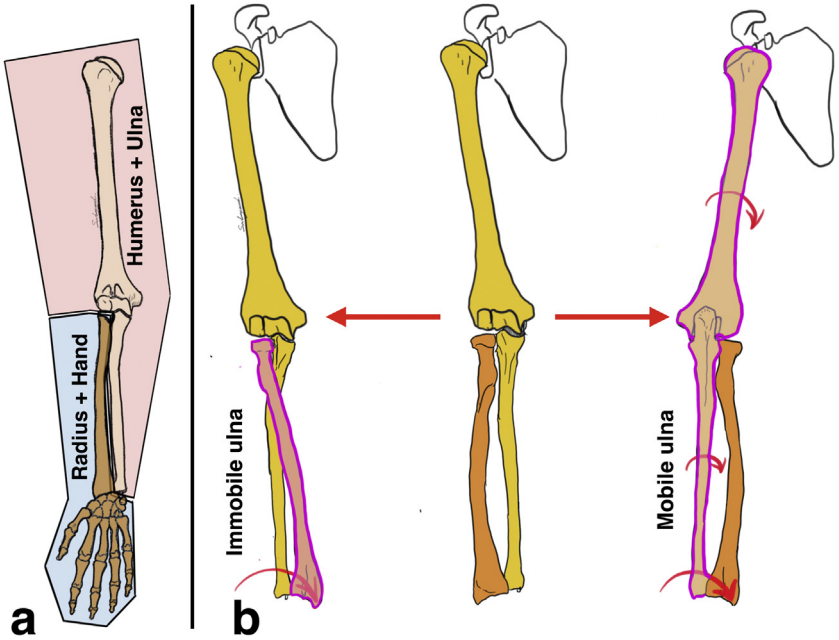

Fig. 1. The two units of hand rotation (a). There are two types of hand rotation, depending on whether the ulna is mobile or immobile (b).