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Force transmission through the wrist during performance of push-ups on a hyperextended and a neutral wrist

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ABSTRACT

Study Design: Cross-sectional cohort.
Introduction: Push-ups are used ubiquitously to evaluate and strengthen the upper body. They are usually performed in 1 of 2 main ways: with the wrist in hyperextension and with the wrist in a neutral position.
Purpose of the Study: The purpose of our study was to compare the dynamic forces in the wrist during the 2 push-up styles.
Methods: Fourteen volunteers performed push-ups in 2 different patterns: on a hyperextended wrist and a neutral wrist (NW). Two force plates and a motion capture system were used to measure the ground reaction forces (GRFs) and the kinematics of the upper extremity during push-ups. Kinematic and kinetic analyses were performed using Matlab software (Mathworks, Natick, MA).
Results: The GRF vector was distributed differently during the different types of push-ups. For both methods, the total GRF carried by the upper dominant extremity was larger than those of the nondominant extremity. In the NW configuration, the GRF vector was more uniform throughout the push-up in the vertical direction. The horizontal distance between the capitate bone location and the GRF origin was smaller in hyperextension. The forces traveled more dorsally over a wider area and more ulnarly in the hyperextended wrist.
Discussion: Forces are transmitted differently through the wrist in the 2 methods. Push-ups on an NW are likely safer because ligaments may be preferentially loaded in hyperextension. Further study may delineate the differences in the anatomic location of force transmission and the long-term clinical effect on the wrist.
Conclusions: This study supports the performance of push-ups on a wrist in neutral flexion extension; both to enable patients after surgery or injury to strengthen the upper body and prevent injury and long-term wear in the wrist. The knowledge gained from this study may assist in outlining guidelines for push-up performance.
Level of Evidence: Diagnostic level 2a.

Introduction

Push-ups are used frequently for the evaluation, strengthening, and training of the upper body.[1-4] They are used in military training and in the training of both professional and amateur athletes of all kinds and ages. Used to promote fitness in general, they are an important part of many rehabilitation protocols after surgery and injuries that cause wasting or weakness of the upper extremity.[5] Furthermore, they are used for upper body strengthening in sedentary individuals engaging in moderate exercise. Slater et al[6] used push-ups to evaluate strength of the upper extremity in professional ice skaters. Smith et al[7] measured muscular strength looking at the ability to perform push-ups and grip strength as measured by a grip meter. Martin et al[8] used push-ups both in the evaluation of muscular endurance and in the training of patients after treatment for breast cancer, whereas Colado et al[9] used push-ups as part of an exercise program for postmenopausal women. Multiple studies have looked at the use of push-ups in physical fitness protocols in children and adolescents.[10-12]

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Conflict of interest: All named authors hereby declare that they have no conflicts of interest to disclose.

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However, despite their common use, there is insufficient evidence in the literature as to how and where the forces are transferred during a push-up. Little is known about their effect in the long term and possible injuries they may cause.[13-15] Even fewer studies provide guidelines as to how they should best be performed.[16-18] This information is especially important in nonprofessional athletes who undertake push-ups to get in shape and may injure their wrists with consequences that may affect their activities of daily living. Recently, studies have begun to address these aspects, evaluating the techniques used in the performance of push-ups and their biomechanical effect. Sandhu et al[19] assessed muscle activity using surface electromyography, comparing push-ups performed on an unstable surface (Swiss ball) with those performed on a stable surface. Another study described muscle activity levels during push-ups with different loads and stability conditions again using surface electromyography. They found that suspended push-ups are a highly effective way to stimulate abdominal muscles and that there was a differential muscle stimulus depending on the push-up conditions.[3] Koch et al[20] compared vertical ground reaction force (GRF) characteristics between the clap push-up and box drop push-ups. Kim et al[21] studied the effect of different hand positions on the shoulder girdle musculature during push-ups. These studies did not distinguish between the different wrist positions.

Chuckpaiwong and Harnroongroj[22] studied the forces applied to the palm in different hand positions and found that various hand positions loaded areas of the palm differentially. The investigators concluded that the lunate area was the most loaded area in the various positions and suggested using this information to modify rehabilitation protocols.

The patterns of load on the wrist during push-up performance may cause overload on certain areas of the upper extremity, causing pain and injury. Multiple studies have described injuries related to push-up performance such as fractures and dislocations.[23-25] In addition, bearing a heavy weight on a hyperextended wrist (HW) can cause early development of wrist pain and associated carpal tunnel syndrome.[26,27]

Although studies have demonstrated clinical relevance of push-up technique, the exact anatomic passage of forces has not been elucidated. This is likely due to the difficulty in measuring and locating these forces in vivo while the wrist is actively moving and being loaded. Several studies have examined the kinematics and loading of the wrist with and without pathology ex vivo. Short et al[28] used a cadaver model to evaluate the distribution of forces and movement of the carpal bones in the wrist. Scaphoid and lunate motions along with radiocarpal and ulnocarpal pressure patterns were continually monitored while the wrist was manipulated through flexion and extension. They reported that, before ligament sectioning, the position of the scaphoid and lunate was dependent on the position of the wrist and the direction of wrist motion. Sectioning the scapholunate interosseous ligament caused increased scaphoid flexion, scaphoid pronation, and lunate extension. Pressure on the radiocarpal and ulnocarpal joints was redistributed after ligament sectioning.

Tencer et al[29] and Viegas et al[30] applied a static force to the second and third metacarpals of cadaver upper limbs. By changing the hand position, they recorded the pressure areas using pressure-sensitive paper. Their results clearly indicate that the pressure area moves across the radial bone according to the position of the hand. In addition, in the HW, the force passes more dorsally than in flexion or in the neutral wrist (NW) positions.[29,30] This result was confirmed by Majima et al[31] using an anatomic computer-aided design model built from computed tomography scans. They loaded the computer-aided design model of the wrist in the hyperextended position by applying static forces to the trapezium and hamate bones and in the neutral position by loading 5 metacarpal bones.[31] Rainbow et al[32] evaluated in vivo kinematics during extreme wrist positions. They concluded that during extreme extension, the radial-scaphoid contact area shifts dorsally. They also found that the lunate-radius and scaphoid-radius contact areas increased 45% ± 22% and 13% ± 16%, respectively, from a neutral grip position.

Clinically, we have observed that the vast majority of patients who are treated for wrist injuries are unable to hyperextend their wrists (often beyond neutral position). The term hyperextension cannot be precisely defined and likely differs between individuals. Everyday activities require a variable range of motion in the wrist. Ryu et al[33] demonstrated that most everyday activities are performed within 60° of extension, which is about 70% of the total extension of the normal wrist. Palmer et al[34] found that most functions require only 30° of extension. Still when the wrist is loaded in extension, the position goes beyond normal everyday extension of the wrist. We defined this position as hyperextension. These patients are often excused from performing push-ups because load on a HW may be painful, even in a wrist that can reach the hyperextended position. Furthermore, many of our patients with a previous wrist injury experience difficulty in performing push-ups.

Some wrist injuries (such as scaphoid fractures and dislocations) have been described as stemming from load on an extended/HW.[23,35] However, we believe that less extreme injuries occur in repetitive less extreme activities such as sports and recreation. Some studies have noted similar observations.[36,37] These problems also apply to other joints in the extremity: bilateral shoulder dislocations, stress fracture of the hamate, and wrist pain have been described along with other injuries that have occurred after different kinds of push-up exercises.[24,25,38-40]

We suggest that push-ups on a HW preferentially load different areas of the wrist when compared with push-ups performed on an NW. Because these areas include ligamentous structures stabilizing joints in the wrist, and joint synovium contains pain receptors,[41,42] this might explain the clinical observations of pain related to hyperextension of the injured wrist and the observed difficulty in performing this style of push-ups after surgery such as open reduction and internal fixation of distal radius fractures or dorsal wrist ganglion excision where the ligaments are involved in the surgery.[31,38] If, indeed, push-ups performed on an NW are healthier for wrist stability and ligamentous integrity and load the ligaments to a lesser degree, NW push-ups could then be safely used for rehabilitation and upper body strengthening in healthy athletes. This could potentially change the way we encourage push-ups to be performed, allowing for prevention of injury, as well as better and earlier rehabilitation.

The purpose of this study was to compare in vivo GRF load vectors in an NW push-up to push-ups performed on a HW. As a first step in elucidating the transfer of forces through the wrist during the performance of push-ups, we hypothesized that the GRF will be distributed differently between the different methods.

Methods

Fourteen healthy subjects were recruited for the study. The number of subjects was based on our experience in biomechanical analysis in the gait laboratory and a review of other published studies. Ethics committee approval was obtained before study commencement. Inclusion criteria included healthy male volunteers with a normal body mass index between 18.5 and 24.9 and a height between 165 and 180 cm. The subjects brought in written documentation of good physical condition and the ability to perform multiple push-ups. Only right-handed subjects were