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Scientific/Clinical Article

Load distribution of the hand during cylinder grip analyzed by Manugraphy

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ABSTRACT

Study Design: Clinical measurement and basic research.
Introduction: Manugraphy allows assessing dynamically all forces applied perpendicular to a cylinder surface by the whole contact area of the hand with a high spatial resolution.
Purpose of the Study: To identify the physiological load distribution of the whole contact area of the hand during cylinder grip.
Methods: A sample of 152 healthy volunteers performed grip force tests with 3 cylinder sizes of the Manugraphy system (novel, Munich, Germany) on 3 different days. The whole contact area of the hand was sectioned into 7 anatomic areas, and the percent contribution of each area in relation to the total load applied was calculated. The load distribution of the dominant and nondominant hands and with different cylinder sizes was compared. Furthermore, the load distribution between the finger phalanges of each finger was analyzed.
Results: The results for the dominant and nondominant hands were in all 7 areas of the hand similar with the percent contribution differing within a range of 1%-4% ($P > .138$). Load distribution changed significantly with different cylinder sizes: all 7 areas differed between 1% and 7% with $P < .001$, most pronounced for the thumb. The load distribution of the phalanges showed that the contribution of the distal phalanges increased with ascending cylinder size, whereas the contribution of the proximal phalanges decreased. The interindividual variability of the load distribution pattern was noticeable.
Discussion: For the clinical practice, Manugraphy might be a useful supplement to traditional grip force measurement for identifying the individual characteristics of a patient's dysfunction and monitoring the progress of hand rehabilitation.
Conclusions: There is no universal or typical load distribution pattern of the hand but only an individual pattern. To evaluate a compromised hand, it is permissible to compare it with the healthy opposite hand as a reference. Several cylinder sizes should be used for load distribution testing. Using smaller handles in the daily life can help to compensate impairment of the thumb and fingertips.
Level of Evidence: 2.

Introduction

Information about the load distribution of the hand during gripping is fundamental for understanding normal hand function and allows for inferences about manual dysfunction and impairment.

Numerous authors have used different kinds of testing devices and methods to gain information from experimental studies. Hazelton et al[1] used a dynamometer with a pulley assembly to measure the finger forces of each digit. Studies by Kozin et al[2] and Talsania and Kozin[3] measured the load applied by each finger using a digital dynamometer with 4 pressure keys equipped with unidirectional force sensors. Amis[4] as well as Radhakrishnan and Nagaravindra[5] measured the forces of each phalanx of the fingers using cylinders of different sizes, which had sensors on cantilever beams; they measured the forces applied by each finger phalanx multidirectionally. All these arrangements could only measure

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force applied at defined points of interest, not all forces applied by the whole hand. Jensen et al[6] introduced small and thin pressure sensors, which could be taped to the fingertips. Mentzel et al[7] used 10 of these pressure sensors integrated in a sensor glove and measured the load applied on the tips and bases of the fingers and thumb. Such arrangements allowed the researchers to measure different kinds of grip patterns with any object. Again, such a limited number of sensors can only measure some selected areas of the hand.

To visualize the whole contact area of the hand while gripping a cylinder, Lee and Rim[8] used cylinders coated with pressure-sensitive photo sheets, which depicted the load applied statically but in a high resolution. As this technique was extensive, the study included only 4 subjects.

Several ergonomic studies have investigated the contact forces that exist between the hand surface and the tool handles during push-and-pull actions applied by a limited number of subjects.[9-11] For this purpose, a large number of low-profile pressure sensors, embedded in elastic mats, covered the cylindrical objects being gripped. Although these arrangements created a dynamic and high-resolution load distribution map of the hand, they did not focus on anatomic or functionally relevant areas of the hand.

To gain more information about the load distribution of the hand while gripping a cylindrical object, we found the Manugraphy system (novel, Munich, Germany) to be an appropriate tool. It consists of 3 cylinders covered with pressure sensor matrices and allows examiners to assess dynamically all forces applied perpendicular to the cylinder surface by the whole contact area of the hand, with a spatial resolution of 2 pressure sensors per cm^2. The measuring procedure was reproducible and practicable to assess a large number of subjects. A previous study approved a valid and constant grip force measurement by the Manugraphy system and a high correlation with the Jamar dynamometer.[12]

In our clinical routine, grip force measurement is an important aspect for assessing hand function. However, to address an underlying pathology therapeutically, it helps to visualize the various deficits within a complex grip function, for example, in neurologic conditions or after complex hand injuries with multidigital tendon and joint involvement (Fig. 1). Manugraphy system can monitor and depict the progress of hand therapy; it may help with planning and adapting the exercise program and provides an additional motivation for the patient and therapist. To adapt orthotic devices or auxiliary handles in a sophisticated manner, Manugraphy system helps one to identify the requirements of an individual with manual impairment.

To use Manugraphy system as a clinical tool, it is necessary to gain basic knowledge and normative values of the load distribution of the hand.

Purpose of the study

This study aims to identify the physiological load distribution of the hand while gripping a cylinder and to investigate the influence of hand dominance and cylinder size on this load distribution.

Methods

Subjects and testing sequence

One hundred fifty-two healthy subjects participated in this study, which was approved by the institutional review board. All subjects gave informed consent before their inclusion in the study. Two medical centers, center A and B, performed the identical protocol, with 1 examiner testing 76 healthy subjects at each center. The number of individuals included was determined by a case sample calculation. Exclusion criteria ruled out patients with disorders or previous injuries of the upper extremities, congenital malformations, myofascial pain syndrome, rheumatoid diseases, or cancer. The subjects tested consisted of 76 males and 76 females between 18 and 65 years. The mean age at center A was 31.7 years and center B 40.0 years (average, 35.8 years). One hundred forty-one subjects were right handed (69/A and 72/B).

Grip force and load distribution were measured using the Manugraphy system, consisting of 3 cylinders covered with pressure sensor matrices. The cylinders had circumferences of 100, 150, and 200 mm, corresponding to 32, 48, and 64 mm diameters, respectively. The subjects performed the study testing in a standardized position as recommended by the American Society of Hand Therapists: During testing, the persons were sitting on a stool without a backrest, with the shoulder in neutral rotation, arm adducted, and elbow flexed at 90° (Fig. 2).[13] The subjects held the cylinder in a vertical orientation with the wrist positioned spontaneously during testing, thereby assuming that the subjects would spontaneously take the most effective wrist position.[14] The subjects could not see the pressure and grip force values on the screen during testing to rule out any influence by visual control.[15] The testing started with the left hand, and this was followed by the right hand. Each subject tested the smallest cylinder consecutively with both hands first, followed by the middle cylinder, and finally the large cylinder. A video of the subject gripping the cylinder was recorded to allow for analysis of the grip position later.

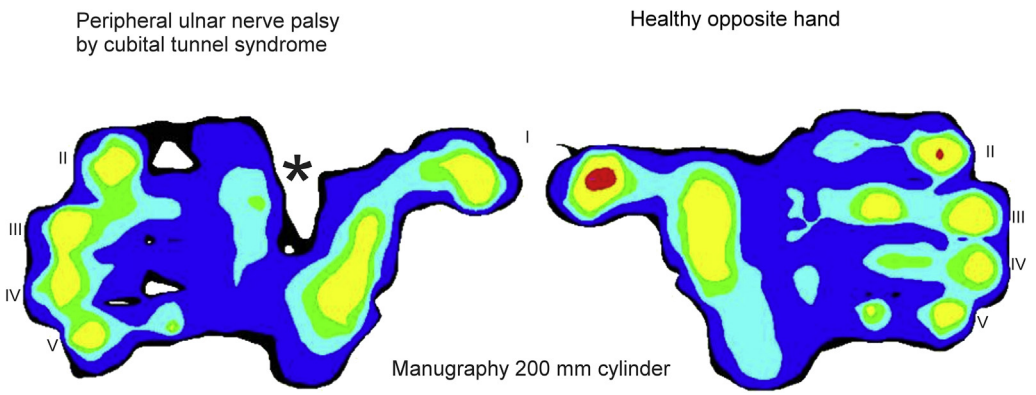

Fig. 1. Example to show the changes in load distribution of the hand by a peripheral ulnar nerve palsy. Atrophy of the first interdigital web space (*) obviously weakens the force transmission by the fingertips of the thumb and index finger.