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# The Hand Grip ForceMap$^{TM}$ System

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***Abstract***- A grip force measurement system is described consisting of a method and transducer for assessing the complex grip capability/capacity of the hand. The grip force system includes a grip force transducer including a high-resolution tactile array adapted to produce a high-resolution grip force signal. A signal conditioning module conditions the high-resolution grip force signal inputting grip force data to a processing device. The processing device processes, analyzes and outputs the grip force data. A display provides images of contact force distribution of individual finger function relative to entire hand function. The grip force transducer includes a high-resolution tactile sensor wherein the greatest distance between adjacent pressure sensing nodes is in the range of 1.0 mm to 10.0 mm.

***Keywords***- *grip strength measurement; grip ForceMap$^{TM}$; grip pressure distribution.*

## I. Introduction

Strength testing of the injured hand and forearm is of immense interest to injured patients, treating physicians, therapists, and insurance providers. The Jamar$^{TM}$ Hand Dynamometer, (herein “the Jamar”), has been the standard clinical strength-testing device of injured and diseased hands for over 50 years.

The Jamar is used to measure grip force by means of grasping two offset parallel bars that can be situated at one of five preset positions to accommodate various hand sizes. The subject is asked to squeeze the offset parallel bars of the device and the highest force exerted is measured and displayed on a mechanical gage. The Jamar is essentially isometric in use and allows almost no perceptible motion of the handles. The Jamar has survived in the face of criticism for inaccuracy, questionable reliability, and lack of meaningful clinical relevance. The handles of the Jamar are parallel offset bars that represent a very limited number of tasks found in activities of daily living. The Jamar is of little use when evaluating the function of a finger or fingers and offers little meaningful information regarding grip analysis. It is believed by some that the Jamar survives because of cost, ease of use, availability, and lack of a suitable replacement.

Medical examinations performed by physicians and therapists rely upon the Jamar to evaluate the functional capacity and disability of the hand, evaluations which directly affect employment and injury award compensation. In addition to the aforementioned limitations, the Jamar is vulnerable to fraudulent efforts on behalf of the subject. Malingering manipulation and falsification at the will of the examinee are an ever-present concern with significant financial ramifications. Patient effort is best surmised through a series of testing methods that distract the subject during testing. However, the results of such methods are suspected to yield unacceptable levels of false positives.

Alternative hand strength testing devices have been designed, tested, and marketed but have failed to gain acceptance. Such testing devices based upon pneumatic and spring mechanisms have been trialed, but have been criticized for inaccuracy, poor reliability, and lack of meaningful clinical relevance. In addition, like the Jamar, specific analysis about individual finger function in the context of the function of entire hand cannot be acquired. Finally, like the Jamar, insight into patient effort can be only surmised through a series of testing methods, which distract the subject during testing. Because these devices were found to be no better and in some manners worse than the Jamar, broad acceptance for implementation of non-hydraulic dynamometers has failed to occur.

Accordingly, there is a need for an improved grip assessment tool that can measure the complex grip capability/capacity of a human hand without the constraints and design drawbacks observed in the prior art. Additionally, advantage may be found in providing a device, method and system for the assessment of grip force that provides analysis and output relating to individual finger function in the context of the function of entire hand.

## II. Methods and Materials

In order to develop the Grip ForceMap$^{TM}$ System the use of a high resolution tactile array sensor was employed. Tactile array sensing involves the measurement of tactile force or pressure. A high-resolution tactile sensor includes an array of electrodes that measure the distribution of tactile pressure over a surface. A typical fabric based tactile sensor array includes a first plurality of parallel electrodes that are placed over a second plurality of electrodes with a non-conductive elastic isolation layer positioned between the first and second pluralities of parallel electrodes. The plurality of electrodes can be made of a stretchable material with each electrode formed as one or more metallic or metalized strands. A capacitor is formed at each of the intersections of the first and second pluralities of parallel electrodes, defining individual pressure sensing nodes. The pressure sensing nodes are selectively scanned and a capacitance at that node and therefore the pressure or force exerted at the node may be measured.

The term high-resolution tactile sensor means an array having a density of pressure sensing nodes wherein the greatest distance between adjacent pressure sensing nodes is in the range of 1.0 mm to 10.0 mm.

In the development of the ForceMap$^{TM}$, a high-resolution tactile array sensor (sensor density≈0.90/cm$^2$) was mounted to a solid Delrin$^{TM}$ cylinder 50x150 mm Delrin$^{TM}$ cylinder (grip force transducer) that was interfaced to an amplifier/processor and laptop computer (Fig. 1).

Figure 1. The Hand Grip ForceMap$^{TM}$ System comprised of a high resolution tactile array sensor mounted to a Delrin$^{TM}$ cylinder (grip force transducer) that is interfaced to an amplifier/processor and laptop computer.

The high-resolution tactile array sensor that is over laid on to the cylinder is referred to as the grip force transducer. The signal generated as the hand squeezes the grip force transducer (100 hertz) is passed on to other system hardware and software.

The ForceMap$^{TM}$ system includes hardware and software required to amplify, modulate, multiplex and digitize the output from the grip force transducer. A processing device is adapted to process the conditioned output from the grip force transducer, analyzing grip force data and providing an output representative of grip force capacity that may be displayed or sent to an imaging device. The ForceMap$^{TM}$ system is adapted to display an output representative of a grip force generated between the hand, fingers and the grip force transducer. Alternately grip at the finger tips or between the thumb and a single digit may be assessed. The output representative of a grip force is presented as a grip force map or graph that allows real time visual correlation between the display and grip function (Fig. 2).

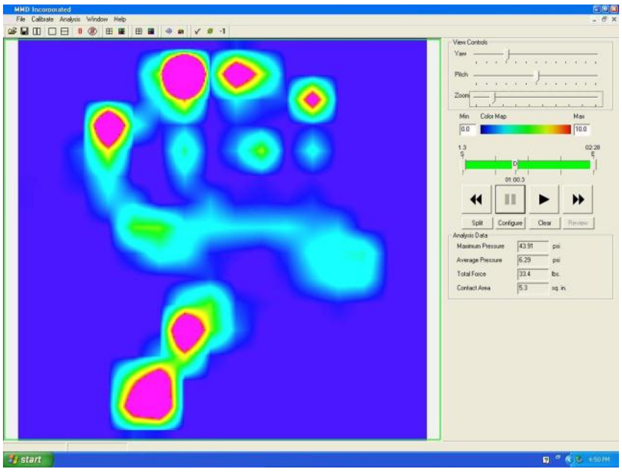

Figure 2. The ForceMap$^{TM}$ system analysis window provides total force and pressure for the entire hand and individual fingers. The analysis

Fig. 3 is a schematic diagram depicting the steps in involved in the collection and presentation of grip contact force and force distribution via the ForceMap$^{TM}$ system.

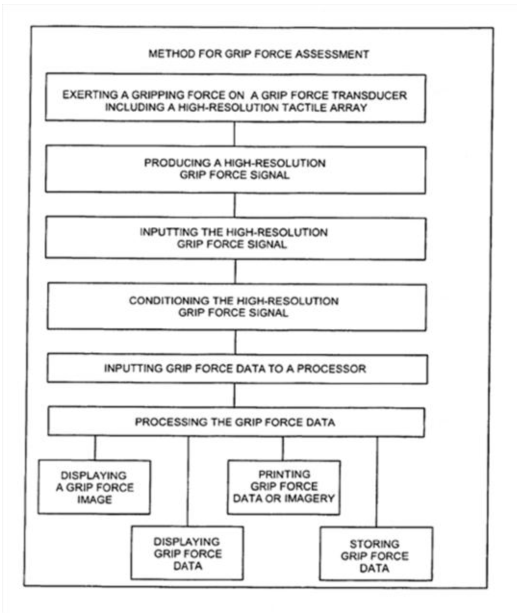


Figure 3. A schematic depicting the steps in involved in the collection and presentation of grip contact force and force distribution via the ForceMap$^{TM}$ system.

## III. RESULTS

The ForceMap$^{TM}$ system provides the following:

- analysis of data representative of individual finger function relative to entire hand function,
- real time graphic feedback and imagery depicting function of an individual finger, and/or the complex grip capability/capacity of the hand,
- two and/or three dimensional imagery and mapping including time lapse imagery and mapping of the grip surface depicting force distribution,
- representation of the grip surface depicting relative forces across a color spectrum, or a gray scale spectrum with an increase in force being represented by color values reaching one or the other ends of the visible spectrum,
- an ability to manipulate a grip force map image by magnification, rotation, variation of image resolution, variation of force scales and variation of image color,
- representation of the grip surface depicting relative forces as a relative increase or decrease in landscape peaks and valleys,
- grip force distribution over time.

## IV. DISCUSSION

The grip ForceMap$^{TM}$ system was designed to provide detailed measurement of the complex grip capability/capacity of a human hand without the constraints and design drawbacks observed with the current standard clinical grip strength-testing device (the Jamar$^{TM}$). Other state of the art hand testers also provide detailed evaluation of grip strength [1], and appear to be good options for the research setting. However, they are not well suited for the clinical setting. The ForceMap$^{TM}$ is a clinically friendly device that provides instant detailed data to the evaluator with essentially no preparation time required.

The grip force transducer's shape, that of a cylinder, was selected as it mimics many handle couplings associated with activities of daily living and work [2]. A previous study [3] suggests that an optimal cylinder handle has a diameter defined as: [Optimal Diameter=inside grip breath-(0.133 x hand length)/π], which is approximately 40 mm (50$^{th}$ percentile anthropometrics). The grip force transducer uses a cylinder diameter of 50 mm covered with a high resolution tactile array sensor, presumably accommodating 95$^{th}$ percentile anthropometrics. Other grip force transducer shapes and sizes are currently under investigation in order to allow for grip force assessment of tasks with differing hand-implement couplings [4].

Norms for maximum grip force (Newtons) and force distribution (thumb; index; middle; ring; little finger; Newtons/cm$^2$) for healthy male and female adults have been established with the ForceMap$^{TM}$ [5]. Additionally, the reliability of the ForceMap system has been assessed as follows: inter-class correlation coefficient r=0.92 and intra-class correlation coefficient ICC=0.92 [5].

Given the ForceMap's, ease of use, normative data base, high degree of reliability and ability to access hand strength (as well detailed information for each finger), it appears that the ForceMap$^{TM}$ is a viable solution to the short comings of the current standard in clinical testing of the hand. Further, the ForceMap$^{TM}$ system may help provide ergonomic solutions related to the design of safe and efficient hand-implement couplings for household, sport and work place tools and equipment.


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