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Abstract

This paper describes the implementation of a new dynamometer system with thermography monitoring of heat dissipation, and the implications of this new system in physiatry, rheumatology and neurology. The system includes a single data processing algorithm and the concept of motor hand function evaluation involving the determination of quantitative indicators.

In rehabilitation medicine, muscle function is assessed during the physical examination of a patient. Although a simple computer- supported approved dynamometer instrument improves the assessment of static strength, it is rarely used in clinical practice where dynamic measurements are preferred. A computer-assisted electronic dynamometer has been developed to enable a clinician to measure dynamic muscle function in standardized manner. Dynamometer comprises a force transducer and a movement transducer interfaced to a personal computer. In the study, dynamic measurement protocols were used that are based on biomechanical analysis. During the execution of test exercise used the method of thermographic recording of heat dissipation using dedicated software for analysis of characteristic parameters. The results obtained showed the possibility of objectification biomechanical properties and heat dissipative characteristics of the hand. The results of data analysis from calculated characteristic parameters show the correlation with patients' clinical status, i.e. the motor status of the hand and efficiency of temperature monitoring (standard deviation 0.92.). From the results of this pilot-study it can be concluded that computer supported dynamometer might be suitable for use in diagnostics in physical and rehabilitation medicine, possibily in conjuction with thermography. Further studies on larger numbers of participants are needed to evaluate these preliminary results.

INTRODUCTION

Patients with the diagnosis of rheumatoid arthritis (RA) have various symptoms, including joint pain and stiffness, loss of the range of movement *(1)* and reduction in muscle power and grip *(2)*. Hands and wrists are affected in 80–90 % of RA patients *(3)* with the symptoms progressing and finally leading to limited everyday activities. Beasley, in 1956, clearly established the need for muscle strength testing methods that are more precise and objective than manual muscle testing *(4)*. Hand strength measurements are of interest in the study of pathology of the that involves f strength loss. Hand strength testing is frequently used for clinical decision-making and outcome evaluation in . It is used to diseases, to evaluate and compare treatments, to document progression of muscle strength, and to provide feedback during the process. In addition, strength testing is often used in areas such as and . In general, hand strength measurements can be divided into manual muscle testing and dynamometry. To create more quantitative assessments of hand muscle strength, dynamometers have been developed. These dynamometer measurements are more sensitive to change compared to manual muscle testing and provide ouput data on a continuous scale. In clinical evaluation and research studies on patients with hand problems, muscle strength measurements are usually based on grip strength and pinch strength dynamometry. The most commonly used grip and pinch dynamometer is the Jamar dynamometer which is considered to be the 'gold standard' among hand-held dynamometers *(5, 6)* and similar devices by other manufacturers. The Jamar dynamometer was tested on several patient groups and these measurements showed a good reliability and validity. In addition, grip and pinch strength are functionally relevant to measure the combined action of a large number of intrinsic and extrinsic hand muscles as well as the combined action of a number of different joints. By comparing outcome with normative data, the degree of muscle strength loss can be determined *(7)*.

Standard dynamometric of a hand through the registration of the force of one grip, or the recording of a series of grips is the assessment and basis for diagnosis of functional anatomy of a whole fist during illness, treatment and rehabilitation. Temperature changes caused by stress monitoring by use of advanced thermographic technology.

Description of method evaluation

Changes in force during grips are measured in time domain, whereas spectral domain has been chosen as the basis for performance of analyses for additional evaluation parameters of hand functionality. Integral transformations level (cancel out) random unwanted artefacts in the original signal, and stable dynamic characteristics of the signal remain preserved. Similarly, it is possible to choose the typical parameters of the cycle that we consider relevant to assess the system in a direct and unique way in the frequency domain. Data acquisition was performed through the measurement system developed at the »Ruđer Bošković« Institute. The system consists of a rubber probe with 4 tensometric sensors incorporated in an ergonomic layout. The system is controlled by a specially developed computer program for acquisition and data processing, and is connected to a PC via a USB port. The results of treatment are displayed graphically and numerically. The device was calibrated by comparing the grip force on a dynamometric mechanical device with similar mechanical grip. It is important to note that the measured values of grip force and velocity significantly depend on how the device was calibrated so they should be considered approximate and qualitative.

The measurement protocol provides synchronized continuous compression, holding and relaxation of the measurement probe with a certain frequency, with a determined number of cycles and holding time. Cycle parameters were determined empirically after a series of attempts, and in relation to the average functional motoric status of hands of ill patients. Thus, the cycle time of 3 seconds was selected. Respondents were given instructions that according to the sound signal (2 different pitches) they should suddenly squeeze the measurement transducer vigorously, keep it squeezed at »maximum« force, and let go at the occurrence of a second tone. »Maximum« force is defined by the grip force of the respondents which does not disturb the regular (synchronous) execution cycle of compression and release. This force is generally less than the maximum grip force which the respondent would achieve with the conventional mechanical dynamometer, which measures the maximum force of a grip.

After series of attempts with the aim of determining the natural rate of relaxation and hand grip phase, the average duration of holding phase of 0.7 sec was determined in healthy subjects. Ill patients were given a condition to complete the grip phase before the second audio signal. In that way, the optimal time between two beeps of 0.8 seconds was determined. In total, fifteen cycles of squeezing, holding and releasing were selected in order to avoid the measurable impact of fatigue on the vigour and stability of the hand grip motor function in the holding phase.

At the time of dynamometric testing thermographic images were collected of both hands with the dorsal and volar side, from a group of patients *(8)*. In the first group there were 6 patients with rheumatoid arthritis and the control group included healthy people. Thermographic images were analyzed according to predetermined regions of the hand *(9)*.

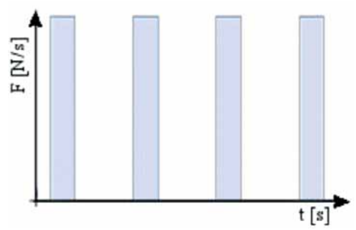

Figure 1a. *Idealized series of a healthy hand grip.*

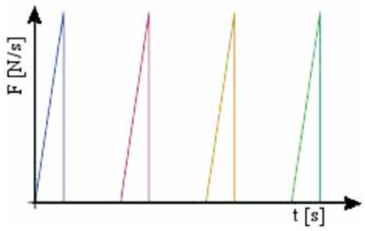

Figure 1b. *Idealized series of an ill hand grip.*

Signal and Image pre-processing

In accordance with the selected measurement protocol, we can define a so called »ideal fist« with time series of grips in Figure 1a. Also, within the given time parameters defined by the cycle, we can define the lower limits of grip speed when subject was completing the grip phase, right before the audio signal for release was played (shown in Figure 1b).

A real hand does not have an infinitely steep edge of grip phase or a completely flat plateau of holding phase, but, depending on the motor potential, it is more or less close to the ideal characteristic. A typical measured signal of a healthy subject is given in Fig. 2a and a typical signal of an ill subject is shown in Fig. 2b.

In Figure 2a,b, grip and holding phases that are relevant for assessing hand function are noticeable. Signal pre-processing consists of the approximation of the grip phase by the direction of tilt, and the holding phase by the flat plateau. The point where the grip phase ends and the holding phase begins is defined as the place of intersection of the line of increasing force and the horizontal line of maximum force. Slope of the increase in force, after testing several different ways of approximation, is defined as the line that lies in such a way that, together with the flat plateau of maximum force, minimizes the absolute value of the sum of differences of ordinates on the boundary defined by the actual data. The condition of minimal differences between left and right areas (and right areas below) from the direction of the tilt and the plateau of maximum grip was imposed, according to Figures 3a and 3b. The point of holding termination phase is determined in a manner that the mirror symmetric line

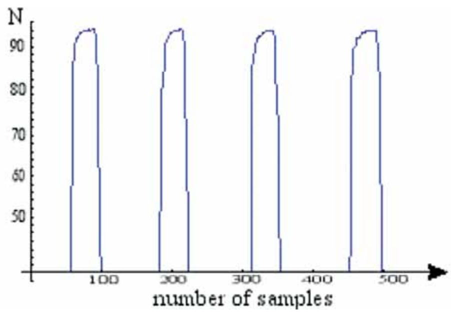

Figure 2a. *A typical grip series of healthy subjects.*

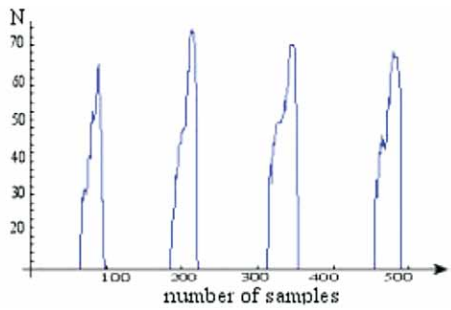

Figure 2b. *A typical grip series of ill subjects.*

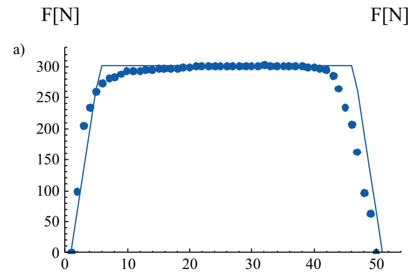

Figure 3a. *Trapezoidal approximation of a healthy grip.*

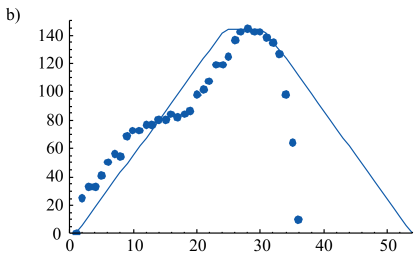

Figure 3b. *Trapezoidal approximation of an ill grip.*

of the slope that starts at the presumed point includes all of the remaining measuring points of the cycle.

In addition to these directly measurable parameters of hand function, an analysis of an idealized series of trapezoids in the spectral domain was conducted. To avoid discontinuities which mask the expected spectral grip and holding phases, a central symmetrically negative semi period (negative trapezium) was added to each cycle.

Thermal Imaging Cameras can be used for monitoring a variety of disease and medical applications. Medical thermography is a non-invasive diagnostic technique that allows the examiner to visualise and quantify changes in skin surface temperature. An infrared detection device is used to convert the infrared radiation emitted from the skin surface into electrical impulses that are visualized in color on a monitor. This visual image graphically maps the body temperature and is referred to as a thermogram. The spectrum of colors indicates an increase or decrease in the amount of infrared radiation being emitted from the body surface. Since there is a high degree of thermal symmetry in the normal body, subtle abnormal temperature asymmetry can be easily identified.

We have several medical thermal images; this series is of a patient suffering from RA. Dynamometer hand strength evaluation by heat dissipation monitoring easily identified in these thermal images that RA causes poor circulation and blood flood to extremities. The concept of IR thermographic monitoring of hand heat dissipation enables the use of IR cameras and computer system for control and thermal image registration. The system is based on a software which governs the operation of cameras analyzes the thermal image that recorded and analyse heat dissipation due to muscular activity related to the movements of the metacarpophalangeal joints.

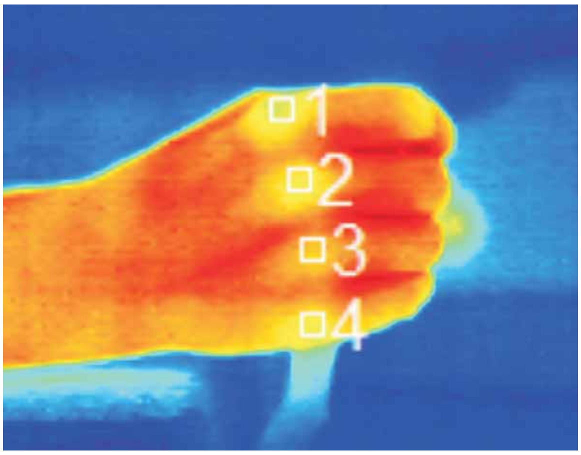

Figure 4. *Image regions for thermal monitoring.*

Imaging was performed using an infrared camera Thermo Tracer TH7102WL (NEC Sanei Instruments, Ltd., Japan). Thermal image processing was determined by the interest and matching region around the joints (Fig. 4). Joints of interest were metacarpophalangeal (MCP) and proximal interphalangeal (PIP) the joints, joints which are most frequently affected in rheumatoid arthritis.

In these regions, an analysis was made of temperature changes at various stages of the pilot experiment.

Experimental Results

We obtained results in pilot measurements with six people with RA diagnosis and six healthy subjects.

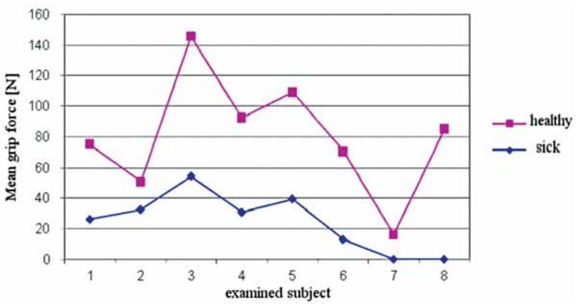

Figure 5a. *Mean grip force for various patients.*

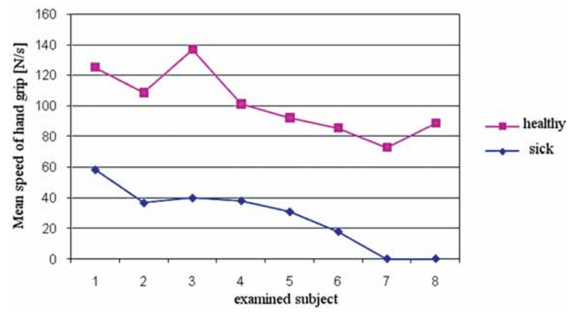

Figure 5b. *Mean speed of hand grip of various patients.*

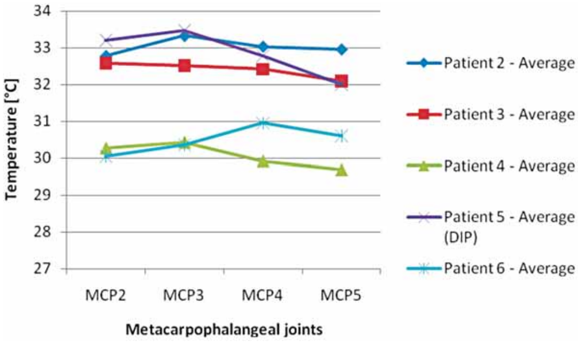

Figure 6a. *Mean values of temperature for patients with RA for joints MCP2 – MCP5.*

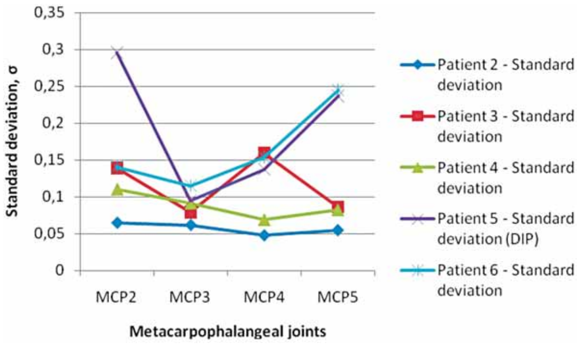

Figure 6b. *Standard deviations of joint temperature for RA patients MCP2 – MCP5.*

Data are presented separately for patients and for healthy people, and a database in Excel program was established for each group and graphs drawn presenting mean values of hand force and standard measurement deviations.

Dynamometric measurements show a significant difference in grip forces (Fig. 5a) between healthy and ill population. Also, great difference was observed in grip speed (Fig. 5b) analytical data are shown in the figures.

By recording the thermogram for the purpose of monitoring heat dissipation changes in the selected images were obtained for further processing. The mean temperature and temperature deviation by regions were obtained by analytical software. Temperature variations (patients and healthy groups) were in the range of several degrees Celsius. Standard deviation of temperature had a similar order of magnitude for all subjects (patients and healthy) who performed the same exercise by dynamometry. Recorded results of joints temperature distribution and standard deviation, for RA patient are presented in Fig. 6a,b and for healthy controls in Fig. 7a,b were performed using dedicated software for analysis of characteristic parameters.

CONCLUSION

The study of the hand strength evaluation by electronic dynamometer with thermographic monitoring showed that the device and the method can objectively

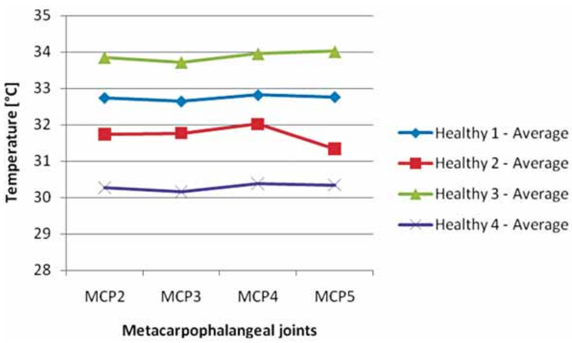

Figure 7a. *Mean values of joint temperature for healthy patients MCP2 – MCP5.*

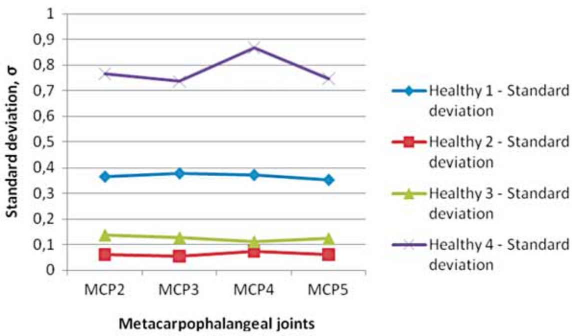

Figure 7b. *Standard deviations of joint temperature for healthy patients MCP2 – MCP5.*

and analytically show the state of the hand motor function and relevant degradation in reumatoid arthritis (RA) patients. The results show no significant change in the thermal dissipation of the hand in the analyzed hands regions (MCP and PIP joints) when loading the dynamometer according to the agreed protocol. Thermal imaging according to thermal imaging temperature changes were observed in the areas of muscle and veins. Registration of grip force is a useful indicator of a level of training in certain occupations (precision mechanics, computer work, playing different musical instruments) as well as in some sports (e.g. gymnastics, still rings, etc.).

These methods encourage the development of a dynamic sensor of specially designed to register the time diagram. Computer supported thermography monitoring of a hand grip force and distribution of heat dissipation need further exploration and methodological improvement. It can be suitable for studying other diseases affecting hands, most notably Raynaud's disease.

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