SIMPLE CLINICAL GAIT MEASUREMENT

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Abstract

A simple clinical gait measurement was developed. Such simple system can be used as a stand alone clinical gait analyzer, or accessory for the measurements whose results are not enough statisticaly weighted, such as TV, Selspot, force plate. Time, distance and velocity parameters are included into the clinical gait analysis. The measured functions are easy to be read, so that the device can be used with recording instrument only. More efficient measurements can be achieved by connecting the measuring system to some inhouse minicomputer or even better to the microcomputer. Time parameters (step and stride time, swing and stance phase and double support phase) are measured via two easy attachable tape switches at each shoe sole. Analog and digital version were provided to analyse distance (stride and step length) and velocity (velocity of center of gravity) parameters. With analog device the velocity is measured by tahometer and distance by potentiometer while using digital method both parameters can be obtained by optical transducer.

Introduction

In the early seventies it was evident that the conceptual principles for gait study and measurement have been laboratory elaborated. On the other hand the clinician who could not afford the expensive gait laboratory was still bare handed and forced to his visual perception and analysis of patients gait. The rapid high integration electronics development involving the calculators achievements, and ROM and RAM memories perfection opened new possibilities which with the microprocessor developments lead, we believe, to a new area in the rehabilitation research.

The calculator technology was first applied to gait evaluation with the socalled gait computer (1). The measurement was based on foot-switch data, and the system was comparing the single stance time to gait cadence in order to estimate the patients performance in comparison with a statistical relation of these parameters typical for normal walkers. A similar selfcontained system attachable to patient was developed in Ljubljana. This measuring system is processing all time parameters and introduces also statistical averaging and computation of the standard deviation for the main walking parameteres (2). Here we would like to present some basic principles of recent developments of the system.

The essential idea is to develop a system for gait evaluation which would have the following advantages: measurement of timing data, e.g. foot-switches, distance measurements, e.g. step-length, walking distance, measurement of velocity and acceleration. It is evident, once this set of gait data has been selected that the question arises how to measure these parameters and which transducers to use. In the same time the traditional dylemmas of gait evaluation remain oppen: how to anylise the data, what would be the criteria for gait evaluation and what kind of lay-out for t he system should be used. The last problem we would like to solve in the manner of a self-contained system. We believe that already today with the present technology development the system can be made sufficient small. In this case the influence of the system to the patient gait could be neglected. Following this idea the multifunctional transducers are to be developed. This can overcome the time consuming mounting and "wireing" of patients. The possibility to place the transducer into the electronics enclosure has to be followed. Having in mind the described principles we have developed the hardware for a simple gait evaluation system which represents an intermittent step in our development of a prototype for a clinical gait measuring system.

Transducers selection

Displacement, velocity and foot-switch data were selected for the measurement. For recording the timing data of the walking our foot switches have been used (3). For velocity measurement in the beginning a tacho-meter was used, similar to the one described and introduced at Crusen Center in Philadelphia (4). For distance recording a potentiometer was used connected to the walking subject with the thin, not elastic thread already used to rotate the tachometer. The set-up of tachometer and potentiometer is schematically shown on Fig. 1., where the thread pulling wheels can be also recognized.

This version was intended for evaluation of transducers, to find the appropriate information processing and to search for practical gait evaluation criteria. The transducers are self standing. The connection to the patient is made through a thin thread and a cable with which the foot-switch data are sent to the electronics. We believe that with a suitable thin wire the thread could be replaced and so the foot-switch cable omitted. In this version an Escap DC tachometer was selected and a 360^{o} functional industrial potentiometer, wire-wound, having 3 Kohm. An lm/s velocity will delever 15 V from the tachometer. The 0, 5 m distance of walking will turn the potentiometer for a full turn. The distance is therefore proportional to linearly rising voltage with 0, 2 V/cm and is after each full rotation turned to zero providing a linear sawtooth voltage, each period presenting 0, 5 m.

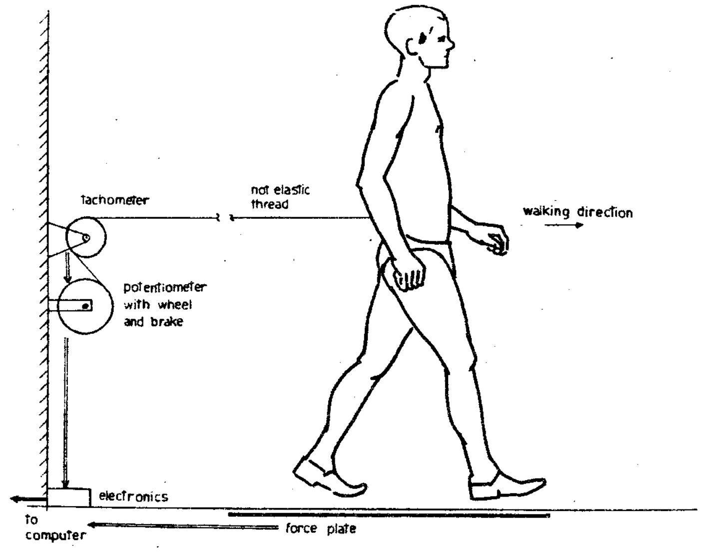

Fig. 1. Schematic presentation of experimental gait measuring set-up.

The experimental system

The experimental system can be installed in any place where exist a sufficiently long walkway for patients testing and the access to a mini-computer is provided. In our case the system was added to the already existing equipment in the locomotion laboratory (5). This setting is suitable to study the relationships between particular walking parameters. The correlation of the measured data and the study of invariability is the best mean for selecting the important and neglecting the less needed data. By help of these studies the measured data which can be statistically treated were compared to the data where statistical proccesing is not possible, like force-plate and Selspot recordings. In this way the criteria for steady-state gait can be obtained enabling the decision if the particular force-plate step was a typical one (measured in steady-state gait) or not. At the present state of the art based on our experiences we are able to build the whole system as self-contained unit and using a mikroprocessor instead of the mini-computer.

Results

The patient starts to walk on the side where the measuring transducers are placed. The thread is fixed to his back in the lumbar region approximately where the body center of gravity is located. After an audio-signal he starts to walk. An analog record of the measured data is shown on Fig. 3.

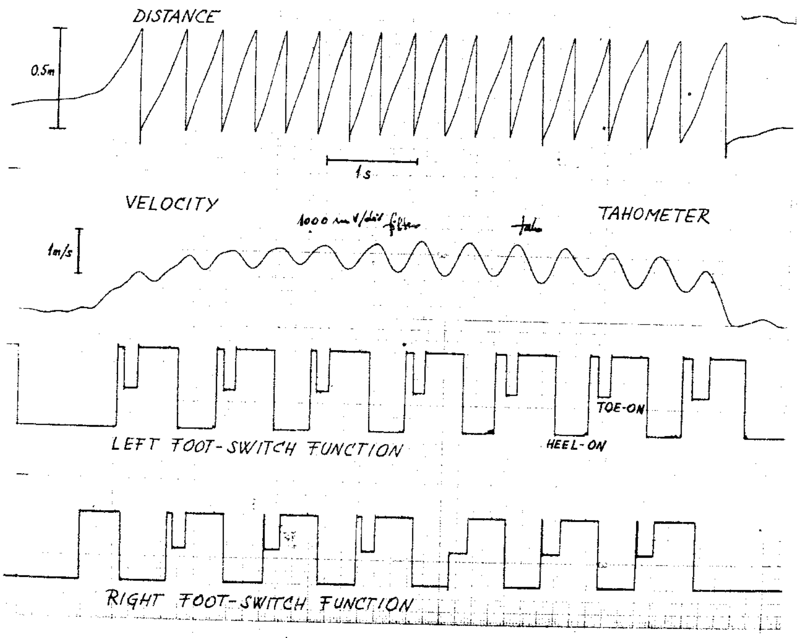

Fig.2. Record of gait parameters measured on a normal subject: center of gravity distance and velocity functions and right and left foot-switch functions.

The processor computer is collecting the functions and prints out the table of results given on Fig. 4. The walking parameters for the right and left side of each step are presented.

Using the velocity record which presents the momentary velocity in the direction of walking progression and the timing data we are looking to the velocity at push-off and the minimal progression velocity. The average

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LE
RIGHT STEP TIME (X0.01SEC)
  80( 3.56)  79  80  85  79  79  77  76  81  74  83  84  81  87
LEFT STEP TIME (X0.01SEC)
  94( 3.67)  94  92  95  99  87  89  90  96  95  95 100  96  97
RIGHT STRIDE TIME (X0.01SEC)
 174( 6.25) 173 172 180 178 166 166 166 177 169 178 184 177 184
LEFT STRIDE TIME (X0.01SEC)
 174( 5.95) 171 175 184 166 168 167 172 176 169 183 180 178
RIGHT STANCE PHASE (X0.01SEC)
 126( 5.12) 128 124 128 133 120 118 117 129 125 126 133 128 132
LEFT STANCE PHASE (X0.01SEC)
 102( 4.25) 101 104 109 101  99 101  97 103  93 106 107 104 118
RIGHT STRIDE LENGTH (CM)
  91( 2.80)  86  88  93  89  92  92  92  96  93  94  94  94  90
LEFT STRIDE LENGTH (CM)
  92( 1.68)  86  91  91  90  93  93  94  95  93  94  94  91
RIGHT PUSH-OFF VELOCITY (CM/SEC)
  76( 5.41)  68  70  71  77  77  82  88  77  90  81  77  80  75
LEFT PUSH-OFF VELOCITY (CM/SEC)
  77( 7.99)  64  65  71  71  78  82  77  91  84  97  85  81  83  60
RIGHT VELOCITY MINIMUM (CM/SEC)
  35( 7.25)  37  36  38  35  42  45  48  37  40  29  26  32  21
LEFT VELOCITY MINIMUM (CM/SEC)
  42( 4.85)  45  48  44  46  48  46  41  41  44  35  38  39  23
RIGHT MINIMUM OCCURENCE (X0.01SEC)
  67( 3.84)  70  64  64  68  58  70  64  69  63  65  68  69  73
LEFT MINIMUM OCCURENCE (X0.01SEC)
  60( 4.05)  55  55  60  62  60  56  59  62  61  66  67  66  73
RIGHT STEP LENGTH (CM)
  44( 2.08)  43  45  43  40  48  46  47  45  43  43  43  44
LEFT STEP LENGTH (CM)
  48( 2.47)  42  45  48  50  49  44  48  48  52  49  52  51  47
CRUTCH STANCE PHASE (X0.01SEC)
 105( 6.44)  99 105 113  96 102 112 109 107  93 107 114 105 141
AVERAGE AXIAL FORCE DURING STANCE (X0.01V)
 243(35.01) 300 272 276 198 193 231 260 295 215 227 216 233
MAX.FORCE OCCURENCE REL. 'HEEL ON' (X0.01SEC)
  73( 4.88)  70  71  80  66  70  78  67  75  69  78  41  39  79
MAXIMUM FO RCE VALUES (X0.01V)
 381(51.88) 476 403 447 311 332 377 391 453 354 359 321 349
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Fig. 3. Computer print-out belonging to an amputee.

of momentary velocity, if horizontal with time axis, corresponds to steady-state gait. But it is not a sufficient condition for determining the walking stationarity, because cadence and stride length could still vary. With the help of equations (1) to (5) the gait stationarty could be easily understood. The velocity v corresponding to each particular step can be defined with the following equation:

$$v = f(STL, CD) = f(STPL, STPT) \qquad (1)$$

where STL means stride length, CD cadence time, STPL step length and STPT step time. The average velocity $\bar{v}$ has to be observed only in the midsection of each patients's run (neglecting the starting and breaking portion). It is therefore defined as the quotient of mid-portion walking distance l' and correspondent time t':

$$\bar{v} = l' / t' \quad (2)$$

or it can be expressed with momentary progression velocity $v(t)$:

$$\bar{v} = {}^{1}/t' \int_{0}^{t'} v(t)\, dt \quad (3)$$

It is obvious that for a steady-state gait the average velocity must be constant and that both parameters defining the velocity must remain constant throughout the time under the consideration:

$$\bar{v} = \text{const. if } \frac{\Delta\, STL}{\Delta t} = \text{const.}, \quad \frac{\Delta\, CD}{\Delta t} = \text{const.}, \quad (4)$$

or

$$\bar{v} = \text{const. if } \frac{\Delta\, STLL}{\Delta t} = \text{const.}, \quad \frac{\Delta\, STPT}{\Delta t} = \text{const.} \quad (5)$$

From this definition it is evident that foot-switch and the velocity record are sufficient for determining the steady-state gait. This certainly is an important finding because by help of these data we are able to determine whether a force plate or Selspot recording is a typical sample of the measured walking run. This knowledge is important if the measured pattern **is to** be compared to some reference or has to be further studied. On the **other** hand during the steady-state gait we can calculate step length data from average velocity and foot-switch data.

By help of the distance record we can also determine the step and stride length. It was shown that the distance difference between two succesive mid-stance velocity minimums corresponds 2% accurately to the step length. Finally the computer calculates and prints out the mean value and the standard deviation (printed in brackets) of each measured parameter.

The question always present when observing the gait data resulting from a measurement is, how do these data help to the clinician.

This implies another question how should these data be processed in order to be of best help for gait evaluation. We tried to find the answers to the above questions but we feel our present knowledge is at present sufficient only to estimate the measured gait parameters on the basis of the observation of the symmetry between right and left leg gait parameters, on the comparison of absolute values of particular parameters belonging to normals and patients and on the repeatibility of measured walking functions (6). Presently we are trying to apply pattern recognition methods to the gait analysis (7). Using these methods, we beleive, that it would be possible selectively to classify particular gait patterns and to study changes among them.

But still the clinical interpretation of mathematical criteria and best information processing from the clinical point of view remain open. In spite of that we think that by giving to the physician a tool for the measurement of various gait parameters with a quantitative document including measured results we made his decisions to be better and easier.

Conclucion

The described gait measuring method is for more than a year permanently used in our rehabilitation center. More than fifty hemiplegic and paraparetic patients together with amputees and normal subjects were analysed. This experience will be used for the prototype completion of the system using a microprocessor and a digital optical transducer instead of the potentiometer and tachometer. All the measuring principles described remain valid and only the computer program has to be changed. Such a transducer can be made enough small to be a part of eloctronics enclosure carried by the patient. This and some other possibilities like the use of ultrasound for velocity and distance measurement will be next introduced in our research before a definite prototype version will be built.

Acknowledgement

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