Development and Assessment of Measuring and Rehabilitation Support Device for Myelopathy Patients with Lower Extremity Function

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Abstract

Disordered function of maniphalanx and difficulty with ambulation will occur insofar as a human has a failure in the spinal marrow. Cervical spondylotic myelopathy as one of the myelopathy emanates from not only external factors but also increased age. In addition, the diacrisis is difficult since cervical spondylotic myelopathy is evaluated by a doctor's neurological remark and imaging findings. As a quantitative method for measuring the degree of disability, hand-operated triangle step test (for short, TST) has formulated. In this research, a full automatic triangle step counter apparatus is designed and developed to measure the degree of disability in an accurate fashion according to the principle of TST. The step counter apparatus whose shape is a low triangle pole displays the number of stepping upon each corner. Furthermore, the apparatus has two modes of operation. Namely, one is for measuring the degree of disability and the other for rehabilitation exercise. In terms of usefulness, clinical practice should be executed before too long.

Keywords: cervical spondylotic myelopathy, disorder of lower limbs, measuring function, rehabilitation function, full automatic apparatus, triangle step test

1 Introduction

The aim of this research is to develop a full automatic and accurate apparatus for myelopathy patient in the measurement of the degree of disability.

1.1 Myelopathy

The cause of myelopathy is that the spinal marrow in the spinal canal is compressed by bone deformation due to increased age and external compression to the spine. The myelopathy is a neurologic disorder in spinal marrow or brain, and sets up a disorder of upper motor neuron. Then, paralysis and painful in upper and lower limbs will come out, and may induce disorders of defecation and urination [1].

Facing with such frame, the authors focused attention on cervical spondylotic myelopathy which is one of the possible medical problems whose possibility is relatively high. Generally, clinical condition of cervical spondylotic myelopathy is comprehended coupled with neurologic remark and imaging findings. However, for understanding accurately the functional disability owing to the damage to the spinal cord, doctor's neurological remark has limitations in objective and quantitative evaluation. Additionally, the neurological remark may not coincide with imaging findings [2]. As one of the improvement plans for such current reality, noninvasive and quantitative procedure has been newly established to evaluate the degree of disturbance of motor function in maniphalanx and lower extremities (ambulation).

1.2 Triangle step test (TST)

One of the authors has been developed a method for measuring the degree of disability in disturbance of motor function, which is called 'triangle step test' (for short, TST). Then the method is applied in clinical practice. As shown in **Fig. 1**, a thin regular triangle board, whose three corners are painted in black, is placed in front of a patient sitting in a chair. The length of a side is 30cm. The patient steps the painted corners in sequence for a given length of time (usually 10 second). A surveyor counts the number of steps by visual judgment to evaluate the degree of disability. By means of TST, the obtained quantitative result has a certain correlation with Nurick scale and JOA score (see **Tables 1** and **2**). Here, Nurick scale is a typical guidepost for Myelopathy and JOA score is a criterion for treatment results for myelopathy defined by the Japanese Orthepaedic Association. Therefore, we can say that TST is a safe and easy procedure, but it depends on visual judgment [3].

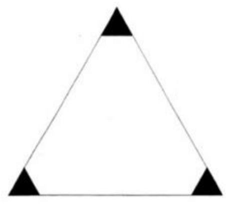


Fig. 1 Regular triangular board applied for TST

Table 1 Nurick scale

Grade	Severity (Degree of disability)
0	Signs or symptoms of root involvement but without evidence of spinal cord disease
1	Signs of spinal cord disease but no difficulty in walking
2	Slight difficulty in walking that does not prevent full- time employment
3	Difficulty in walking that prevents full-time employment or the ability to perform housework, but that is not severe enough to require someone else's help to walk
4	Able to walk with someone else's help or the with aid of a frame
5	Chair bound or bedridden

Table 2 JOA score

Grade	Severity (Degree of disability)
0	Unable to walk
1	Can walk on flat floor with walking aid
2	Can walk up and/or down stairs with handrail
3	Can walk up and/or down stairs with handrail
4	Lack of stability and smooth gait
5	No difficulties

However, in the simplified measuring technique using a triangle board, the stepping force to the triangle board is not detected. Therefore, a patient intends to let the sole slide quickly on the board in order to increase the number of steps. This thing may lead to doubtful result for judging the degree of disability and deficiency in assuredness.

Thus the authors deal with a design and development of a prototype of full automatic and accurate step counter apparatus, by which the functional evaluation based on TST and additional rehabilitation exercise of motion in lower limb can be performed.

The step counter apparatus consists of a stepstool (triangle step board; for short, TSB) and a processing box (for short, PB). In what follows further details about the step counter apparatus are described.

2 Structure of device developed

In this study, the step counter divides into two devices, developed separately. One is "Triangle Step Board (TSB)" as a device to step. The other is “Processing box (PB)”.

2.1 Triangle step board (TSB)

In each corner of the TSB shown in **Fig. 2**, a regular triangle plate, 10cm on a side, tilts with a mechanism of hinge and spring. A pressure- sensitive sensor is allocated under the plate, Thus existence or nonexistence of stepping force is detected when a patient steps on the plate on the corner. Furthermore, directly-aligned LEDs along the side of triangle board are lighting-up to indicate the circling direction which means the stepping sequence. The circling direction can be changed by a selecting switch arranged in the lateral side of the TSB.

A double-digit seven-segments LED allocated at a nearby site of each corner displays a number of stepping on relevant plate on the corner. In addition, a triple-digit seven-segments LED displays a total number of stepping to all plates on three corners. This is, so-called, an up-counter. Such number count is executed for a given length of time (usually 10 s [2]). The length of time can be given by a triple-digit BCD switch, arranged in the lateral side of the TSB, between 0 to 999 second. Remaining time is displayed on the triple-digit seven-segments LED allocated near the center of TSB. This is, so-called, a countdown timer.

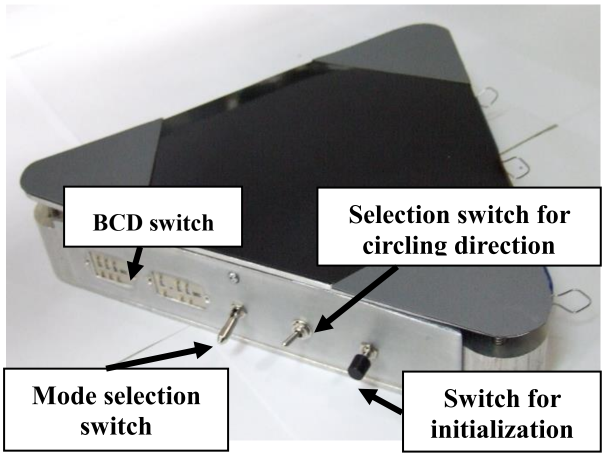


Fig. 2 Triangle step board (TSB)

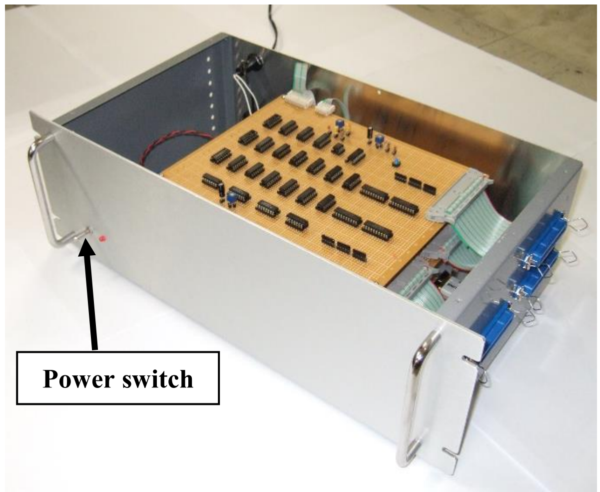
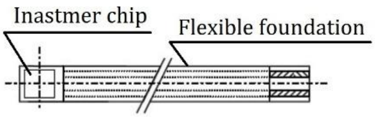


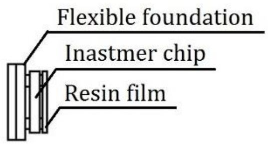
Fig. 3 Processing box (PB)

The above-mentioned function can be performed in a measurement mode and a buzzer sound plays at the same moment of stepping on each plate of TSB.

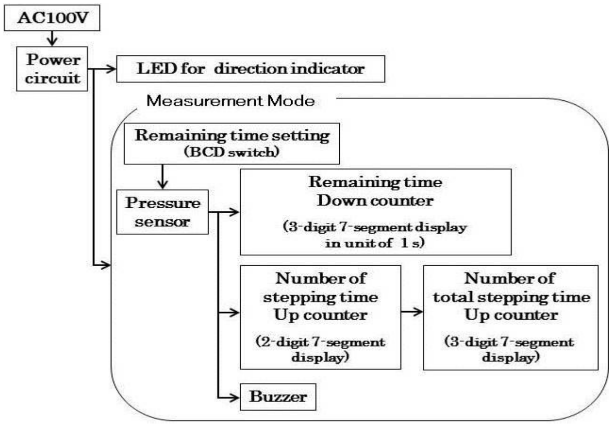
A mode select switch is also allocated in the lateral side of the TSB. By this switch, two performance modes can be selected. Namely, one is a mode for measurement of the degree of disability and the other for rehabilitation exercise. In the rehabilitation exercise mode, a patient can try to step the plates in tune with the buzzer sound played at a constant frequency. The constant period in 0.01 second can be set by a triple-digit BCD switch arranged in the lateral side of the TSB. Moreover, the performance time in 0.01 second is displayed (as a countdown timer) on another triple-digit seven-segments LED allocated near the cen-



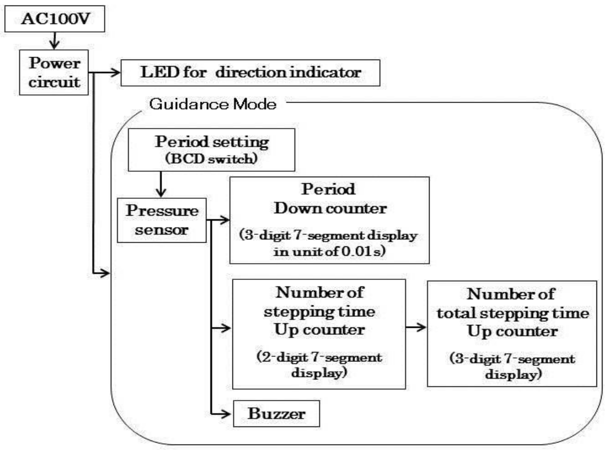
(a) Outline view



(b) Sensing part
Fig. 4 Inastmer®



(a) Measurement mode



(b) Rehabilitation exercise mode
Fig. 5 Structure of electrical circuit

ter of TSB. The authors expect this function to have a beneficial effect on rehabilitation treatment.

2.2 Processing box (PB)

Figure 3 shows the controller. The controller consists of three substrates are classified into a power supply unit, a timer unit, a counting unit, respectively. Further details about the above-mentioned (2) and (3) circuits are described later.

2.3 Pressure-sensitive sensor

A pressure-sensitive sensor whose trade name is Inastomer® (made by Inaba Rubber Co., Ltd.) is applied in this development. **Figures 4**(a) and 5(b) represent a specification of Inastomer and detecting principle, respectively. Basically, Inastomer is made from an Inastomer chip, resin film and flexible foundation (lead film tracks). Inastomer chip is produced from conductive rubber material (elastomer).

As shown in **Fig. 4**(b), the conductive materials do not make contact with each other and the resistance between the leads is infinite (insulator) when no force (load) is applied. Then, the resistance value decreased with increasing applied force. In other words, the relationship between the contacting area between conductive materials occurred by the applied force and the resistance value is in inverse proportion [4]. Therefore, when a force above a certain level is loaded, the apparatus recognizes existence of stepping on the corner plate of TSB.

Furthermore, threshold-based evaluation of the degree of disability may be capable by means of changing the threshold level for the resistance value.

3 Function of electrical circuits

This system has two modes which are measuring mode and guidance mode. A signal from a pressure-sensitive sensor is processed by threshold. When the stepping force is large and the pressure-sensitive sensor signal exceeds the threshold, a pulse signal is generated.

In the measuring mode, once a pulse signal is generated from any one of three stepping points, a countdown timer begins to tick from an initial setting time (typically, 10 second) fixed by triple digits BCD switches. Then, the numbers of steps of each stepping point and total number of steps are displayed by seven-segments LEDs. When the measuring time comes to an end, the function for counting the number of steps terminates. In addition, a buzzer sounds at the same time by the above mentioned pulse signal.

In the guidance mode, regardless of existence or nonexistence of stepping, a buzzer sounds at regular intervals (0.01 second to 9.99 second) fixed by triple digits BCD switches. A patient gives exercise to step the TSB in tune with the buzzer sound in order to improve the degree of disability. As a matter of course, the number of steps is displayed in the same fashion of measuring mode.

Figure 5 represents schematic illustrations of the circuit developed.

4 Verification experiment

The functions of this full automatic and accurate step counter apparatus were confirmed. In other words, response of pressure-sensitive sensor (Inastmer), display of all seven-segments LEDs were correct as expected. **Figure 6** represents the appearance of verification experiment.

What is troubling is that there are too many conducting wires between TSB and PB and mechanistic weak point for pressure-sensitive sensor arising from repeating steps.

5 Utility in clinical practice

To confirm the availability, the developed device (TSB) was clinically used to 30 spondylotic myelopathy

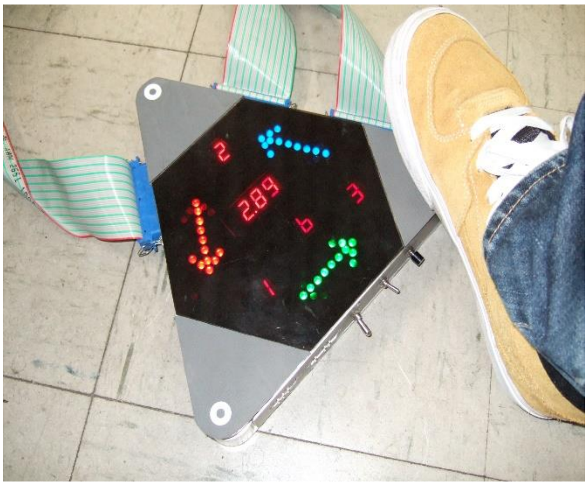
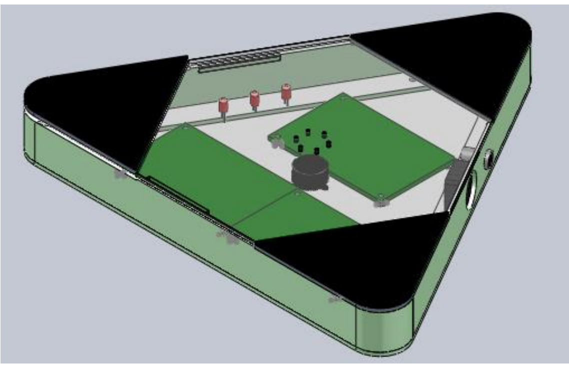
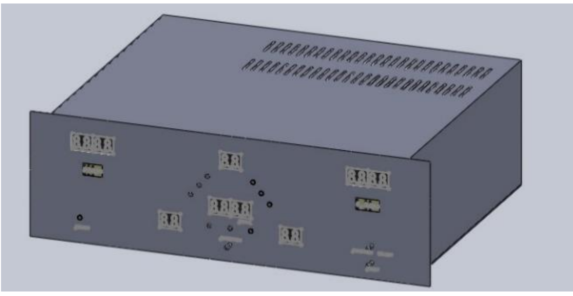


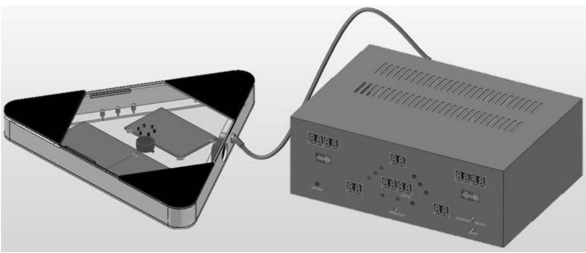
Fig. 6 Appearance of verification experiment



(a) TSB for second prototype



(b) PB for second prototype



(c) Use situation

Fig. 7 Second prototype to be developed

patients and 5 well persons in Yokohama Minami Kyosai Hospital. **Table 3** represents the result.

In the result of well persons, TST values and TSB values are almost the same. However, in comparison of the mean values of the number of steps in the patients, TSB values are smaller than TST values. This proves

Table 3 Comparison between patients and well persons

		Patients		Well persons	
		Mean number of steps	Std. dev.	Mean number of steps	Std. dev.
TST	R	21.1	5.9	27.8	3.6
	L	20.9	5.9	27.4	2.6
TSB	R	18.3	6.3	28.8	7.8
	L	18.6	5.8	29.4	8.7
Dif.	R	-2.8		1.0	
	L	-2.3		2.0	

Note: R=Right leg, L=left leg, Dif.=Difference

TSB values are smaller than TST values. This proves that an inadequate step of a patient can be detected by the newly developed TSB system, and TSB represses rubbing movement of a foot.

In the traditional TST method, the number of steps is counted by a tester (human). In this case, the tester cannot discriminate a rubbing movement from a regular step. However, an accurate result to evaluate the degree of disability of patient can be expected by using the developed TSB system.

6 Second prototype

Figure 7 shows some images of a second prototype of TSB system being developed. The part of basic display and several mechanical switches is moved to the front panel of PB. In the second prototype, the stepping mechanism is improved. Thus, the number of connecting wires between TSB and PB are greatly reduced. Then, the height of TSB can become thinner. Furthermore, the degree of stepping force can be observed easily by both examinee and tester.

7 Conclusion

In this research, a full automatic and accurate measuring/rehabilitation exercise apparatus has been developed to evaluate the degree of disturbance of motor function in lower limb for myelopathy patient. Then the functions of the prototype were verified. To confirm the reliability and durability, clinical experiment is proposed at some early date.

Moreover, since the height, 45mm of this first prototype is comparatively thick and the practical usefulness is slim, a second prototype is designed to upgrade the practical utility. In addition, timer and number count displays will be moved to the front panel of processing box in order to check the counted results easily by both surveyor and patient.

The first prototype has been used for real clinical usage in Yokohama Minami Kyosai Hospital. Some mechanical defects are reported and they have been fixed.

The authors should bring the second prototype to completion as soon as possible and verify the utility in clinical practice.

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