การปรับเทียบเตียงพร้อมอุปกรณ์วัดแรงและระบบบันทึกการเคลื่อนไหวในการวัดแรงและระยะทาง

นางเมธาวี แก้วประเสริฐ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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คณะสหเวชศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2554

ลิขสิทธิ์ของจุฬาลงกรณ์มหาวิทยาลัย
บทคัดย่อและแฟ้มข้อมูลฉบับเต็มของวิทยานิพนธ์ตั้งแต่ปีการศึกษา 2554 ที่ให้บริการในคลังปัญญาจุฬาฯ (CUIR)
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CALIBRATION OF AN INSTRUMENTED COUCH WITH A MOTION CAPTURE SYSTEM IN MEASURING FORCE APPLIED AND DISTANCE

Mrs. Methawee Kaewprasert

A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of Master of Science Program in Physical Therapy

Department of Physical Therapy

Faculty of Allied Health Sciences

Chulalongkorn University

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Thesis Title	CALIBRATION OF AN INSTRUMENTED COUCH WITH A MOTION CAPTURE SYSTEM IN MEASURING FORCE APPLIED AND DISTANCE
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Field of Study	Physical Therapy
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เมธาวี แก้วประเสริฐ: การปรับเทียบเตียงพร้อมอุปกรณ์วัดแรงและระบบบันทึกการเคลื่อนไหวในการวัดแรงและระยะทาง. (CALIBRATION OF AN INSTRUMENTED COUCH WITH A MOTION CAPTURE SYSTEM IN MEASURING FORCE APPLIED AND DISTANCE) อ. ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร.อดิษฐ์ จิรเดชนันท์, 71 หน้า.

งานวิจัยนี้มีวัตถุประสงค์ เพื่ออธิบายการทำงานของเตียงพร้อมอุปกรณ์วัดแรงและระบบบันทึกการเคลื่อนไหว และทำการสอบเทียบหาความเที่ยงตรง และความน่าเชื่อถือของเครื่องมือที่ประยุกต์ขึ้นมา โดยค่าความเที่ยงตรงและความน่าเชื่อถือของเตียงพร้อมอุปกรณ์วัดแรงจะถูกประเมินใน 2 เงื่อนไข คือการทดสอบบนเตียงเปล่า และการทดสอบขณะมีน้ำหนัก 70 กิโลกรัมวางบนเตียง โดยทำการทดสอบทั้ง 2 เงื่อนไขใน 3 แกน คือ แกนตั้ง แกนนอนตามขวาง และแกนนอนตามยาว ในกรณีของการสอบเทียบระบบบันทึกการเคลื่อนไหว ทำโดยใช้กระดาษตารางขนาด 40 × 40 เซนติเมตร^2 ความเที่ยงตรงของเตียงพร้อมอุปกรณ์วัดแรงและระบบบันทึกการเคลื่อนไหว ถูกวิเคราะห์โดยการคำนวณหาค่าสัมประสิทธิ์สหสัมพันธ์เพียร์สัน ความน่าเชื่อถือของเตียงพร้อมอุปกรณ์วัดแรงใช้การคำนวณหาค่าสัมประสิทธิ์สหสัมพันธ์ภายในกลุ่ม [$ICC_{(2, 1)}$] และยังได้นำการคำนวณหาความคลาดเคลื่อนเป็นร้อยละมาคำนวณทั้ง เตียงพร้อมอุปกรณ์วัดแรงและระบบบันทึกการเคลื่อนไหว

ผลการวิจัยพบว่า เตียงพร้อมอุปกรณ์วัดแรงและระบบบันทึกการเคลื่อนไหวมีค่าสัมประสิทธิ์สหสัมพันธ์เพียร์สันเท่ากับ 1.00 ($p<0.05$) ในส่วนของการคำนวณสัมประสิทธิ์สหสัมพันธ์ภายในกลุ่ม [$ICC_{(2, 1)}$] ของเตียงพร้อมอุปกรณ์วัดแรงพบว่ามีค่าเท่ากับ 1.00 ($p<0.05$) ในขณะที่ค่าร้อยละของความคลาดเคลื่อนของเตียงพร้อมอุปกรณ์วัดแรงพบว่ามีค่าเฉลี่ยอยู่ระหว่าง 0.41-1.12 ในกรณีของระบบบันทึกการเคลื่อนไหวพบว่าค่าร้อยละของความคลาดเคลื่อนในการวัดระยะทางเท่ากับ 0 จากผลการวิจัยสามารถสรุปได้ว่า เตียงพร้อมอุปกรณ์วัดแรงและระบบบันทึกการเคลื่อนไหวมีความเหมาะสมสำหรับใช้วัดแรงและการเคลื่อนที่ขณะทำการรักษาด้วยมือ

ภาควิชา กายภาพบำบัด ลายมือชื่อนิสิต..

สาขาวิชา กายภาพบำบัด ลายมือชื่ออ.ที่ปรึกษาวิทยานิพนธ์หลัก...

ปีการศึกษา 2554

5177216537: MAJOR PHYSICAL THERAPY
KEYWORDS: FORCE/ DISPLACEMENT/ MEASUREMENT/ CALIBRATION OF THE INSTRUMENTED COUCH

METHAWEE KAEWPRASERT: CALIBRATION OF AN INSTRUMENTED COUCH WITH A MOTION CAPTURE SYSTEM IN MEASURING FORCE APPLIED AND DISTANCE. ADVISOR: ASST. PROF. ADIT CHIRADEJNANT, Ph.D, 71 pp.

The objectives of this study were (i) to describe an instrumented couch which would be able to synchronize with the motion capture system in details; (ii) to calibrate this device. The criterion-related validity and test-retest reliability of the couch were investigated in two conditions: empty couch and a couch with dead weight of known mass of 70 kg. Both conditions were investigated in three directions: vertical, medial-lateral and caudad-cehalad directions. The motion capture system was also investigated by using the grid paper size 40× 40 cm^2. The criterion-related validity of both the couch and motion capture system were analyzed by Pearson's product moment correlation. The test-retest reliability of the couch was analyzed by Intraclass correlation coefficients [$ICC_{(2, 1)}$]. The percentage error was calculated for both the couch and motion capture system.

The Pearson's product moment correlation of this study showed 1.00 ($p<0.05$) in both the couch and motion capture system. The $ICC_{(2, 1)}$ of the couch was 1.00 ($p<0.05$). The percentage error of the couch showed average percentage error to be ranged from 0.41-1.12%. The percentage error of the motion capture system showed 0%. In conclusion, the instrumented couch and the motion capture system are appropriate to investigate both amount of force applied and displacement during manual therapy.

Department: Physical Therapy Student' Signature……………………………
Field of Study: Physical Therapy Advisor' Signature……..………………………
Academic Year: 2011

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Ultimately, I would like to give my indispensable thanks to my parents, my husband and my sister for their love, understanding, encouragement, finance and all support. The benefit of this thesis, I dedicate to my parents and all the teachers who have taught me since I was young.

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LIST OF ABBREVIATIONS

cm	=	Centimeter
CI	=	Confidence interval
DPIS	=	Descending pain inhibitory system
dPAG	=	Dorsal periaqueductal gray
F	=	The applied force by the therapist to the patient
G	=	The ground force measured by the force platform
Hz	=	Hertz
ICC	=	Intraclass correlation coefficients
kg	=	Kilogram
MRI	=	Magnetic resonance imaging
MT	=	Manipulative therapy
N	=	Newton
PAG	=	Periaqueductal gray
vPAG	=	Ventral periaqueductal gray
SG	=	Substantia gelatinosa
T cell	=	Transmission cell
W	=	Weight of therapist

CHAPTER I

INTRODUCTION

1.1 Background and rationale

Manipulative therapy (MT) is commonly used in the treatment of musculoskeletal disorders. It has been noted that MT was effective in pain reduction known as the neurophysiological mechanism whereas the effect on mobility is still unclear. In order to investigate the effectiveness on mobility, a number of devices were developed such as spinal physiotherapy simulator (Lee & Svensson, 1990; Lee et al, 1998), spinal mobiliser (Lee & Evan, 1992), the spinal assessment machine (Latimer et al, 1996a; Latimer et al, 1996b) and the spinal posteroanterior mobiliser (Edmondston et al, 1998). Such devices are very useful for researching, unfortunately they are not commercial available and costly. Due to such limitations, a number of devices were therefore developed in order to quantify force applied during MT. These include a flexible pressure pad (Grant, 1985; Hessell et al., 1990; Herzog et al., 1993), a force plate (Matyas & Bach, 1985; Petty & Messenger, 1996) and instrumented couch (Harm et al., 1995b; Chiradejnant et al., 2001; Snodgrass et al., 2008).

Nevertheless, these devices mentioned previously have some disadvantages to be concerned as follows. The use of the flexible pressure pad seems to be the most convenient method. This is because it can be not only set in clinical practice but also directly quantify the applied force. However, the position of the pad is argued to diminish the therapist's perception of the joint movement being treated (Harm et al., 1995b). In order to allow the therapist to perceive a joint movement during MT, the force plate was used instead of the pressure pad to quantify the force. The use of this device seems to be somewhat more beneficial than that of the pressure pad. However, the limitations of this device were reported as follows. First, the use of this device is argued to be inappropriate. Second, this device can quantify the force applied in static while the MT is applied dynamically. As a result, a therapist would have to hold the application of force applied for 0.5 to 1 second during the data collection (Matyas & Bach, 1985; Petty & Messenger, 1996). Therefore, the force and time data obtained from the force plate may not represent the real force during MT. Up to present, the couch mounted with load cells has been claimed to reduce the disadvantages mentioned previously, because it can directly measure the force applied and does not interfere the therapist's perception during MT (Harm et al., 1995b; Chiradejnant et al., 2001; Snodgrass et al., 2008).

Additionally, there are a number of methods used to investigate spinal displacement occurred during MT. These include X-rays (Lee & Evan, 1997), magnetic resonance imaging (MRI) (McGregor et al., 2001; Power et al., 2003; McGregor et al., 2004; Kulig et al., 2004) and motion analysis (Watson, 1989; Gal et al., 1995; Gal et al., 1997). Once again, the used of such methods seem to be beneficial to both researchers and practices. For example it provides normative data with regard to spinal displacement and the effect of the forces applied to the adjacent spines.

Therefore, it is a clear need to develop a device which would be able to quantify both applied force and distance in order to explain the effect of MT on mechanical properties. The aims of this study were to describe an instrumented couch which would be able to synchronize with the motion capture system in details and to calibrate this device.

1.2 Objectives

The objectives of this study were to validate an instrumented couch and the motion capture system in quantifying the applied force and distance, respectively.

1.3 Specific objectives

The criterion-related validity of the instrumented couch and the motion capture system in quantifying the applied force and distance were investigated using dead weight of known mass and a grid paper as a gold standard, respectively. The percentage error of both the couch and the motion capture system was also calculated. Also the test-retest reliability of the instrumented couch was investigated in two occasions. All tests were investigated both in three directions and two conditions: an empty couch and a couch with dead weight of known mass 70 kilograms (kg).

1.4 Hypotheses

There would be no statistically significant differences between the data obtained from the couch with the motion capture system and the gold standard. The Pearson's product moment correlation represents the criterion-related validity of the couch and motion capture system to be more than 0.95. The Intraclass correlation coefficients [$ICC_{(2, 1)}$] represent the test-retest reliability of the couch in measuring the force to be more than 0.95. The percentage error of the data obtained from the couch and motion capture system were less than 3%. The *p* values of all statical analyses were set less than 0.05.

1.5 Scope of the study

This study focused on the criterion-related validity of both the instrumented couch in quantifying the applied force compared to a set of dead weights of known mass (gold standard) and the motion capture system in quantifying the distance compared to the distance of the grid paper (gold standard). The criterion-related validity of the couch was investigated in both two conditions: an empty couch and a couch with dead weight of known mass 70 kg and three directions: vertical, medial-lateral and caudad-cephalad directions.

1.6 Brief method

The criterion-related validity and test-retest reliability of the couch were investigated in two different conditions: an empty couch and a couch with dead weight of known mass 70 kg. Fore readings were undertaken twice in three directions: vertical, medial-lateral and caudad-cephalad directions using a set weights of known mass as a gold standard. The criterion-related validity of the couch was investigated by correlating the data obtained from the couch to the gold standard using the Pearson's product moment correlation. The percentage error in measuring the force was also calculated. The test-retest reliability of the couch was investigated by correlating the first lots of the data to the second lots of data using $ICC_{(2, 1)}$.

The criterion-related validity of the motion capture system was investigated by using a grid paper size 40 × 40 centimeters^2 (cm^2) as a gold standard. The grid paper was attached to a box and then positioned on the couch in order to ensure the grid paper position to be in the vertical direction. The motion capture system was focused on the grid paper and the distance measurement was then taken place. The criterion-related validity of the motion capture system was investigated by correlating the data obtained from the motion capture system to the value obtained from the grid paper using the Pearson's product moment correlation. The percentage error in measuring the distance was also calculated.

1.7 Advantage of the study

After calibrating, this device would be used for investigating an applied force and displacement during the application of spinal and peripheral joints MT.

CHAPTER II

LITERATURE REVIEW

This chapter describes about the effectiveness of MT and developed devices in researching with the use of MT including spinal stiffness, force quantification and spinal displacement.

2.1 Effect of manipulative therapy

The effectiveness of MT has been proposed known as neurophysiological mechanism (Melzack & Wall, 1965; Wright, 1995; Brown, 2005) and mechanical mechanism (Maitland et al., 2008; Threlkeld, 1992). The details of these two mechanisms were discussed as follows.

2.1.1 Neurophysiological mechanism

It has been suggested that MT would stimulate several neural tissues in both spinal level known as gate control theory (Melzack & Wall, 1965; Brown, 2005) and supra spinal level known as descending pain inhibitory system (DPIS) (Wright, 1995), respectively. With regard to the gate control theory, it has been proposed that MT stimulates mechanoreceptor and proprioceptor; and the afferent input would be sent by a large diameter nerve fiber (A-beta) whereas pain stimulates nociceptor and afferent input would be sent by a small diameter nerve fiber (C). Due to the size of nerve fiber, MT afferent input would be conducted faster than pain afferent input. Therefore, this would result in stimulation interneuron in substantia gelatinosa (SG) for inhibiting impulse from the pain afferent input in T cell. The output from T call that ascending to the brain is reduced so the pain intensity is decreased (Figure 2.1) (Melzac& Wall, 1965; Brown, 2005).

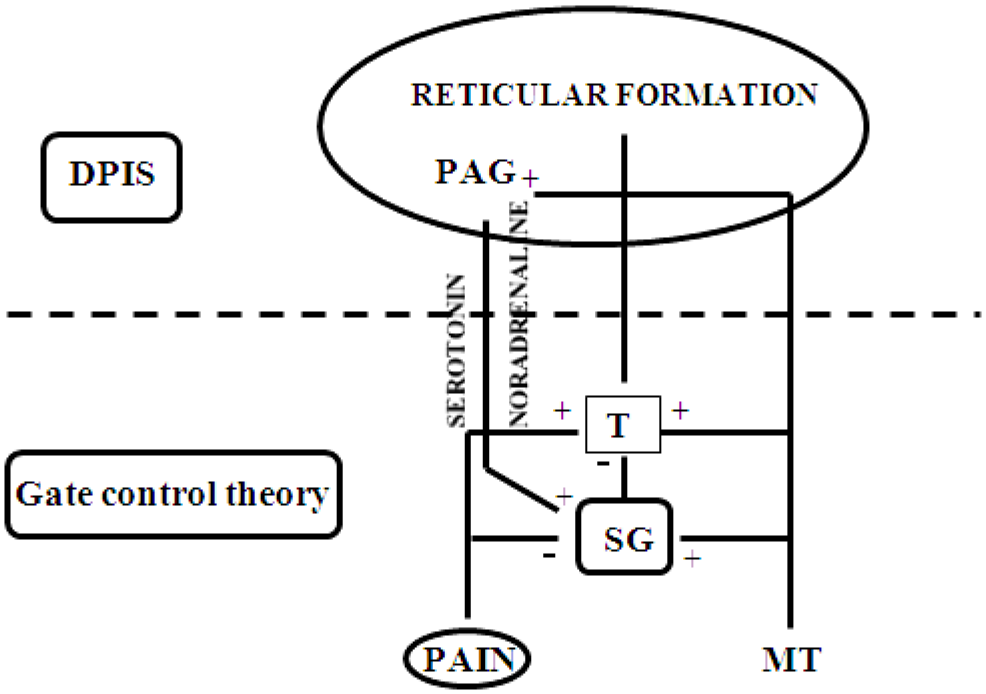

Figure 2.1 Neurophysiological mechanism (modified from Melzack & Wall, 1965; Brown, 2005). SG and T represent substantia gelatinosa and transmission cell, respectively. + and - signs represent activation of the impulse and inhibition of the impulse, respectively.

Additionally, the impulse of MT is sent via lateral pathway of the spinal cord to the midbrain and activated PAG (Figure 2.1). The mechanism in PAG can be described in two projecting pathways as dorsal periaqueductal gray (dPAG) and ventral periaqueductal gray (vPAG). In dPAG, MT stimulates the projection neuron to produce sympathoexhibition process for pain inhibiting. The mechanism from dPAG is an immediate effect which occurred within 1 minute after applying MT. In vPAG, MT and sympathoexhibition process from dPAG stimulate vPAG to produce sympathoinhibition process for inhibiting pain. The mechanism from vPAG is latent effect which occurred after MT was applied for 20 to 40 minutes (Wright, 1995). Moreover, the neurotransmitters from PAG, noradrenaline and serotonin, are sent via dorsolateral funiculus to stimulate interneuron in SG for inhibiting pain in T cell. This mechanism can be described by DPIS (Figure 2.1) (Brown, 2005).

2.1.2 The mechanical mechanism

It has been suggested that MT would produce tissue elongation effect (Maitland et al., 2008). A study on quantification of the amount of force applied to the cadaveric specimen was noted to be between 244 and 1,136 Newtons (N) in order to result in the tissue elongation (Threlkeld, 1992). On the other hand, a number of studies investigating the amount of force applied to human subjects noted to be less than 250 N (Harm & Bader, 1997; Chiradejnant et al., 2002; Cook et al., 2002; Snodgrass et al., 2007). It could be seen that the amount of force applied to live subjects was less than that applied to the cadaveric specimen. Therefore, the change in mechanical properties would not be well explained by this evidence. However, caution needs to be exercised to interpret these results due to the differences in the tissue properties. In order to investigate the change in mechanical properties, a number of devices were developed aiming to quantify stiffness of the investigated joint by quantifying displacement and the amount of applied force.

2.2 The devices developed to quantify stiffness

There are a number of devices developed to quantify stiffness using similar principle of development. These include the spinal physiotherapy simulator (Lee & Svensson, 1990; Lee et al, 1998), spinal mobiliser (Lee & Evan, 1992), the spinal assessment machine (Latimer et al, 1996a; Latimer et al, 1996b) and the spinal posteroanterior mobiliser (Edmondston et al, 1998). Briefly, these devices have a force applicator mounted to a potentiometer and a load cell. The data from potentiometer and the load cell represent the displacement and amount of force occurred during the force application, respectively. These data would be able to synchronize with the force time data. A special program was developed to plot force and displacement graph and calculate the slope of the graph. The slope of the force and displacement curve represents a stiffness of the joint being investigated. All data were kept for further analysis (Lee & Evan, 1992; Latimer et al, 1996a; Latimer et al, 1996b; Lee et al, 1998; Edmondston et al, 1998).

These devices were used in a number of studies (Latimer et al, 1996c; Lee et al, 1998; Edmondston et al, 1999; Nicholson et al, 2001) in order to quantify the spinal stiffness at the application point, investigate human spinal properties and investigate the relationship between pain and stiffness. Such information was very useful for both research and clinic with regards to the use of MT. Unfortunately these devices are not commercial available and costly. Due to such limitations, a number of devices were developed in order to quantify force applied during MT, including a flexible pressure pad (Grant, 1985; Hessell et al., 1990; Herzog et al., 1993), a force plate (Matyas &

Bach, 1985; Petty & Messenger, 1996) and instrumented couch (Harm et al., 1995b; Chiradejnant et al., 2001; Snodgrass et al., 2008).

2.3 The devices developed to quantify force

The flexible pressure pad and the force plate were developed using similar principle of development. Briefly, these devices use a capacitive transducer to quantify the amount of force applied to their surface. The force measurement was noted using the change in the distance between the electrodes (Grant, 1985; Orlin & McPoil, 2000). There are disadvantage and advantage between these two devices. First, the flexible pressure pad was claimed to diminish the therapist's perception of the joint movement being applied. This is because the flexible pressure pad has position between the therapist's thumb and the spinous process. However, the use of the flexible pressure pad seems to be the most convenient method because it can be not only set in clinical practice but also directly quantify the applied force with an error less than 7% (Hessell et al., 1990).

In order to allow the therapist to perceive a joint movement during MT, the force plate was used instead of the pressure pad to quantify the force. The use of this device seems to be somewhat more beneficial than that of the pressure pad. However, there are some limitations as follows. During the data collection, the force plate was placed under a therapist's feet in order to quantify the force applied in the vertical direction (Matyas & Bach, 1985; Petty & Messenger, 1996). This method has been defined as an indirect method as the force was quantified under therapist's feet instead of the force application point (Figure 2.2). Moreover, the therapist was asked to hold or statically apply the force during the data collection (Matyas & Bach, 1985; Petty & Messenger, 1996). These have been argued to be an inappropriate method and procedure to quantify the force with regards to be the use of the force plate. Finally the force plate can quantify the force in only the vertical direction.

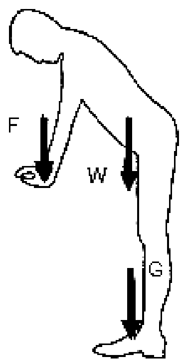

Figure 2.2 The forces calculated by force plate (modified from Petty & Messenger, 1996). The force applied to the subject can be calculated from formula F = W–G. F, G and W represent the force applied by the therapist to the patient, the ground force measured by the force platform and weight of therapist, respectively.

To diminish such limitations, a standard treatment couch was developed by mounting resistive load cells to the couch frame in order to quantify the applied force to its surface (Harm et al., 1995a). Briefly, the six load cells were attached under the frame of the treatment couch. The two load cells were perpendicular to measure the force in three directions. The error of force measurement was ranged from 1.55% to 4.53% and the criterion-related validity in force measurement was recorded with the Pearson's product moment correlation to be 0.999 ($p < 0.001$) (Harm et al., 1995b).

After that, the instrumented couch was modified from the principle of the previous studies (Harm et al., 1995a; Harm & Bader, 1997). The seven S beam load cells were mounted to the couch frame for using quantified force in three directions. Four load cells were used to quantify force in vertical direction. Two load cells were used to quantify the force in medial-lateral direction and another one was used to quantify the force in caudad-cephalad direction (Chiradejnant et al., 2001; Snodgrass et al., 2008). The positions of seven load cells were showed in Figure 2.3. The capacity of each load cell in measuring the force was 100 kg (Chiradejnant et al., 2001). The accuracy of this instrumented couch was showed with percentage error range between 0.17% to 4.14% (Chiradejnant et al., 2001) and the reliability was showed with $ICC_{(2, 1)}$ being range 0.99 to 1 (95% CI) (Chiradejnant et al., 2001; Snodgrass et al., 2008).

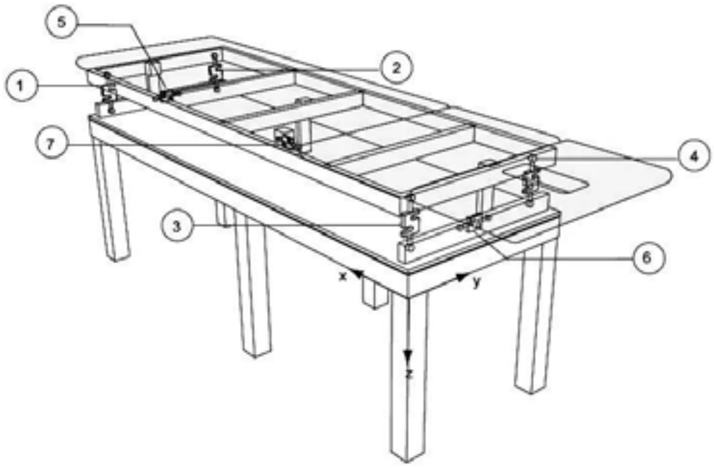

Figure 2.3 The positions of load cells (Chiradejnant et al., 2001; Snodgrass et al., 2008). 1 to 4 represent the positions of load cells in vertical direction, 5 to 6 represent the position of load cell in medial-lateral direction and 7 represents the position of load cell in caudad-cephalad direction. X, Y and Z represent the axes of the instrumented couch, respectively.

The use of these devices seem to be somewhat more beneficial than that use of other two devices mentioned previously because these devices are directly to quantify the force that the therapist applied to the subject and did not diminish the perception of therapist during the application of MT. Moreover, these devices could quantify force in three directions. The instrumented couch has been suggested to be appropriate device to quantify the force applied in clinical practice. For describing the change in mechanical properties, the device for quantifying the displacement that occurred during the application of MT has been mattered.

2.4 The devices developed to quantify spinal displacement

Images and motion analysis were used to investigate only the spinal displacement occurred during MT. The uses of such devices are useful and seem to be more beneficial than the use of the devices mentioned in section 2.2. This is because it would be possible to quantify the spinal displacement of the adjacent spines. Additionally, the use of these devices provides not only normative data regarding spinal displacement but also the effect of the forces applied to the adjacent spines.

The X-rays seems to be the simplest and convenient method to quantify the spinal displacement occurred during MT. During the data collection, the therapist required to statically applied MT (Lee & Evan, 1997), therefore the amount of displacement noted in that previous study represents the static displacement occurred during statically applied MT. This is argued to be inappropriate method as the MT is applied dynamically in practices (McGregor et al., 2001). In order to diminish such limitation, the MRI was used to investigate the spinal displacement (McGregor et al., 2001; Power et al., 2003; McGregor et al., 2004; Kulig et al., 2004). The use of the MRI seems to be more beneficial than the X-rays. This is because MRI would be able to dynamically quantify the spinal displacement during the application of MT. However the size of the equipment seems to interfere a therapist to apply MT.

Up to present, the use of motion analysis using the cartesian optoelectronic dynamic anthropometer (Watson, 1989) and high speed video camera (Gal et al., 1995; Gal et al., 1997) is claimed to be suitable for quantifying the spinal displacement even though this method is argued to be an indirect method. The use of motion analysis would not only be able to quantify the displacement occurred in real time but also set in practices. Moreover, these methods do not interfere positions of the therapist and subject during MT procedure.

2.5 Summary

A number of devices were developed to investigate the amount of force applied, spinal stiffness and displacement occurred during the MT. To date, the instrumented couch and the motion analysis seem to be the most appropriate instrument to quantify the amount of force applied and spinal displacement, respectively. In order to investigate the change in mechanical properties, it is needed to develop a new device which would be able to investigate both force applied and displacement at the same time.

CHAPTER III

METHODOLOGY

This chapter describes the study design, researcher, materials, procedure and data analysis.

3.1 Study design

Criterion-related validity studies were conducted to investigate the validity of both the couch in measuring the force applied to its surface and the motion capture system in measuring the distance. A test-retest study was also conducted to investigate the reliability of the couch in measuring the force applied.

3.2 Researcher

The researcher in this study was Kaewprasert M., who enrolled in a Master degree of Musculoskeletal Physical Therapy Program, Faculty of Allied Health Sciences, Chulalongkorn University.

3.3 Materials

This section describes the materials in this study including the set weights of known mass, pulley and sling, a grid paper and a modified instrumented couch and a motion capture system.

3.3.1 The set weights of known mass

The set weights of known mass were the gold standard in this study. All weights were tested from Thai Industrial Standards Institute. The set weights of known mass were divided into 36 weights ranged from 0.5 to 80 kg for testing in each direction. The set weights of known mass 0.5 to 80 kg were tested in the vertical direction and empty couch condition. Moreover, the set weights of known mass 0.5 to 40 kg were tested in the vertical direction (condition with the dead weight of known mass 70 kg), medial-lateral and caudad-cephalad directions, respectively (Table 3.1).

Table 3.1 The set weights of known mass used in this study

Weights (kg) tested in vertical direction	**Weights (kg) tested in medial-lateral, caudad-cephalad directions and condition with the dead weight of known mass 70 kg**
0.5, 1, 1.5, 2, 5, 7, 8.5, 10, 12.5, 15, 17.5, 20, 22.5, 25, 27.5, 30, 32.5, 35, 37.5, 40, 42.5, 45, 47.5, 50, 52.5, 55, 57.5, 60, 62.5, 65, 67.5, 70, 72.5, 75, 77.5, 80	0.5, 1, 1.5, 2, 5, 7, 8.5, 10, 12.5, 15, 17.5, 20, 22.5, 25, 27.5, 30, 32.5, 35, 37.5, 40

3.3.2 A pulley system and sling

A pulley system and sling were used for testing the weight in the medial-lateral and caudad-cephalad directions (Figure 3.1). They were mounted to the bed by the hook fastened beneath the couch frame to hang the dead weights of known mass ranging from 0.5 to 40 kg (Table 3.1).

Figure 3.1 A pulley system and sling

3.3.3 A grid paper

A grid paper (Figure 3.2) size 40 × 40 cm^2 was used for investigating the criterion-related validity of the high speed video camera in the motion capture system.

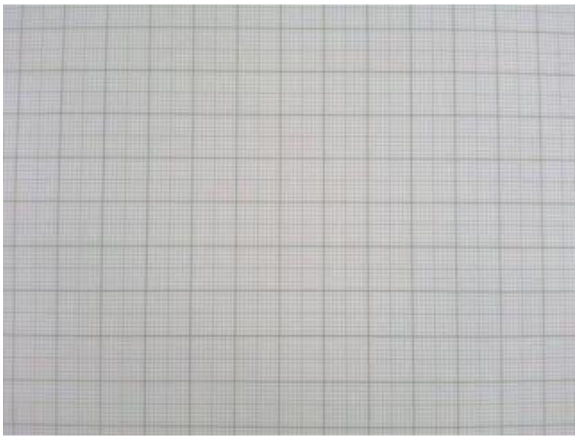

Figure 3.2 A grid paper

3.3.4 A modified instrumented couch with a motion capture system

3.3.4.1 A treatment couch

A treatment couch (Manumed Optimal 1-section electric H/L type 323, Model no. 5100103, Enraf Nonius Medical Equipment CO., LTD., Netherlands) (Figure 3.3) was used to modify an instrumented couch.

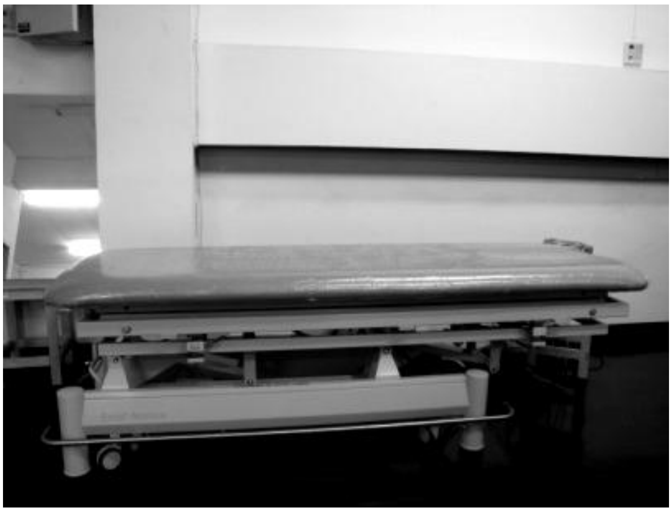

Figure 3.3 A treatment couch

3.3.4.2 Load cells

A total of seven resistive load cells (Tension S Cell, Mettler Toledo, Thailand) were used to quantify the force in this study. The capacity of each load cell in measuring the force is 100 kg. The S beam load cell was showed in Figure 3.4.

Figure 3.4 A load cell

3.3.4.3 High speed video cameras and tripods

The two high speed video cameras (Basler scA640, Basler AG An der Strusbek 60-62 D-22926 Ahrensburg, Germany) with tripods were used in this study to quantify displacement. The cameras have conscientiousness 658×492 pixels with sampling frequency to be 71 Hertz (Hz).

Figure 3.5 The motion capture system. A and B represent the high speed video camera and tripods, respectively.

3.3.4.4 Procedure of development an instrumented couch with a motion capture system

A treatment couch was modified using the similar concept noted in the previous studies (Harm et al., 1995b; Chiradejnant et al., 2001; Snodgrass et al., 2008). Briefly, a treatment couch (3.3.4.1) was modified by mounting seven resistive load cells (3.3.4.2) to the base of the couch frame. Four, two and one load cells were positioned in the vertical, medial-lateral and caudad-cephalad directions, respectively (Figure 3.6).

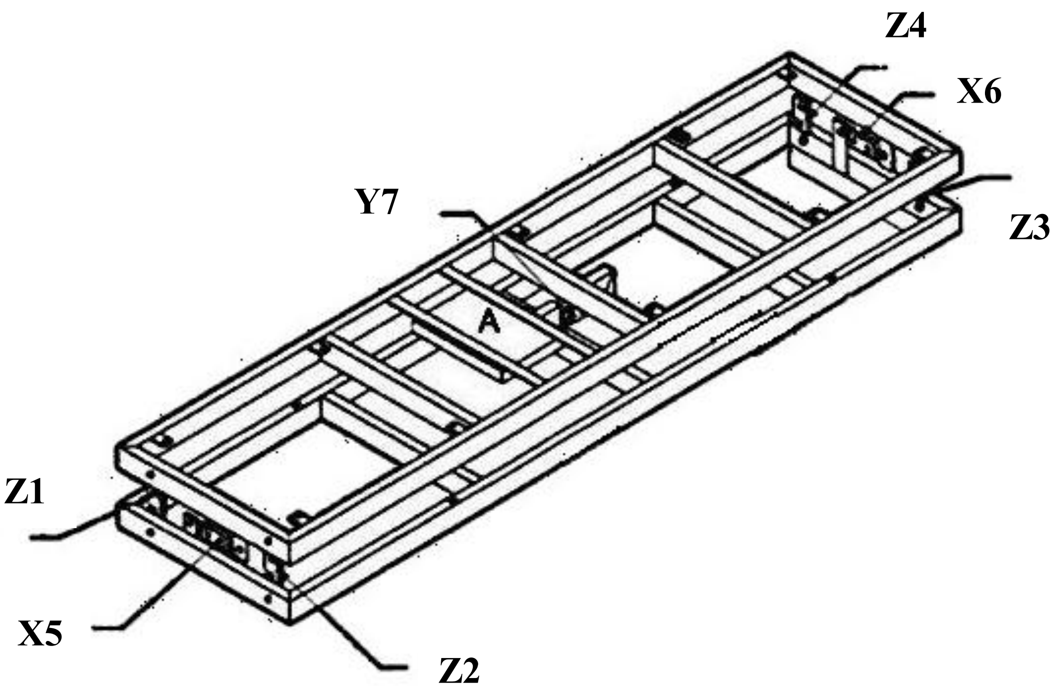

Figure 3.6 Positions of load cells mounted to the couch frame. Z1 to Z4, X5 to X6 and Y7 represent the location of the four load cells in the vertical, two load cells in medial-lateral and one load cells in caudad-cephalad directions, respectively. A represents the amplifier.

All signals from load cells are sent to a custom made amplifier (Figure 3.6 position A) which is mounted to the couch frame via a high speed cable. The signals from the amplifier are sent to a display box (Figure 3.7 position C), the box also has a zero function allowing to set the applied force on the couch as zero. The signals from the display box are sent to a signal translator (Figure 3.7 position D) before sent to the computer (Figure 3.7 position E) and can be saved as a Microsoft excel file for further analysis using the Contemplas templo motion analysis software (GmbH Albert-Eintein-Straße 6 87437 D-Kempten; Germany). The frequency of data sampling would be able to set as from 30 to 1,000 Hz.

Two high speed video cameras with the tripods (Figure 3.7 positions B_1 and B_2) are also connected to the computer in order to investigate movement occurred during MT. The data obtained from the cameras are able to be imported and saved as the Microsoft excel file for further investigation. Once again, the data obtained from the cameras are able to synchronize with the force-time data obtained from the load cells by plotting graph in the Microsoft excel file.

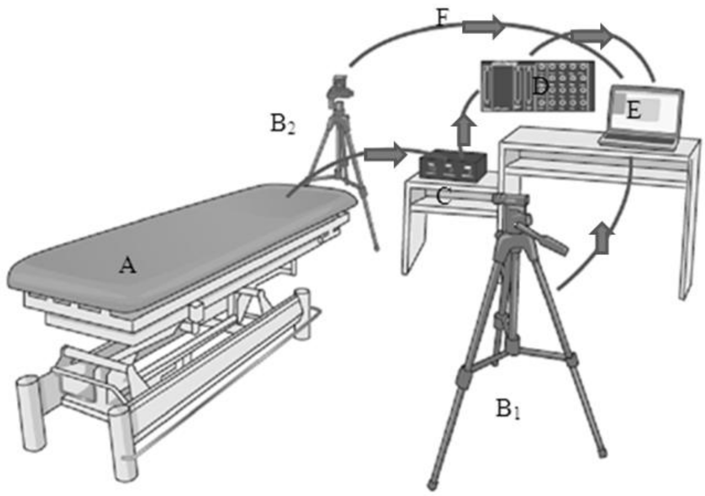

Figure 3.7 Functional processes of the data obtained from the instrumented couch and two cameras flowed to the computer. A to F represent the instrumented couch, the cameras, display box, signal translator, computer and the high speed cable for sending the data, respectively. The symbol, arrows, show directions of the data flowed from the instrumented couch and two cameras to the computer.

3.4 The calibration procedure

The calibration procedure was conducted at the laboratory room number 304, Health Sciences Service Center, Faculty of Allied Health Sciences, Chulalongkorn

University, and the details were separated into two parts. The first past was to investigate the criterion-related validity and test-retest reliability of the couch in two different conditions: an empty couch and a couch with dead weight of known mass 70 kg. The second part was to investigate the criterion-related validity of the high speed video camera in motion capture system.

3.4.1 The instrumented couch test

3.4.1.1 Test on an empty couch condition

The criterion-related validity test

The set weights of known mass were used to investigate the criterion-related validity of the couch in three directions. The weights ranging from 0.5 to 80 kg were placed on the couch in three different positions: the midline of the couch in the cephalad, middle and caudad, respectively (Figure 3.8 positions A to C); to investigate the criterion-related validity of the couch in the vertical direction.

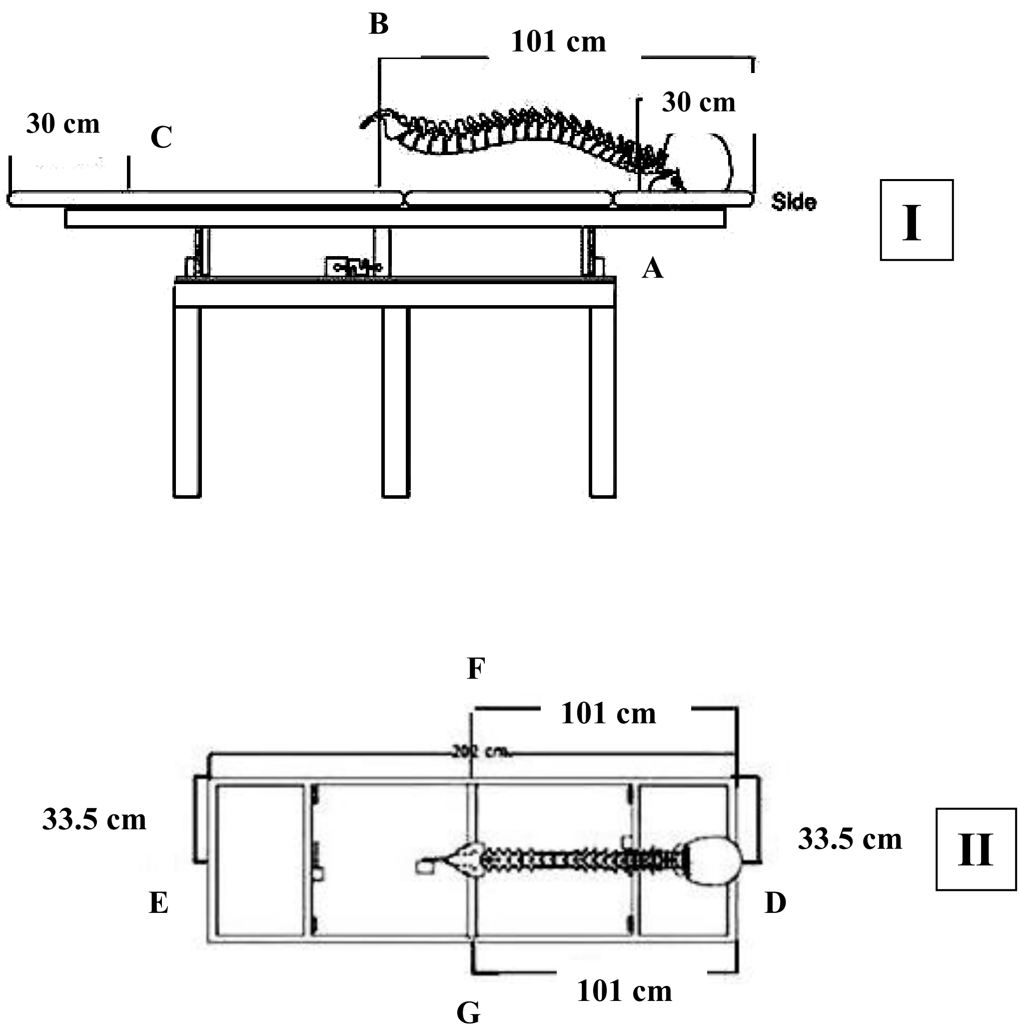

Figure 3.8 Positions of the weight on the couch (I) and positions of a pulley system attached to the couch frame (II). A, B, C represent the midline of the couch in the cephalad, middle and caudad, respectively. (A = 30 cm from the end of cephalad frame in midline; B= 101 cm from the end of cephalad frame in midline and C= 30 cm from the end of caudad frame in midline). D to G represent the positions that were attached the hook fastened beneath the couch frame in the middle of the cephalad, caudad, left and right of the couch, respectively.

In the medial-lateral and the caudad-caphalad directions, the weights were tested by pulley. The pulley was attached to the couch by the hook fastened beneath the couch frame in four positions: middle in the cephalad, caudad, left and right (Figure 3.8

positions D to G); to hang the set weight of known mass ranging from 0.5 to 40 kg (Table 3.1). The weight was then left for 10 seconds in order to leave it until it was steady, the measurement was undertaken. The force reading obtained from the couch and the known mass obtained from the dead weight were kept for analyzing the criterion-related validity. Finally, the measurement would be recorded in three directions in order to investigate the cross talk during the force measurement.

The test-retest reliability test

The details of test-retest reliability test were similar to the criterion-related validity test mentioned previously. The test-retest reliability was undertaken twice, the retest was tested 10 minutes after the first test. The data from these two tests were used to investigate the correlation between the two tests.

3.4.1.2 Test on weight of known mass 70 kg

The criterion-related validity test

A dead weight of known mass of 70 kg was selected in order to represent a body weight of a human subject. The weight was divided into three parts and put on three positions on the couch, two sets of the 20 kg and 30 kg were put on the cephalad and caudad parts, and in the middle of the couch, respectively. Prior to collecting the data, the couch was set as zero using the zero function of the software. The weights ranging from 0.5 to 40 kg (Table 3.1) were placed on the top of the weight of known mass in three positions mentioned previously (Figure 3.8 positions A to C), and the measurement was then recorded. In the medial-lateral and caudad-caphalad directions, the pulley was attached to the couch by the hook fastened beneath the couch frame in four positions: cephalad, caudad, left and right (Figure 3.8 positions D to G). The pulley was used to hang the set weight of known mass ranging from 0.5 to 40 kg (Table 3.1). The force reading obtained from the couch and the known mass obtained from the dead weight were kept for analyzing the criterion-related validity. Finally, the measurement would be recorded in three directions in order to investigate the cross talk during the force measurement.

The test-retest reliability test

Once again the similar procedure mentioned in the section 3.4.1.1 under the test-retest reliability was then repeated in two occasions with 10 minutes interval.

3.4.2 The motion capture system test

The motion capture system included two high speed video cameras with tripods which were set in the lateral side of the couch. The camera was calibrated by the grid paper (3.3.3), which was marked by the marker as a graph. The grid paper was attached to a box and then positioned on the couch in order to ensure the grid paper position to be in the vertical direction. The motion capture system was focused on the grid paper and the distance measurement was then taken place.

The procedure of the calibration occurred after recording. The high speed video camera was analyzed after setting the distance calibration in Contemplas Temple Motion Analysis Program. The distance calibration was set from the real distance of the grid paper, using the distance from marker to marker. After setting, when the researcher drew a line from the marker 1 to the marker 2, the distance would be appeared on the computer screen. The distance data was recorded and kept for further analysis (Figure 3.9).

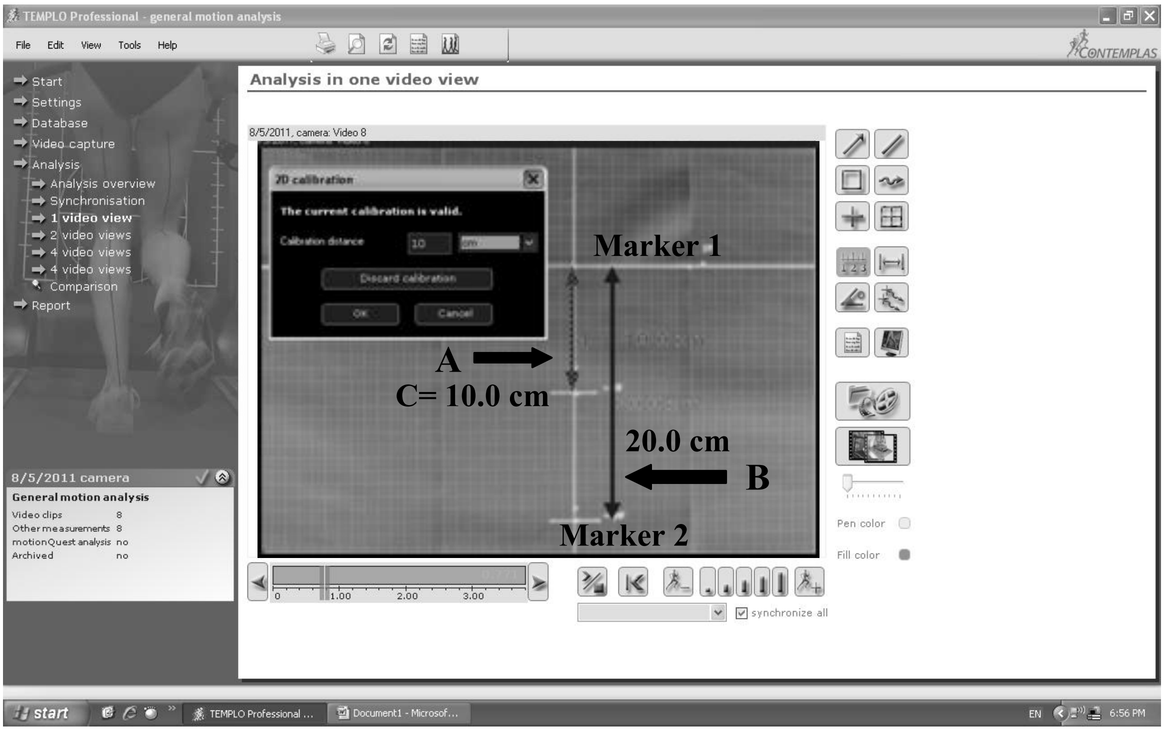

Figure 3.9 Display screen of the motion capture system. A to C represent the line set for calibration, the line drawn after setting line for calibration and the distance set for using the calibration line, respectively.

3.5 Data analysis

The Pearson's product moment correlation was used to investigate the criterion-related validity of the instrumented couch and motion capture system. The $ICC_{(2, 1)}$ was used to investigate test-retest reliability of the couch. Both the Pearson's product moment correlation and the $ICC_{(2, 1)}$ were investigated by using the SPSS program version 16. The percentage error of the couch was calculated by using Formula 1. The percentage error of the motion capture system was calculated by using Formula 2 and the percentage cross talk was calculated by using Formula 3. The definition of the correlation coefficient is presented in Table 3.2.

Formula 1: The percentage error of the couch = $[F_{couch} - F_{true} / F_{true}] \times 100$

Formula 2: The percentage error of the motion capture system = $[D_{camera} - D_{true} / D_{true}] \times 100$

Formula 3: The percentage cross talk = $[F_{talk} - 0 / F_{true}] \times 100$

F_{couch} and F_{true} represent the force reading obtained from the couch and the known mass, respectively. D_{camera} and D_{true} represent the distance obtained from the high speed video camera and the distance obtained from the grid paper, respectively. F_{talk} represents the force in other directions that were not tested.

Table 3.2 The definition of the correlation coefficient (Portney & Watkins, 1993)

The correlation coefficient value	Definition
0 to 0.25	No reliability
0.25 to 0.50	Fair
0.50 to 0.75	Moderate to good
0.75 to 1.00	Good to excellent

CHAPTER IV

RESULTS

The results of this study are showed in this chapter. The criterion-related validity, percentage error and test-retest reliability results presented as follows.

4.1 The criterion-related validity and the percentage error

The criterion-related validity of the instrumented couch was presented in the Pearson's product moment correlation (Table 4.1). The Pearson's product moment correlation were 1.00 for defining correlation between the force obtained from the instrumented couch and the gold standard ($p<0.05$). The percentage errors of both in an empty couch and in the couch with dead weight of known mass 70 kg conditions were presented to be no significant difference. The average of percentage errors was less than 1.2% in an empty couch condition, while it was less than 0.9% in the condition with dead weight of known mass 70 kg. The range of percentage errors in the empty couch and the couch with dead weight of known mass 70 kg conditions was between 0 and 2 % (Table 4.2).

Table 4.1 The correlation of the instrumented couch in measuring force applied.

Conditions	Pearson's values	$ICC_{(2, 1)}$
All directions in empty couch condition	1.00*	1.00*
All directions in the couch with known mass 70 kg	1.00*	1.00*

* represents statistically significant ($p<0.05$).

Table 4.2 The percentage error of the instrumented couch

Directions	Percentage error		
	Average	**Maximum**	**Minimum**
Vertical A	1.12	2.00	0.00
Vertical B	0.90	1.53	0.00
Vertical C	1.06	2.00	0.64
Medial-Lateral G	0.92	2.00	0.00
Medial-Lateral F	0.88	2.00	0.00
Caudad-Cephalad	0.71	2.00	0.00
Cephalad-Caudad	0.71	2.00	0.00
On Wt.* Vertical A	0.75	1.63	0.00
On Wt.* Vertical B	0.69	2.00	0.00
On Wt.* Vertical C	0.85	2.00	0.00
On Wt.* Medial-Lateral G	0.41	2.00	0.00
On Wt.* Medial-Lateral F	0.91	2.00	0.00
On Wt.* Caudad-Cephalad	0.73	2.00	0.00
On Wt.* Cephalad-caudad	0.69	1.50	0.00

A, B and C in vertical direction represent the positions of the test in cephalad, middle and caudad, respectively (Figure 3.8). G and F in medial-lateral direction represent the positions that the weights were hanged on (Figure 3.8). * represents the couch with dead weight of known mass 70 kg condition.

The result of the criterion-related validity of the motion capture system was showed very high with Pearson's product moment correlation after the lines in contemplas templo motion analysis program were drawn comparing with the gold standard. The Pearson's product moment correlation were 1.00 for defining correlation between the distance obtained from the motion capture system and the gold standard ($p<0.05$). The percentage error of measurement of 0% was also showed.

The percentage cross talk showed an average value less than 1.03 % in all directions. The minimum and maximum cross talks were showed to be 0% and 2.76 %, respectively (Table 4.3). Figure 4.1 shows the force in three directions when weights were loaded in the vertical direction.

Table 4.3 The percentage cross talk

Directions	Percentage cross talk		
	Average	**Maximum**	**Minimum**
Vertical A	0.69	2.76	0.00
Vertical B	1.03	2.60	0.00
Vertical C	0.75	2.09	0.20
Medial-Lateral G	0.57	2.00	0.00
Medial-Lateral F	0.81	2.00	0.00
Caudad-Cephalad	0.82	2.00	0.00
Cephalad-Caudad	0.55	2.00	0.00
On Wt.* Vertical A	0.19	2.00	0.00
On Wt.* Vertical B	0.74	2.00	0.00
On Wt.* Vertical C	1.03	2.60	0.00
On Wt.* Medial-Lateral G	0.62	2.67	0.00
On Wt.* Medial-Lateral F	0.71	2.47	0.00
On Wt.* Caudad-Cephalad	0.54	2.20	0.00
On Wt.* Cephalad-caudad	0.77	2.20	0.00

A, B and C in vertical direction represent the positions of the test in cephalad, middle and caudad, respectively (Figure 3.8). G and F in medial-lateral direction represent the positions that the weights were hanged on (Figure 3.8). * represents the couch with dead weight of known mass 70 kg condition.

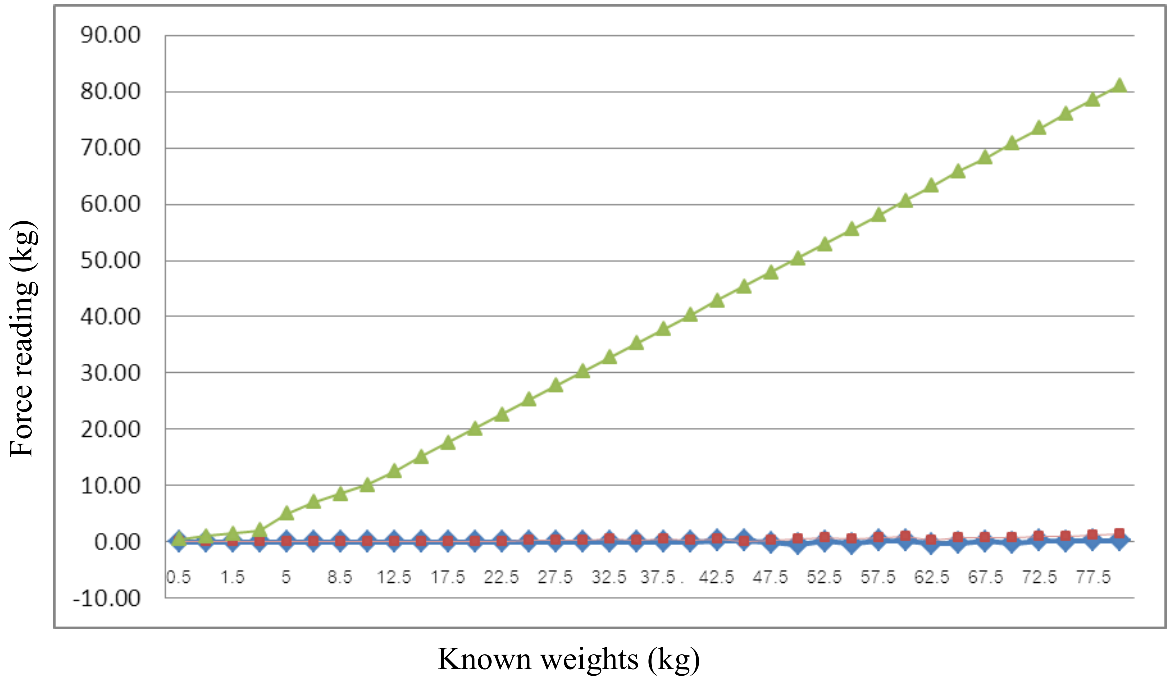

Figure 4.1 The relationship between known weight values (vertical loading) and the force readings in three directions. The vertical direction results demonstrate a linear relationship between the weights and vertical force reading; the medial-lateral and caudad-cephalad directions results demonstrate the negligible cross talk when loading in the vertical direction. (green line with triangles) represents load in vertical direction that the couch measure. (blue line with diamonds) represents load in medial-lateral direction that the couch measure. (red line with squares) represents load in caudad-cephalad direction that the couch measure.

4.2 The test-retest reliability

The test-retest reliability of the instrumented couch is presented in Table 4.1. It showed high reliability for all directions when the loads were applied twice. The 95% CI for $ICC_{(2,\ 1)}$ values were 1.00 in all directions ($p<0.05$). The values of $ICC_{(2,\ 1)}$ were 1.00 in both single measure and average measure.

CHAPTER V

DISCUSSION

The objective of this study was to validate the instrumented couch and the motion capture system in measuring applied force and distance, respectively. This chapter is going to discuss on the results of this study.

5.1 The criterion-related validity and the percentage error of the instrumented couch

The results showed high criterion-related validity of the instrumented couch with Pearson's product moment correlation being 1.00. This finding indicates excellent correlation coefficients with the gold standard (Portney & Watkins, 1993). Additionally, this finding is consistent to the Pearson's product moment correlation noted in previous studies (Harm et al., 1995b; Snodgrass et al., 2008).

The percentage errors of this study have been showed very low because the average of percentage error was less than 1% in the condition with weight of known mass 70 kg while in the empty couch condition was less than 1.2%. The previous studies reported the maximum percentage error to be more than 4% (Harm et al., 1995b; Chiradejnant et al., 2001). The maximum error of this study was to be 2% which was less than the maximum error of all previous studies (Harm et al., 1995b; Chiradejnant et al., 2001).

The range of the cross talks of this study have been showed very low (0.19-1.03%). Only one study reported on the range of the cross talk (0.02-1.97%) which is well within the range noted in the current study (Chiradejnant et al., 2001). With regard to the range of the cross talk, it has been suggested that the cross talk being less than 5% indicates the acceptable the error value (Portney& Watkins, 1993). Based on these results, the instrumented couch shows to be a valid device in quantifying the force applied to its surface.

5.2 The test-retest reliability of the instrumented couch

The test-retest reliability of the instrumented couch was presented very high with $ICC_{(2, 1)}$ being 1.00 in every test. This finding is consistent to the ICCs noted in previous studies (Chiradejnant et al., 2001; Snodgrass et al., 2008). It would imply that the couch is reliable in measuring the force applied to its surface.

5.3 The motion capture system

From this study, the motion capture system has been showed to be high criterion-relate validity with Pearson's product moment correlation being 1.00. The percentage error of this measurement showed 0%. Once again, the motion capture system is a valid device in quantifying the distance from a reference point.

5.4 The clinical implication of this study

The advantage of this study was to validate the instrumented couch and motion capture system. This device would be appropriate to quantify the force applied and displacement occurred during MT. Additionally, the device would be able to be used for researching as well as teaching tools in the use of both spinal and peripheral joint MT.

CHAPTER VI

CONCLUSION

The purpose of this study was to validate the instrumented couch in quantifying the applied force and the motion capture system in quantifying the distance. The results show that both the instrumented couch and the motion capture system were valid with the r of being 1 and the percentage error of measurement being less than 1.2% and 0, respectively. The reliability of the couch in quantifying the applied force has been shown to be high with the $ICC_{(2,1)}$ being 1. With regard to these findings, it can be implied that the null hypotheses of this study were accepted. To conclude, the instrumented couch and the motion capture system are appropriate to investigate both amount of force applied and distance during MT.

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APPENDICES

APPENDIX A

DATA COLLECTION SHEET

Vertical direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		X	Y
0.5 kg									
1 kg									
1.5 kg									
2 kg									
5 kg									
7 kg									
8.5 kg									
10 kg									
12.5 kg									
15 kg									
17.5 kg									
20 kg									
22.5 kg									
25 kg									
27.5 kg									
30 kg									
32.5 kg									
35 kg									
37.5 kg									
40 kg									
45 kg									
47.5 kg									
50 kg									
52.5 kg									

Vertical direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		X	Y
55 kg									
57.5 kg									
60 kg									
62.5 kg									
65 kg									
67.5 kg									
70 kg									
72.5 kg									
75 kg									
77.5 kg									
80 kg									

On wt.70 kg vertical direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		X	Y
0.5 kg									
1 kg									
1.5 kg									
2 kg									
5 kg									
7 kg									
8.5 kg									
10 kg									
12.5 kg									
15 kg									
17.5 kg									
20 kg									
22.5 kg									
25 kg									
27.5 kg									
30 kg									
32.5 kg									
35 kg									
37.5 kg									
40 kg									

Medial-lateral direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		Y	Z
0.5 kg									
1 kg									
1.5 kg									
2 kg									
5 kg									
7 kg									
8.5 kg									
10 kg									
12.5 kg									
15 kg									
17.5 kg									
20 kg									
22.5 kg									
25 kg									
27.5 kg									
30 kg									
32.5 kg									
35 kg									
37.5 kg									
40 kg									

On Wt. 70 kg medial-lateral direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		Y	Z
0.5 kg									
1 kg									
1.5 kg									
2 kg									
5 kg									
7 kg									
8.5 kg									
10 kg									
12.5 kg									
15 kg									
17.5 kg									
20 kg									
22.5 kg									
25 kg									
27.5 kg									
30 kg									
32.5 kg									
35 kg									
37.5 kg									
40 kg									

Cephalad-caudad direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		X	Z
0.5 kg									
1 kg									
1.5 kg									
2 kg									
5 kg									
7 kg									
8.5 kg									
10 kg									
12.5 kg									
15 kg									
17.5 kg									
20 kg									
22.5 kg									
25 kg									
27.5 kg									
30 kg									
32.5 kg									
35 kg									
37.5 kg									
40 kg									

On wt. 70 kg cephalad-caudad direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		X	Z
0.5 kg									
1 kg									
1.5 kg									
2 kg									
5 kg									
7 kg									
8.5 kg									
10 kg									
12.5 kg									
15 kg									
17.5 kg									
20 kg									
22.5 kg									
25 kg									
27.5 kg									
30 kg									
32.5 kg									
35 kg									
37.5 kg									
40 kg									

APPENDIX B

RAW DATA OF MAIN STUDY

Cross talk testing while loading the force at the A (Figure 3.8) in the vertical direction.

Vertical direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*X*	*Y*
0.5 kg.	0.00	0.01	0.49	0.00	0.00	0.51	**2.00**	*0.00*	*2.00*
1 kg.	0.00	0.00	0.98	0.01	0.01	0.98	**2.00**	*0.00*	*0.00*
1.5 kg.	0.01	0.01	1.50	0.01	0.00	1.48	**0.00**	*0.67*	*0.67*
2 kg.	0.02	0.01	1.96	0.02	0.01	1.96	**2.00**	*1.00*	*0.50*
5 kg.	-0.05	0.05	5.10	0.01	0.04	5.03	**2.00**	*1.00*	*1.00*
7 kg.	0.01	0.04	6.94	0.14	0.05	6.96	**0.86**	*0.14*	*0.57*
8.5 kg.	0.01	0.04	8.60	0.01	0.05	8.61	**1.18**	*0.12*	*0.47*
10 kg.	0.00	0.05	10.09	0.02	0.17	10.09	**0.90**	*0.00*	*0.50*
12.5 kg.	0.01	0.17	12.47	0.01	0.16	12.46	**0.24**	*0.08*	*1.36*
15 kg.	0.01	0.28	15.00	0.01	0.35	15.01	**0.00**	*0.07*	*1.86*
17.5 kg.	0.01	0.30	17.64	0.13	0.35	17.53	**0.80**	*0.06*	*1.71*
20 kg.	0.01	0.46	20.20	-0.05	0.46	20.19	**1.00**	*0.05*	*2.30*
22.5 kg.	-0.04	0.47	22.74	-0.05	-0.02	22.71	**1.07**	*0.18*	*2.09*
25 kg.	0.01	-0.02	25.27	-0.05	0.04	25.28	**1.08**	*0.04*	*0.08*
27.5 kg.	-0.04	0.17	27.83	-0.05	0.17	27.83	**1.20**	*0.15*	*0.62*
30 kg.	-0.05	-0.10	30.24	0.02	-0.13	30.24	**0.80**	*0.17*	*0.33*
32.5 kg.	-0.05	0.65	32.78	-0.05	0.35	32.79	**0.86**	*0.15*	*2.00*

Cross talk testing while loading the force at the A (Figure 3.8) in the vertical direction (continue).

Vertical direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*X*	*Y*
35 kg.	-0.05	0.05	35.31	-0.05	0.28	35.29	**0.86**	*0.14*	*0.14*
37.5 kg.	0.01	0.34	37.92	-0.29	-0.12	37.82	**1.12**	*0.03*	*0.91*
40 kg.	-0.29	-0.09	40.32	-0.29	-0.11	40.43	**0.80**	*0.73*	*0.23*
42.5 kg.	-0.01	0.27	42.86	0.24	0.15	42.99	**0.85**	*0.02*	*0.63*
45 kg.	0.61	0.15	45.37	0.13	-0.14	45.53	**0.82**	*1.35*	*0.33*
47.5 kg.	-0.61	-0.44	47.94	0.74	0.27	47.93	**0.93**	*1.28*	*0.93*
50 kg.	-1.38	0.34	50.46	-0.60	0.76	50.45	**0.92**	*2.76*	*0.68*
52.5 kg.	0.02	0.53	53.00	-1.50	-0.14	52.98	**0.95**	*0.04*	*1.01*
55 kg.	-1.26	0.16	55.52	-0.01	0.77	55.52	**0.94**	*2.29*	*0.29*
57.5 kg.	0.01	0.28	58.10	-1.26	0.16	58.22	**1.04**	*0.02*	*0.49*
60 kg.	-0.35	1.06	60.70	-0.78	-0.18	60.81	**1.17**	*0.58*	*1.77*
62.5 kg.	-1.20	-0.02	63.38	-0.65	-0.43	63.37	**1.41**	*1.92*	*0.03*
65 kg.	-0.66	0.64	65.93	-0.66	0.27	65.82	**1.26**	*1.01*	*0.98*
67.5 kg.	0.34	0.64	68.37	-0.90	0.64	68.48	**1.29**	*0.50*	*0.95*
70 kg.	-0.59	0.36	71.01	-0.05	0.76	71.05	**1.44**	*0.84*	*0.51*
72.5 kg.	0.00	0.34	73.72	-0.30	0.34	73.62	**1.68**	*0.00*	*0.47*
75 kg.	-0.26	0.47	76.24	0.31	0.63	76.26	**1.65**	*0.35*	*0.63*
77.5 kg.	0.32	0.65	78.68	0.30	0.64	78.79	**1.52**	*0.41*	*0.84*
80 kg.	0.31	0.76	81.33	-0.91	0.28	81.19	**1.66**	*0.39*	*0.95*

Cross talk testing while loading the force at the B (Figure 3.8) in the vertical direction.

Vertical direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*X*	*Y*
0.5 kg.	0.01	0.01	0.50	0.00	0.01	0.51	**0.00**	*2.00*	*2.00*
1 kg.	-0.02	-0.01	0.99	-0.02	-0.01	0.99	**1.00**	*2.00*	*1.00*
1.5 kg.	-0.01	-0.01	1.48	-0.02	-0.02	1.44	**1.33**	*0.67*	*0.67*
2 kg.	0.00	0.00	1.99	0.00	0.01	2.00	**0.50**	*0.00*	*0.00*
5 kg.	0.01	0.13	5.06	0.00	0.13	5.06	**1.20**	*0.20*	*2.60*
7 kg.	0.05	0.16	7.03	0.10	0.17	7.06	**0.43**	*0.71*	*2.28*
8.5 kg.	0.11	0.16	8.63	0.11	0.17	8.61	**1.53**	*1.29*	*1.88*
10 kg.	0.09	0.17	10.09	0.10	0.17	10.10	**0.90**	*0.90*	*1.70*
12.5 kg.	0.09	0.22	12.43	0.10	0.23	12.48	**0.56**	*0.72*	*1.76*
15 kg.	0.09	0.22	14.98	0.10	0.22	15.10	**0.13**	*0.60*	*1.46*
17.5 kg.	0.10	0.23	17.52	-0.03	0.23	17.52	**0.11**	*0.57*	*1.31*
20 kg.	-0.03	0.23	20.21	0.11	0.23	20.08	**1.05**	*0.15*	*1.15*
22.5 kg.	-0.02	0.22	22.71	0.10	0.47	22.71	**0.93**	*0.09*	*0.98*
25 kg.	0.10	0.64	25.27	0.10	0.65	25.22	**1.08**	*0.40*	*2.56*
27.5 kg.	0.13	0.48	27.84	0.09	0.64	27.82	**1.24**	*0.47*	*1.74*
30 kg.	0.15	0.34	30.22	-0.03	0.52	30.23	**0.73**	*0.50*	*1.13*
32.5 kg.	0.11	0.47	32.78	0.10	0.46	32.65	**1.17**	*0.34*	*1.45*
35 kg.	0.15	0.52	35.30	0.10	0.77	35.18	**0.86**	*0.43*	*1.49*
37.5 kg.	0.17	0.84	37.72	0.15	0.65	37.81	**0.59**	*0.45*	*2.24*
40 kg.	0.16	0.52	40.16	0.16	0.77	40.29	**0.40**	*0.40*	*1.30*

Cross talk testing while loading the force at the B (Figure 3.8) in the vertical direction (continue).

Vertical direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*X*	*Y*
42.5 kg.	0.16	0.64	42.85	-0.21	-0.02	42.85	**0.83**	*0.38*	*1.50*
45 kg.	-0.14	0.06	45.38	0.47	0.52	45.37	**0.84**	*0.31*	*0.13*
47.5 kg.	0.25	0.77	47.92	0.17	0.76	47.94	**0.88**	*0.53*	*1.62*
50 kg.	0.10	0.77	50.31	0.14	0.83	50.33	**0.62**	*0.20*	*1.54*
52.5 kg.	0.17	0.65	52.84	0.16	0.77	52.84	**0.65**	*0.32*	*1.34*
55 kg.	0.16	0.83	55.38	0.17	0.35	55.38	**0.69**	*0.29*	*1.51*
57.5 kg.	0.71	1.13	57.98	0.72	1.07	58.12	**0.83**	*1.23*	*1.96*
60 kg.	0.78	1.26	60.67	0.29	0.46	60.58	**1.12**	*1.30*	*2.10*
62.5 kg.	0.27	0.64	63.25	0.17	0.77	63.11	**1.20**	*0.43*	*1.02*
65 kg.	0.16	0.83	65.82	0.09	0.76	65.80	**1.26**	*0.25*	*1.28*
67.5 kg.	0.10	0.82	68.35	0.16	1.06	68.24	**1.26**	*0.15*	*1.21*
70 kg.	0.10	0.96	70.77	0.09	0.94	70.76	**1.10**	*0.01*	*1.37*
72.5 kg.	0.15	1.13	73.44	0.29	1.26	73.34	**1.30**	*0.20*	*1.56*
75 kg.	0.17	1.36	75.99	0.29	1.38	76.00	**1.32**	*0.23*	*1.81*
77.5 kg.	0.40	1.44	78.54	-0.21	0.22	78.44	**1.34**	*0.52*	*1.85*
80 kg.	0.41	1.56	81.09	-0.20	0.35	80.99	**1.36**	*0.51*	*1.95*

Cross talk testing while loading the force at the C (Figure 3.8) in the vertical direction.

Vertical direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*X*	*Y*
0.5 kg.	0.00	0.01	0.49	-0.01	0.01	0.51	**2.00**	*0.00*	*2.00*
1 kg.	-0.01	0.01	1.01	0.00	0.00	0.99	**1.00**	*1.00*	*1.00*
1.5 kg.	0.01	0.02	1.48	0.00	0.01	1.46	**1.33**	*0.67*	*1.33*
2 kg.	0.01	-0.03	2.03	-0.01	-0.03	2.06	**1.50**	*0.50*	*1.50*
5 kg.	0.01	0.05	5.06	-0.01	0.04	5.08	**1.20**	*0.20*	*1.00*
7 kg.	0.00	0.05	7.05	0.00	0.05	7.03	**0.71**	*0.00*	*0.71*
8.5 kg.	-0.02	0.04	8.61	0.00	0.05	8.62	**1.29**	*0.23*	*0.47*
10 kg.	0.00	0.15	10.09	-0.03	0.16	10.08	**0.90**	*0.00*	*1.50*
12.5 kg.	0.07	0.05	12.58	0.01	-0.01	12.59	**0.64**	*0.56*	*0.40*
15 kg.	0.00	0.05	15.12	0.00	0.05	15.13	**0.80**	*0.00*	*0.40*
17.5 kg.	0.07	0.17	17.63	0.00	0.17	17.64	**0.74**	*0.40*	*0.97*
20 kg.	0.00	0.17	20.18	-0.01	0.28	20.20	**0.90**	*0.00*	*0.85*
22.5 kg.	0.00	0.18	22.71	-0.01	0.16	22.71	**0.93**	*0.00*	*0.80*
25 kg.	0.00	0.46	25.27	0.04	0.47	25.26	**1.08**	*0.00*	*1.84*
27.5 kg.	0.06	0.53	27.81	0.00	0.65	27.83	**1.13**	*0.22*	*1.93*
30 kg.	-0.01	0.52	30.24	0.00	0.47	30.24	**0.80**	*0.03*	*1.73*
32.5 kg.	-0.01	0.46	32.75	0.18	0.47	32.89	**0.77**	*0.03*	*1.41*
35 kg.	0.01	0.53	35.30	0.07	0.53	35.43	**0.86**	*0.03*	*1.51*
37.5 kg.	0.07	0.29	37.92	0.05	0.28	37.76	**1.12**	*0.19*	*0.77*
40 kg.	0.05	0.35	40.31	0.06	0.34	40.29	**0.77**	*0.12*	*0.87*

Cross talk testing while loading the force at the C (Figure 3.8) in the vertical direction (continue).

Vertical direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*X*	*Y*
42.5 kg.	0.62	0.83	42.84	0.05	1.12	42.84	**0.80**	*1.46*	*1.95*
45 kg.	0.14	0.32	45.42	0.13	0.30	45.46	**0.93**	*0.31*	*0.71*
47.5 kg.	0.25	0.37	47.93	0.12	0.37	47.96	**0.97**	*0.53*	*0.78*
50 kg.	0.14	0.49	50.40	0.13	0.61	50.46	**0.80**	*0.28*	*0.98*
52.5 kg.	0.05	0.76	52.99	0.17	0.83	52.96	**0.93**	*0.09*	*1.45*
55 kg.	0.18	0.82	55.51	0.18	0.95	55.50	**0.93**	*0.33*	*1.49*
57.5 kg.	0.08	0.82	57.99	0.18	1.45	58.07	**0.85**	*0.14*	*1.43*
60 kg.	0.19	0.94	60.69	0.17	1.56	60.68	**1.15**	*0.32*	*1.57*
62.5 kg.	-0.05	0.50	63.31	-0.04	0.50	63.30	**1.30**	*0.08*	*0.80*
65 kg.	0.01	0.67	65.83	0.01	0.62	65.74	**1.28**	*0.02*	*1.03*
67.5 kg.	-0.05	0.79	68.29	-0.01	0.78	68.31	**1.17**	*0.07*	*1.17*
70 kg.	0.00	0.91	70.80	0.01	0.92	70.87	**1.14**	*0.00*	*1.30*
72.5 kg.	0.49	1.26	73.48	0.06	1.37	73.33	**1.35**	*0.65*	*1.74*
75 kg.	0.36	1.25	76.00	0.07	1.44	76.00	**1.33**	*0.48*	*1.67*
77.5 kg.	0.06	1.43	78.54	0.18	1.25	78.48	**1.34**	*0.08*	*1.84*
80 kg.	0.07	1.67	81.07	0.17	1.36	81.07	**1.34**	*0.09*	*2.09*

Cross talk testing with 70 kg of known mass while loading the force at the A (Figure 3.8) in the vertical direction.

Vertical direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*X*	*Y*
0.5 kg	0.00	0.01	0.50	-0.01	0.00	0.49	**0.00**	*0.00*	*2.00*
1 kg	0.00	0.01	1.00	0.01	0.01	0.99	**0.00**	*0.00*	*1.00*
1.5 kg	0.00	0.00	1.51	0.00	0.00	1.52	**0.67**	*0.00*	*0.00*
2 kg	0.01	0.01	2.03	0.00	0.01	2.02	**1.50**	*0.50*	*0.50*
5 kg	0.00	0.00	4.96	0.00	0.01	4.95	**0.80**	*0.00*	*0.00*
7 kg	0.00	0.00	7.05	0.00	0.01	7.06	**0.71**	*0.00*	*0.00*
8.5 kg	0.01	0.01	8.51	-0.01	0.00	8.49	**0.12**	*0.12*	*0.12*
10 kg	0.00	0.01	9.99	-0.01	0.00	9.97	**0.10**	*0.00*	*0.10*
12.5 kg	0.00	0.00	12.47	0.00	0.00	12.47	**0.24**	*0.00*	*0.00*
15 kg	-0.01	0.00	15.10	-0.01	0.00	15.11	**0.67**	*0.07*	*0.00*
17.5 kg	-0.01	0.06	17.66	0.00	0.06	17.65	**0.91**	*0.06*	*0.34*
20 kg	0.00	0.01	20.21	0.04	0.00	20.21	**1.05**	*0.00*	*0.05*
22.5 kg	0.11	0.01	22.60	0.12	0.00	22.59	**0.44**	*0.49*	*0.04*
25 kg	-0.01	0.00	25.25	0.00	0.01	25.28	**1.00**	*0.04*	*0.00*
27.5 kg	0.12	-0.11	27.79	0.12	-0.12	27.81	**1.05**	*0.44*	*0.04*
30 kg	0.13	-0.11	30.37	0.12	-0.11	30.37	**1.23**	*0.43*	*0.37*
32.5 kg	0.00	0.02	33.03	0.01	-0.06	33.03	**1.63**	*0.00*	*0.06*
35 kg	-0.01	0.00	35.41	0.11	0.00	35.40	**1.17**	*0.03*	*0.00*
37.5 kg	0.13	0.01	37.89	0.13	0.02	37.82	**1.04**	*0.35*	*0.03*
40 kg	0.18	0.06	40.29	0.19	0.07	40.30	**0.73**	*0.45*	*0.15*

Cross talk testing with 70 kg of known mass while loading the force at the B (Figure 3.8) in the vertical direction.

Vertical direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*X*	*Y*
0.5 kg	0.00	0.00	0.49	0.01	0.00	0.50	**2.00**	*0.00*	*0.00*
1 kg	0.00	0.00	1.00	0.01	0.01	0.98	**0.00**	*0.00*	*0.00*
1.5 kg	0.00	0.00	1.47	0.00	-0.01	1.46	**2.00**	*0.00*	*0.00*
2 kg	0.00	0.00	2.03	0.00	0.00	2.03	**1.50**	*0.00*	*0.00*
5 kg	-0.01	0.00	4.94	-0.01	0.00	4.94	**1.20**	*0.20*	*0.00*
7 kg	-0.06	0.13	7.04	-0.05	0.12	7.03	**0.57**	*0.88*	*1.86*
8.5 kg	-0.06	0.13	8.47	-0.06	0.13	8.49	**0.35**	*0.70*	*1.53*
10 kg	0.12	0.19	10.07	0.11	0.20	10.16	**0.70**	*1.20*	*1.90*
12.5 kg	-0.04	0.24	12.48	-0.07	0.24	12.45	**0.16**	*0.32*	*1.92*
15 kg	-0.05	0.30	14.98	-0.06	0.30	14.99	**0.13**	*0.33*	*2.00*
17.5 kg	0.05	-0.09	17.61	0.02	-0.08	17.62	**0.63**	*0.29*	*0.51*
20 kg	0.04	-0.09	20.17	0.05	-0.09	20.14	**0.85**	*0.23*	*0.45*
22.5 kg	-0.17	0.24	22.61	-0.16	0.25	22.62	**0.49**	*0.75*	*1.07*
25 kg	-0.06	0.42	25.17	-0.07	0.43	25.14	**0.68**	*0.24*	*1.68*
27.5 kg	-0.05	0.48	27.69	-0.04	0.50	27.70	**0.69**	*0.18*	*1.74*
30 kg	-0.04	0.49	30.12	-0.05	0.49	30.10	**0.40**	*0.13*	*1.63*
32.5 kg	-0.05	0.61	32.68	0.01	0.49	32.77	**0.55**	*0.15*	*1.88*
35 kg	0.02	0.62	35.30	0.01	0.73	35.29	**0.86**	*0.06*	*1.77*
37.5 kg	0.00	0.72	37.66	0.01	0.72	37.64	**0.43**	*0.00*	*1.92*
40 kg	0.02	0.79	40.21	0.01	0.79	40.17	**0.52**	*0.05*	*1.98*

Cross talk testing with 70 kg of known mass while loading the force at the C (Figure 3.8) in the vertical direction.

Vertical direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*X*	*Y*
0.5 kg	0.01	0.00	0.50	0.03	0.01	0.50	**0.00**	*2.00*	*0.00*
1 kg	0.02	0.02	0.99	0.02	0.00	0.98	**1.00**	*2.00*	*2.00*
1.5 kg	0.02	-0.01	1.49	0.01	0.01	1.50	**0.67**	*1.33*	*0.67*
2 kg	0.03	0.01	2.04	0.03	0.02	2.04	**2.00**	*1.50*	*0.50*
5 kg	-0.01	0.00	4.96	-0.01	0.00	4.96	**1.60**	*2.20*	*2.60*
7 kg	-0.01	0.01	7.04	-0.02	-0.01	7.09	**0.71**	*1.57*	*2.43*
8.5 kg	-0.01	0.00	8.57	-0.02	-0.01	8.59	**0.35**	*0.35*	*2.24*
10 kg	0.00	0.01	10.19	-0.01	0.01	10.19	**1.30**	*1.00*	*2.00*
12.5 kg	-0.01	0.01	12.67	-0.02	0.00	12.68	**0.72**	*0.08*	*2.48*
15 kg	-0.02	-0.01	15.29	-0.02	0.00	15.33	**0.20**	*0.20*	*2.53*
17.5 kg	-0.10	0.36	17.55	-0.11	0.37	17.60	**0.29**	*0.57*	*2.06*
20 kg	0.02	0.01	20.34	0.03	0.02	20.33	**1.70**	*0.10*	*0.05*
22.5 kg	-0.01	0.01	22.77	0.02	0.01	22.75	**0.98**	*0.04*	*0.04*
25 kg	0.03	0.13	25.23	0.02	0.14	25.20	**0.92**	*0.12*	*0.52*
27.5 kg	0.02	0.18	27.76	0.03	0.19	27.75	**0.95**	*0.07*	*0.65*
30 kg	0.02	0.30	30.24	0.00	0.31	30.24	**0.80**	*0.07*	*1.00*
32.5 kg	0.02	0.37	32.77	0.02	0.38	32.81	**0.68**	*0.06*	*1.14*
35 kg	0.08	0.49	35.33	0.07	0.49	35.32	**0.94**	*0.23*	*1.40*
37.5 kg	0.01	0.61	37.71	0.03	0.60	37.71	**0.56**	*0.03*	*1.63*
40 kg	0.03	0.67	40.23	0.02	0.68	40.20	**0.58**	*0.08*	*1.68*

Cross talk testing while loading the force at the F (Figure 3.8) in the medial-lateral direction.

Medial-lateral direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*Y*	*Z*
0.5 kg	0.50	0.00	-0.01	0.49	0.00	-0.03	**0.00**	*0.00*	*2.00*
1 kg	1.02	0.00	0.00	1.02	-0.01	0.04	**2.00**	*0.00*	*0.00*
1.5 kg	1.50	0.00	-0.01	1.50	0.00	0.01	**0.67**	*0.00*	*0.67*
2 kg	2.04	0.00	-0.01	1.97	0.01	-0.01	**2.00**	*0.00*	*0.50*
5 kg	4.94	0.03	0.04	4.94	0.02	-0.02	**1.20**	*0.60*	*0.80*
7 kg	6.89	0.04	0.08	6.88	0.02	0.08	**1.57**	*0.57*	*1.14*
8.5 kg	8.42	0.04	0.09	8.42	0.03	0.09	**0.94**	*0.47*	*1.06*
10 kg	9.89	-0.10	0.09	9.88	-0.08	0.08	**1.10**	*1.00*	*0.90*
12.5 kg	12.37	-0.08	0.09	12.37	-0.10	0.10	**1.04**	*0.64*	*0.72*
15 kg	14.78	-0.08	0.09	14.77	-0.08	0.09	**1.47**	*0.53*	*0.60*
17.5 kg	17.50	-0.27	0.09	17.49	-0.27	0.10	**0.00**	*1.54*	*0.51*
20 kg	19.98	0.02	0.20	20.00	0.04	0.24	**0.10**	*0.10*	*1.00*
22.5 kg	22.23	-0.45	0.31	22.25	-0.44	0.34	**1.20**	*2.00*	*1.38*
25 kg	24.85	-0.44	0.31	24.85	-0.44	0.33	**0.60**	*1.76*	*1.24*
27.5 kg	27.66	-0.16	0.43	27.62	-0.15	0.34	**0.58**	*0.58*	*1.56*
30 kg	30.20	-0.13	0.43	30.19	-0.14	0.46	**0.67**	*0.43*	*1.43*
32.5 kg	32.60	0.02	0.46	32.64	0.04	0.45	**0.31**	*0.06*	*1.41*
35 kg	35.18	0.03	0.57	35.18	0.03	0.56	**0.51**	*0.08*	*1.63*
37.5 kg	37.78	0.03	0.60	37.80	0.03	0.58	**0.75**	*0.08*	*1.60*
40 kg	40.35	0.04	0.66	40.35	0.04	0.61	**0.87**	*0.10*	*1.65*

Cross talk testing while loading the force at the G (Figure 3.8) in the medial-lateral direction.

Medial-lateral direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*Y*	*Z*
0.5 kg	-0.49	0.01	-0.01	-0.49	0.01	-0.01	**2.00**	*2.00*	*2.00*
1 kg	-0.99	0.00	0.01	-0.99	0.00	-0.02	**1.00**	*0.00*	*1.00*
1.5 kg	-1.53	0.01	0.02	-1.53	0.00	-0.02	**2.00**	*0.67*	*1.33*
2 kg	-2.01	0.00	-0.02	-2.01	0.00	-0.02	**0.50**	*0.00*	*1.00*
5 kg	-4.96	0.00	0.03	-4.95	0.00	-0.01	**0.80**	*0.00*	*0.60*
7 kg	-6.96	-0.01	-0.08	-6.97	0.01	-0.08	**0.57**	*0.14*	*1.14*
8.5 kg	-8.43	0.00	-0.13	-8.44	-0.01	-0.09	**0.82**	*0.00*	*1.53*
10 kg	-9.96	-0.01	-0.11	-9.95	0.01	-0.07	**0.40**	*0.10*	*1.10*
12.5 kg	-12.43	-0.01	-0.08	-12.41	0.00	-0.18	**0.56**	*0.08*	*0.64*
15 kg	-14.97	-0.01	-0.18	-14.97	-0.01	-0.22	**0.20**	*0.07*	*1.20*
17.5 kg	-17.79	0.01	-0.15	-17.79	0.00	-0.18	**1.66**	*0.06*	*0.86*
20 kg	-20.27	0.00	-0.21	-20.27	0.00	-0.18	**1.35**	*0.00*	*1.05*
22.5 kg	-22.52	-0.01	-0.21	-22.52	-0.01	-0.29	**0.09**	*0.04*	*0.93*
25 kg	-25.10	-0.01	-0.33	-25.08	0.01	-0.30	**0.40**	*0.36*	*1.32*
27.5 kg	-27.75	0.00	-0.44	-27.86	0.00	-0.44	**0.91**	*0.00*	*1.60*
30 kg	-30.09	-0.02	0.03	-30.11	-0.01	0.01	**0.30**	*0.07*	*0.10*
32.5 kg	-32.88	0.00	0.02	-32.88	-0.01	0.03	**1.17**	*0.00*	*0.06*
35 kg	-35.51	0.01	-0.06	-35.54	-0.01	-0.08	**1.46**	*0.03*	*0.17*
37.5 kg	-37.87	0.17	0.06	-37.86	0.18	0.02	**0.99**	*0.45*	*0.16*
40 kg	-40.49	0.35	-0.10	-40.48	0.34	-0.09	**1.22**	*0.87*	*0.25*

Cross talk testing with 70 kg of known mass while loading the force at the F (Figure 3.8) in the medial-lateral direction.

Medial-lateral direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*Y*	*Z*
0.5 kg	0.49	0.01	-0.01	0.51	0.00	0.03	**2.00**	*2.00*	*2.00*
1 kg	1.01	-0.01	-0.02	1.01	-0.01	-0.03	**1.00**	*1.00*	*2.00*
1.5 kg	1.52	-0.02	-0.01	1.53	0.00	-0.02	**1.33**	*1.33*	*0.67*
2 kg	1.99	-0.01	-0.02	2.01	0.00	-0.01	**0.50**	*0.50*	*1.00*
5 kg	4.99	-0.01	0.08	5.03	0.00	0.10	**0.20**	*0.20*	*1.60*
7 kg	7.09	0.00	0.07	7.08	-0.01	0.06	**1.29**	*0.00*	*1.00*
8.5 kg	8.50	-0.01	0.21	8.50	0.00	0.21	**0.00**	*0.12*	*2.47*
10 kg	9.96	-0.15	0.20	9.95	-0.14	0.21	**0.40**	*1.50*	*2.00*
12.5 kg	12.53	-0.13	-0.14	12.49	-0.14	-0.14	**0.24**	*1.04*	*1.12*
15 kg	15.06	-0.14	-0.03	15.06	-0.12	-0.02	**0.40**	*0.93*	*0.20*
17.5 kg	17.56	-0.14	-0.01	17.55	-0.12	-0.01	**0.34**	*0.80*	*0.06*
20 kg	20.11	-0.12	-0.02	20.11	-0.14	-0.02	**0.55**	*0.60*	*0.10*
22.5 kg	22.72	-0.13	-0.04	22.73	-0.13	-0.01	**0.98**	*0.58*	*0.18*
25 kg	25.26	-0.12	-0.04	25.27	-0.12	-0.01	**1.04**	*0.48*	*0.16*
27.5 kg	27.86	-0.12	-0.04	27.87	-0.12	-0.01	**1.31**	*0.44*	*0.15*
30 kg	30.49	-0.14	-0.02	30.49	-0.13	0.00	**1.63**	*0.47*	*0.07*
32.5 kg	32.94	-0.13	-0.01	33.06	-0.13	-0.03	**1.35**	*0.40*	*0.03*
35 kg	35.66	-0.13	-0.01	35.67	-0.12	0.01	**1.89**	*0.37*	*0.03*
37.5 kg	37.92	0.00	-0.13	37.91	-0.01	-0.15	**1.12**	*0.00*	*0.35*
40 kg	40.21	-0.01	-0.14	40.23	-0.01	-0.11	**0.53**	*0.03*	*0.35*

Cross talk testing with 70 kg of known mass while loading the force at the G (Figure 3.8) in the medial-lateral direction.

Medial-lateral direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*Y*	*Z*
0.5 kg	-0.49	-0.01	-0.01	-0.48	0.00	-0.01	**2.00**	*2.00*	*2.00*
1 kg	-0.98	-0.01	0.00	-0.98	-0.01	0.00	**2.00**	*1.00*	*0.00*
1.5 kg	-1.49	0.00	-0.02	-1.50	0.01	0.01	**0.67**	*0.00*	*1.33*
2 kg	-2.00	0.00	0.01	-2.00	-0.01	0.00	**0.00**	*0.00*	*0.50*
5 kg	-5.01	0.00	0.01	-5.01	-0.01	-0.02	**0.20**	*0.00*	*0.20*
7 kg	-7.01	0.00	0.02	-7.01	0.00	-0.01	**0.14**	*0.00*	*0.28*
8.5 kg	-8.48	-0.02	-0.07	-8.47	0.00	-0.10	**0.23**	*0.23*	*0.82*
10 kg	-9.99	0.00	-0.11	-10.00	0.00	-0.12	**0.10**	*0.00*	*1.10*
12.5 kg	-12.46	-0.01	-0.22	-12.47	0.00	-0.23	**0.32**	*0.08*	*1.76*
15 kg	-14.99	0.00	-0.22	-15.01	0.00	-0.22	**0.07**	*0.00*	*1.47*
17.5 kg	-17.53	0.07	-0.22	-17.60	0.06	-0.12	**0.17**	*0.40*	*1.26*
20 kg	-19.95	0.06	-0.21	-19.94	0.05	-0.21	**0.25**	*0.24*	*1.05*
22.5 kg	-22.46	0.07	-0.24	-22.45	0.17	-0.24	**0.18**	*0.31*	*1.07*
25 kg	-25.01	0.18	-0.38	-25.01	0.19	-0.35	**0.04**	*0.72*	*1.52*
27.5 kg	-27.56	-0.08	0.23	-27.55	-0.06	0.25	**0.22**	*0.29*	*0.84*
30 kg	-30.01	-0.07	0.25	-29.96	-0.06	0.26	**0.03**	*0.23*	*0.83*
32.5 kg	-32.55	0.00	0.14	-32.55	0.00	0.13	**0.15**	*0.00*	*0.43*
35 kg	-35.11	0.00	0.01	-35.13	-0.01	0.00	**0.31**	*0.00*	*0.03*
37.5 kg	-37.72	0.11	0.00	-37.72	0.13	0.01	**0.59**	*0.29*	*0.00*
40 kg	-40.44	0.13	-0.12	-40.44	0.18	-0.11	**1.10**	*0.32*	*0.30*

Cross talk testing while loading the force at the E (Figure 3.8) in the caudad-cephlad direction.

Caudad-cephlad direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*X*	*Z*
0.5 kg	0.01	0.50	0.00	0.00	0.51	-0.02	**0.00**	*2.00*	*0.00*
1 kg	-0.01	1.02	0.02	-0.01	1.02	0.00	**2.00**	*1.00*	*2.00*
1.5 kg	0.00	1.52	0.01	0.01	1.51	0.04	**1.33**	*0.00*	*0.67*
2 kg	-0.01	1.99	0.03	0.00	2.00	0.03	**0.50**	*0.50*	*1.50*
5 kg	-0.01	5.02	0.01	-0.02	5.01	0.01	**0.40**	*0.20*	*0.20*
7 kg	-0.06	6.98	0.01	-0.06	6.97	0.07	**0.28**	*0.86*	*0.14*
8.5 kg	-0.03	8.55	0.03	-0.03	8.54	0.01	**0.59**	*0.35*	*0.35*
10 kg	-0.04	10.09	0.11	-0.03	10.10	0.03	**0.90**	*0.40*	*1.10*
12.5 kg	-0.19	12.53	0.22	-0.19	12.54	0.25	**0.24**	*1.52*	*1.76*
15 kg	-0.05	15.14	0.22	-0.07	15.14	0.24	**0.93**	*0.33*	*1.47*
17.5 kg	-0.18	17.56	0.24	-0.19	17.56	0.24	**0.34**	*1.03*	*1.37*
20 kg	-0.18	20.07	0.24	-0.19	20.07	0.24	**0.35**	*0.90*	*1.20*
22.5 kg	-0.19	22.69	0.22	-0.17	22.69	0.23	**0.84**	*0.84*	*0.97*
25 kg	-0.18	25.11	0.36	-0.18	25.11	0.36	**0.44**	*0.72*	*1.44*
27.5 kg	-0.07	27.64	0.35	-0.07	27.64	0.35	**0.51**	*0.25*	*1.27*
30 kg	0.00	30.21	0.50	0.00	30.16	0.47	**0.70**	*0.00*	*1.67*
32.5 kg	0.31	32.81	0.46	0.31	32.82	0.49	**0.95**	*0.95*	*1.41*
35 kg	0.00	35.31	0.35	0.00	35.31	0.35	**0.89**	*0.00*	*1.00*
37.5 kg	-0.05	37.88	0.33	0.00	37.83	0.39	**1.01**	*0.13*	*0.88*
40 kg	-0.08	40.37	0.42	-0.06	40.36	0.40	**0.92**	*0.20*	*1.05*

Cross talk testing while loading the force at the D (Figure 3.8) in the caudad-cephlad direction.

Caudad-cephlad direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*X*	*Z*
0.5 kg	0.00	-0.49	-0.01	0.00	-0.49	0.00	**2.00**	*0.00*	*2.00*
1 kg	0.00	-1.02	0.01	0.00	-1.01	0.01	**2.00**	*0.00*	*1.00*
1.5 kg	0.00	-1.50	-0.01	0.00	-1.52	0.00	**0.00**	*0.00*	*0.67*
2 kg	0.00	-1.99	0.02	0.00	-1.98	-0.01	**0.50**	*0.00*	*1.00*
5 kg	0.04	-4.94	-0.01	0.02	-4.94	-0.03	**1.20**	*0.80*	*0.20*
7 kg	0.03	-6.94	-0.05	0.02	-6.94	-0.12	**0.86**	*0.43*	*0.71*
8.5 kg	0.03	-8.48	-0.14	0.03	-8.48	-0.13	**0.23**	*0.35*	*1.65*
10 kg	0.04	-9.98	-0.09	0.04	-9.99	-0.12	**0.20**	*0.40*	*0.90*
12.5 kg	0.03	-12.44	-0.12	0.02	-12.45	-0.13	**0.32**	*0.24*	*0.96*
15 kg	0.15	-14.96	-0.03	0.16	-14.96	-0.02	**0.27**	*1.00*	*0.20*
17.5 kg	0.15	-17.39	-0.03	0.14	-17.39	-0.03	**0.63**	*0.86*	*0.17*
20 kg	0.16	-19.98	-0.12	0.16	-19.98	-0.11	**0.10**	*0.80*	*0.60*
22.5 kg	0.03	-22.57	-0.21	0.04	-22.56	-0.22	**0.31**	*0.13*	*0.93*
25 kg	0.00	-25.18	-0.14	-0.01	-25.18	-0.14	**0.72**	*0.00*	*0.56*
27.5 kg	0.07	-27.77	-0.21	0.00	-27.78	-0.22	**0.80**	*0.25*	*0.76*
30 kg	0.00	-30.38	-0.14	0.00	-30.39	-0.13	**1.27**	*0.00*	*0.47*
32.5 kg	0.00	-32.87	-0.26	-0.01	-32.87	-0.26	**1.14**	*0.00*	*0.80*
35 kg	-0.01	-35.09	-0.25	-0.02	-35.09	-0.27	**0.26**	*0.03*	*0.71*
37.5 kg	-0.01	-37.68	-0.40	-0.01	-37.68	-0.39	**0.48**	*0.03*	*1.07*
40 kg	0.08	-40.40	-0.48	0.10	-40.40	-0.46	**1.00**	*0.20*	*1.20*

Cross talk testing with 70 kg of known mass while loading the force at the E (Figure 3.8) in the caudad-cephlad direction.

Caudad-cephlad direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*X*	*Z*
0.5 kg	0.01	0.49	0.00	0.00	0.49	-0.01	**2.00**	*2.00*	*0.00*
1 kg	0.00	0.98	-0.01	0.01	0.97	0.00	**2.00**	*0.00*	*1.00*
1.5 kg	0.00	1.52	0.01	0.01	1.53	0.01	**1.33**	*0.00*	*0.67*
2 kg	0.00	2.00	0.01	0.00	2.00	-0.05	**0.00**	*0.00*	*0.50*
5 kg	0.11	5.02	0.00	-0.04	5.01	0.00	**0.40**	*2.20*	*0.00*
7 kg	0.11	6.96	-0.01	0.11	6.96	0.00	**0.57**	*1.57*	*0.14*
8.5 kg	-0.02	8.48	-0.02	0.09	8.49	-0.01	**0.25**	*0.25*	*0.25*
10 kg	-0.01	9.98	-0.01	-0.03	9.98	0.00	**0.20**	*0.10*	*0.10*
12.5 kg	0.00	12.59	0.02	-0.01	12.58	0.00	**0.72**	*0.00*	*0.16*
15 kg	-0.19	15.05	0.16	-0.18	15.07	0.22	**0.33**	*1.27*	*1.07*
17.5 kg	-0.19	17.59	0.23	-0.18	17.60	0.25	**0.51**	*1.08*	*1.31*
20 kg	-0.31	20.32	0.26	-0.30	20.32	0.24	**1.60**	*1.55*	*1.30*
22.5 kg	0.01	22.63	0.04	0.00	22.62	0.02	**0.58**	*0.04*	*0.18*
25 kg	0.00	25.15	0.00	0.00	25.18	0.03	**0.60**	*0.00*	*0.00*
27.5 kg	-0.13	27.88	0.00	-0.12	27.87	0.01	**1.38**	*0.47*	*0.00*
30 kg	0.20	30.33	0.00	0.19	30.35	0.01	**1.10**	*0.67*	*0.00*
32.5 kg	0.20	32.55	-0.01	0.20	32.44	0.01	**0.15**	*0.61*	*0.03*
35 kg	0.22	35.01	0.01	0.21	35.01	-0.03	**0.03**	*0.63*	*0.03*
37.5 kg	0.33	37.79	-0.13	0.33	37.79	-0.12	**0.77**	*0.88*	*0.35*
40 kg	0.33	40.02	-0.11	0.31	40.01	-0.09	**0.05**	*0.82*	*0.27*

Cross talk testing with 70 kg of known mass while loading the force at the D (Figure 3.8) in the caudad-cephlad direction.

Caudad-cephlad direction	Test			Retest			Error (%)	Cross talk (%)	
	X	Y	Z	X	Y	Z		*X*	*Z*
0.5 kg	0.00	-0.50	0.00	0.00	-0.50	0.00	**0.00**	*0.00*	*0.00*
1 kg	0.01	-1.01	0.00	0.02	-0.99	-0.02	**1.00**	*1.00*	*0.00*
1.5 kg	0.02	-1.48	0.00	0.02	-1.48	-0.02	**1.33**	*1.33*	*0.00*
2 kg	0.02	-2.03	-0.01	0.02	-2.03	-0.02	**1.50**	*1.00*	*0.50*
5 kg	-0.11	-4.93	-0.04	-0.11	-4.92	-0.01	**1.40**	*2.20*	*0.80*
7 kg	-0.11	-6.93	-0.01	-0.10	-6.93	-0.03	**1.00**	*1.57*	*0.14*
8.5 kg	-0.11	-8.56	0.00	-0.10	-8.52	-0.01	**0.70**	*1.29*	*0.00*
10 kg	-0.11	-9.98	-0.03	-0.18	-9.97	-0.01	**0.20**	*1.10*	*0.30*
12.5 kg	-0.24	-12.53	-0.12	-0.24	-12.53	-0.11	**0.24**	*1.92*	*0.96*
15 kg	-0.23	-15.06	-0.10	-0.24	-15.14	-0.12	**0.40**	*1.53*	*0.67*
17.5 kg	0.14	-17.66	0.03	0.13	-17.66	-0.01	**0.91**	*0.80*	*0.17*
20 kg	0.12	-19.90	-0.02	0.14	-19.90	0.00	**0.50**	*0.60*	*0.10*
22.5 kg	0.14	-22.50	-0.10	0.14	-22.50	-0.08	**0.00**	*0.62*	*0.44*
25 kg	0.19	-25.22	-0.21	0.19	-25.23	-0.22	**0.88**	*0.76*	*0.84*
27.5 kg	0.20	-27.53	-0.21	0.18	-27.64	-0.24	**0.11**	*0.72*	*0.76*
30 kg	0.30	-30.29	-0.37	0.31	-30.36	-0.33	**0.97**	*1.00*	*1.23*
32.5 kg	0.32	-32.79	-0.34	0.32	-32.79	-0.36	**0.89**	*0.98*	*1.05*
35 kg	0.14	-35.08	-0.23	0.14	-35.09	-0.21	**0.23**	*0.40*	*0.66*
37.5 kg	0.19	-37.61	-0.33	0.23	-37.66	-0.32	**0.29**	*0.51*	*0.88*
40 kg	0.42	-40.46	-0.36	0.44	-40.45	-0.33	**1.15**	*1.05*	*0.90*

The motion capture system test

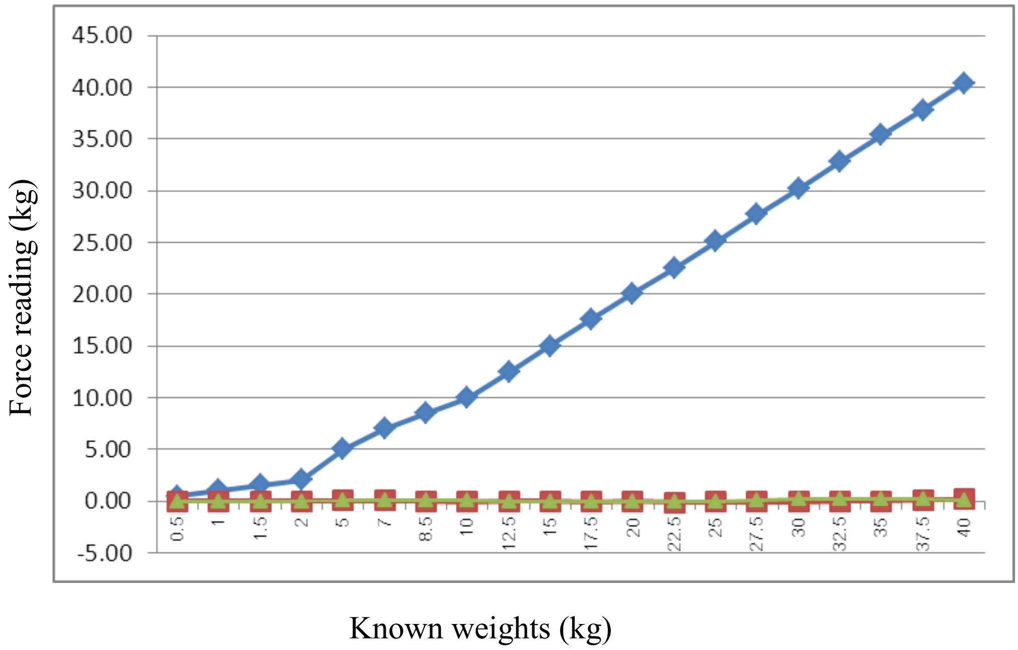
Real distance (cm)	Distance from test (cm)	Pearson's values	Error (%)
0.5	0.5	1.00*	0
1	1	1.00*	0
1.5	1.5	1.00*	0
2	2	1.00*	0
2.5	2.5	1.00*	0
3	3	1.00*	0
3.5	3.5	1.00*	0
4	4	1.00*	0
4.5	4.5	1.00*	0
5	5	1.00*	0

* represents statistically significant ($p<0.05$)

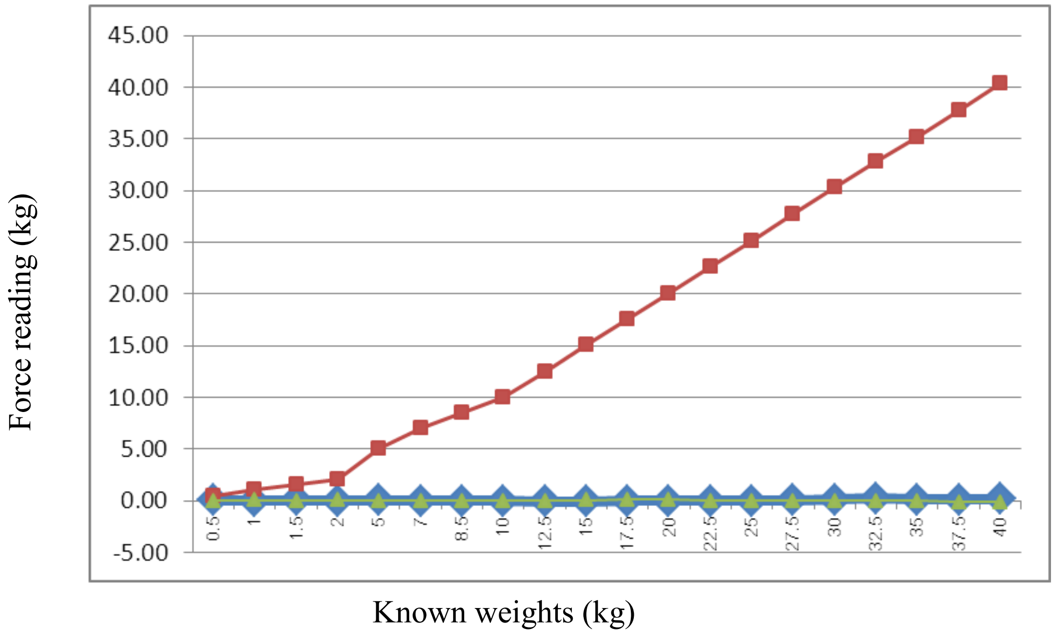
The correlation of the couch in measuring force applied

Directions	Pearson's values	$ICC_{(2, 1)}$
Vertical A	1.00*	1.00
Vertical B	1.00*	1.00
Vertical C	1.00*	1.00
Medial-Lateral G	1.00*	1.00
Medial-Lateral F	1.00*	1.00
Caudad-Cephalad	1.00*	1.00
Cephalad-Caudad	1.00*	1.00
On Wt. + Vertical A	1.00*	1.00
On Wt. + Vertical B	1.00*	1.00
On Wt. + Vertical C	1.00*	1.00
On Wt. + Medial-Lateral G	1.00*	1.00
On Wt. + Medial-Lateral F	1.00*	1.00
On Wt. + Caudad-Cephalad	1.00*	1.00
On Wt. + Cephalad-caudad	1.00*	1.00

A, B and C in vertical direction represent the positions that were tested in cephalad, middle and caudad, respectively (Figure 3.8). G and F in medial-lateral direction represent the positions that the weights were hanged on (Figure 3.8). + represents the condition that the couch with dead weight of known mass 70 kg. * represents to the correlation statistically significant ($p<0.05$).



The relationship between known weight values (medial-lateral loading) and the force readings in three directions. The medial-lateral direction results demonstrate a linear relationship between the weights and medial-lateral loading reading; the vertical and caudad-cephalad directions results demonstrate the negligible cross talk when loading in the medial-lateral direction. (blue line with diamonds) represents load in medial-lateral direction that the couch measure. (green line with triangles) represents load in vertical direction that the couch measure. (red line with squares) represents load in caudad-cephalad direction that the couch measure.



The relationship between known weight values (caudad-cephalad loading) and the force readings in three directions. The caudad-cephalad direction results demonstrate a linear relationship between the weights and caudad-cephalad force reading; the vertical and medial-lateral directions results demonstrate the negligible cross talk when loading in the caudad-cephalad direction. represents load in caudad-cephalad direction that the couch measure**.** represents load in vertical direction that the couch measure. represents load in medial-lateral direction that the couch measure**.**

BIOGRAPHY

Mrs Methawee Kaewprasert was born on April 11, 1979 in Sukhothai, Thailand. She graduated her high school from Sawanananwittaya School, Sukhothai, in 1998. In 2002, she graduated her Bachelor's degree in Physical Therapy from school of Physiotherapy Faculty of Siriraj Medicine, Mahidol University. After she graduated her degree, she worked as a physical therapist in Department of Rehabilitation and Medicine, Nawaminetharathiraj University. In June 2008, she enrolled in a Master degree in Musculoskeletal Physical Therapy, Faculty of Allied Health Science, Chulalongkorn University.