

A Quantitative Measurement System of Endpoint during Lachman test with Force Sensor

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Abstract—Lachman test is one of manual tests for examining the anterior cruciate ligament (ACL). An examiner discriminates an injured degree of the ACL by feeling finger stress. Some measurement devices for Lachman test have been developed. However, these devices aim to analyze not the stress but a motion of the knee joint. Therefore, we set the goal of this study to develop a measurement system for the finger stress with force sensor during Lachman test. In the experiment, the developed system was applied to twelve healthy knees of six subjects by a beginner, and one injured and one healthy knee of two subjects by an expert. In the results, the maximum force of "endpoint" during Lachman test was analyzed. The variation of inter-subjects was larger than intra-subjects. Future works are to improve the finger force sensors, and to apply more subjects, so that the system could classify an examiner into a skill level.

Keywords—Lachman test, Force Sensor, Anterior Cruciate Ligament, Manual test

I. INTRODUCTION

Lachman test is a manual test used for examining the Anterior Cruciate Ligament (ACL) of the knee for patients where there is a suspicion of a torn ACL. The Lachman test is recognized by most authorities as the most reliable and sensitive clinical test for the determination of ACL integrity, superior to the Anterior Drawer test commonly used in the past. To do this, lay the patient supine on an examination table. Put the patient's knee in about 20-30 degrees flexion, also according to Bates' Guide to Physical Examination the leg should be externally rotated [1]. The examiner should place one hand behind the tibia and the other on the patient's thigh. It is important that the examiner's thumb be on the tibial tuberosity. On pulling anteriorly on the tibia, an intact ACL should prevent forward translational movement of the tibia on the femur ("firm endpoint") as shown in Fig. 1. Anterior translation of the tibia associated with a soft or a mushy endpoint indicates a positive test. More than about 2 mm of anterior translation compared to the uninvolved knee suggests a torn ACL ("soft endpoint"), as does 10 mm of total anterior translation. An instrument called a "KT-1000" can be used to determine the magnitude of movement in mm [2-4]. "KT-1000" was not to be used as a device to measure the injured ACL [5]. This test can be done in an on the field evaluation in an acute injury setting, or in a clinical setting when a patient presents with knee pain. In either situation, ruling out fracture is important in the evaluation process. Also when evaluating the integrity of the ACL, it is

important to test the integrity of the Medial Collateral Ligament (MCL), because this is a common ligament torn in an ACL injury as well. Some studies have reported the stress during Lachman test [6], however, they could not obtain the force data dynamically.

In previous studies, quantitative measurement of Pivot Shift test by three-dimensional electromagnetic sensors have been made [7, 8]. A quantitative force measurement of fingers of examiner during Lachman test has not been developed. This study set the goal to develop a quantitative measurement system of Lachman test with force sensors. The system could enable us to analyze a mechanism of the "endpoint" that indicates an injured degree of the ACL. This study explains mainly the principle of the measurement system. In the experiment, the developed system was applied to twelve healthy knees of six subjects. In the results, the maximum force of "endpoint" during Lachman test was analyzed. The variation of inter-subjects was larger than intra-subjects.

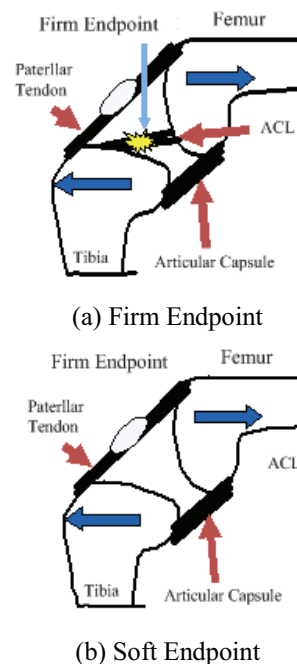


Figure 1. Endpoint

II. METHOD

A. Force Sensor

A force sensor is made by using conductive rubber (sili-us Fuso Gomu Co. Ltd.). Thickness of this rubber is 0.05mm. The rubber is cut as dimensions of 6.0 (mm) x 7.0 (mm) x 0.05 (mm). Then, a set of pattern for the sensor is made by using an extension board (ICB-075 san-hayato Co. Ltd.) which has copper foils over the entire surface. This process is made use of thermal transfer printing method.

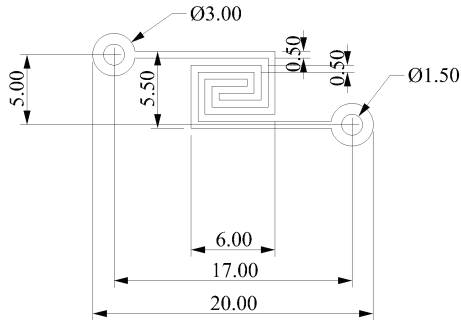


Figure 2. Design

Next, the rubber and copper foils are fixed by a laminating machine (LPD3213, Fujipura Co. Ltd.). Then, a profile of this sensor is modified as a bending shape by using a thermal heating device (EH-NW80-K, Panasonic Co. Ltd.) as shown in Fig. 3.

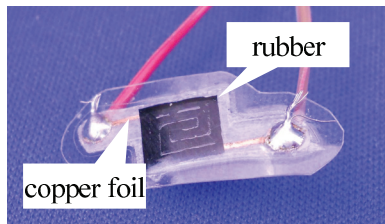


Figure 3. Real Sensor

A finger brace (Sawamura prosthetics and orthotics service Co. Ltd.) is used for fixing the force sensors to fingers. Then, the force sensor is pasted double-sided tape (NW-10S, Nichiban Co. Ltd.) on the surface of the board. Two sensors are attached to one finger brace. The finger brace is molded by using thermoplastic (JJ-210, Daicel Finechem Co. Ltd.). In this study, the attached sensor is called as "Finger Force Sensor" as shown in Fig. 4.

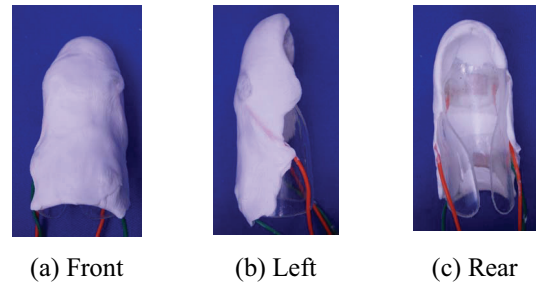
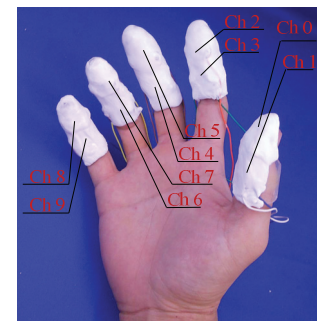
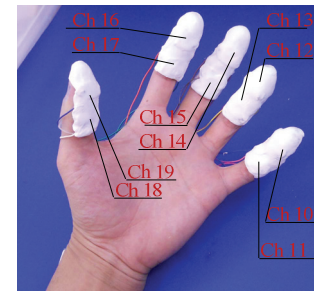


Figure 4. Finger Force Sensor

This measurement system has ten finger force sensors. All the finger force sensors are attached to all fingers tightly. The channels number of thumb of right hand are Ch 0 and Ch 1. A channel number is allocated to sensors of right hand from thumb in order. The sensors of the little finger of the left hand are numbered as Ch 10 and Ch 11. Next channels are allocated to left thumb in order as shown in Fig. 5.



(a) Right hand



(b) Left hand

Figure 5. Finger Force Sensors

B. Measurement Circuit

1) Two Gauges Method

Sensor making use of a variable resistance as this force sensor is energy control type. Sensor of energy control type is easily affected by temperature. In this study, for guarantee of temperature two gauges method was used. This method used two sensors for one measurement as shown in Fig. 6. One of the sensors was for measurement, the another one was dummy. A measurement system measures a difference of a

measurement sensor and a dummy sensor. The measurement sensor and the dummy sensor are placed as same temperature, so that influence of temperature is same as both sensors. Thus, this system could measure without influence of any temperature.

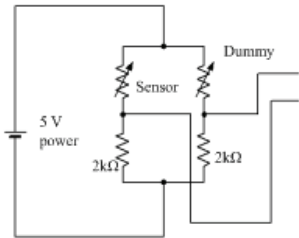


Figure 6. Two Gauges Method

2) Differential Amplifier Circuit

A differential value of the measurement sensor and the dummy sensor is small. A change of the differential value is more small. It is difficult to measure the real value due to a noise. Therefore, the differential value should be amplified. This measurement circuit has a differential amplifier circuits used by an operational amplifier (Fig. 7).

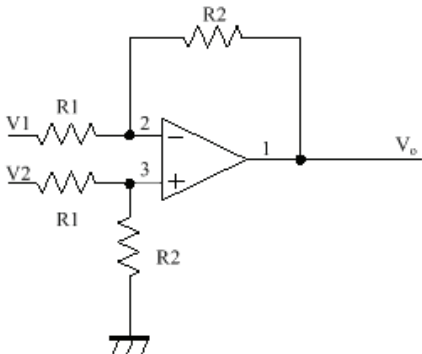


Figure 7. Differential Amplifier

The output value of this differential amplifier is

$$V_o = \frac{R_2}{R_1}(V_2 - V_1). \tag{1}$$

In this measurement circuit,

$$R_1 = 1.0 \times 10^3. \tag{2}$$

The R_2 is a variable resistance. A resistance of sensors is deviated for each sensors. Then, the resistance is adjusted so that the deviation should be controlled. In this study, a

deviation of differential voltage is controlled by using a factor R_2 which is a variable resistance. However, two resistances of R_2 are necessary for one measurement sensor. To control for two normal variable resistances is difficult, because values of two variable resistances must be same. In this study, control of deviation of differential voltage is used double volume resistance (RV16A01F-10-20S-B100KΩ, Aicoh electronics Co. Ltd.) as shown in Fig. 8.

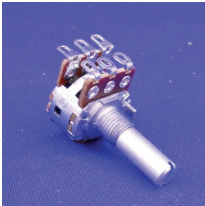


Figure 8. Double Volume Resistance

C. Measurement System

A measurement system consists of a personal computer, an analog / digital (AD) converter, and finger force sensors. The A/D converter is AIO-16320FX-USB (CONTEC Co. Ltd.)(Fig. 9). This converter could connect by using USB. The data sampling is 1 [kHz]. The input range is from -10 to 10 V. The resolution is 16 bits (Table I).



Figure 9. A/D converter

TABLE I. SPECIFICATION OF A/D CONVERTER

Communication Bus	USB
Faculty	Input , output
Input ch num	Single end 32 ch (differential 16 ch)
Input range	±10 V, ±5 V, ±2.5 V, 0~10 V, 0~5 V, 0~2.5 V
Output ch num	2 ch
Output range	±10 V, ±5 V, ±2.5 V, ±1.25 V, 0~10 V, 0~5 V, 0~2.5 V
resolution	16 bit
A/D convert speed	2 μsec/ch(max.)
D/A convert speed	10 μsec(max.)

This measurement circuit is in aluminium case. In this circuit, there are a power supply, a circuit of power supply, a circuit for sensors, a circuit for differential amplifier (for right hand) and a circuit for differential amplifier (for left hand) as shown in Fig. 10. In this circuit of power supply, there are 5 [V] power supply for sensor and -15 [V] and 15 [V] power supply for operational amplifier. First, an analog amplified signal is converted to a digital signal by the A/D converter, the

digital signal is sent to personal computer by the universal serial bus. Finally, the voltage data is converted to load data by a program.

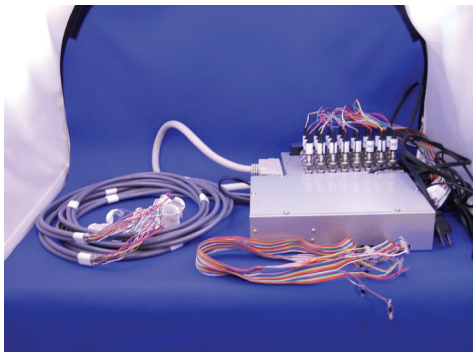


Figure 10. Measurement System

III. EXPERIMENT

A. Calibration Experiment

This system should calibrate before measuring the load data. A mechanical testing device is developed by using an electroactuation (PWA II Cyllinder, Orientalmotor Co., Ltd.), a load cell (Thin type load cell (multi-force sensor), Kyowa Electronic Instruments Co., Ltd) as shown in Fig. 11. Specification of the electroactuation is tabulated in Table II.

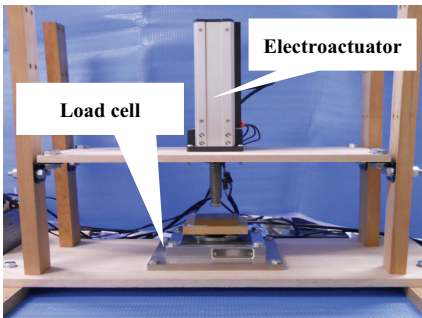


Figure 11. Mechanical testing Device

TABLE II. SPECIFICATION OF ELECTROACTUATION

Stroke (mm)	Maximum Load (N)	Resolution (mm)
100	1000	0.01

Calibration is performed for the force sensors beforehand (Fig. 12.) A plastic lump is inserted to each finger force sensor as shown in Fig. 12. Because the finger brace will be bent so that the calibration value is not measured well, if the calibration is performed without the plastic lump. These finger force sensors are calibrated at loads of 20 N, 40 N, 60N, 80 N, 100 N, 120 N, 140 N, 160 N, 180 N and 200 N. The load is vertically applied for surface of the finger force sensor. The tip of the stick of this electroactuator set to be placed the center of the conductive rubber of the sensor. On characteristic of the conductive rubber, the voltage values are measured at a

few seconds later when the load had be steady condition. In this experiment, steady values are used for the calibration data .

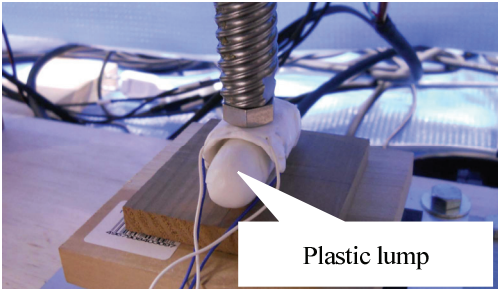


Figure 12. Calibration Scene

B. Manual test Experiment

1) Measurement by a beginner

Twelve knees joint of a subject (Table III) are observed by using the developed system. #2 and #6 in subjects had a injured knee except for the ACL. Lachman test is applied for the knee five times as usual manner. This Lachman test is expected as the finger of the right second finger, the right third finger and the left thumb are loaded. Other fingers are supported. Then, force distribution of the finger force sensors are analyzed when the maximum and minimum forces are detected. Data of 5 times of Lachman test in right and left knees of one subject are evaluated at student t-test (significance, $P \leq 0.01$).



Figure 13. Manual test Scene

TABLE III. SUBJECT INFORMATION BY A BEGINNER

Num	Sex	Height [cm]	Weight [kg]	Knee	Condition	History
#1	Male	174	66	Left	Intact	No
				Right	Intact	No
#2	Male	175	73	Left	Intact	Yes
				Right	Intact	No
#3	Male	170	78	Left	Intact	No
				Right	Intact	No
#4	Male	175	63	Left	Intact	No
				Right	Intact	No
#5	Male	163	70	Left	Intact	No
				Right	Intact	No
#6	Male	167	66	Left	Intact	Yes
				Right	Intact	No

2) Measurement by an expert

Two knees joint of a subject (TABLE IV) were observed by using the developed system. This measurement was observed by an expert who was an orthopedic surgeon in familier with Lachman test. One knee of observed knees was the injured ACL. These observed data were compared.

TABLE IV. SUBJECT INFORMATION BY A EXPERT

Num	Sex	Height [cm]	Weight [kg]	Knee	Condition	History
#1	Female			Right	Injured	No
#2	Male	168	70	Right	Intact	No

IV. RESULTS

A. Calibration Experiment

In this measurement circuit, the voltage is increased with loading, because the relationship of the voltage and the resistance has an inverse proportion. In Fig. 14, all the sensor show the relationship of the voltage and the load. This result is used for calculation of the force applied to the finger force sensors in the following experiment.

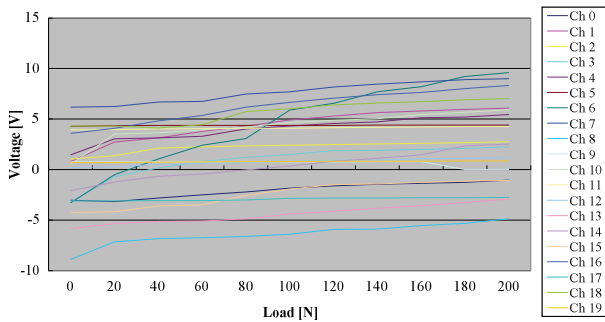


Figure 14. Result of Calibration

B. Manual test Experiment

1) Measurement of the beginner

A force changes of time course measured in the experiment is shown in Fig. 15. In this figure, only specific Chs are shown so that it is easy to understand the change. This change is depicted as one time anterior motion of the knee. In the end period, comparatively higher force was observed. It is considered as "endpoint." The maximum force is analyzed among each trial. In the Lachman test, five endpoints were observed in one trial, because five anterior drawer motions were performed in one trial.

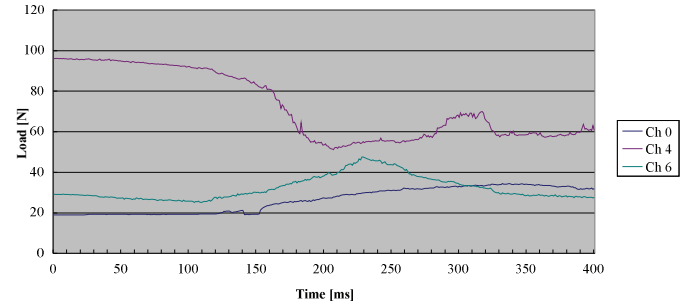


Figure 15. Result of Lachman test

The maximum forces of endpoints are shown in Fig. 16. In this figure, average and standard deviation are calculated in one trial. Then, the last column means averages of five trials. In this figure, The variation of inter-subjects was larger than intra-subjects. In the result of t-test, both knees of #2 and #6 had significant differences.

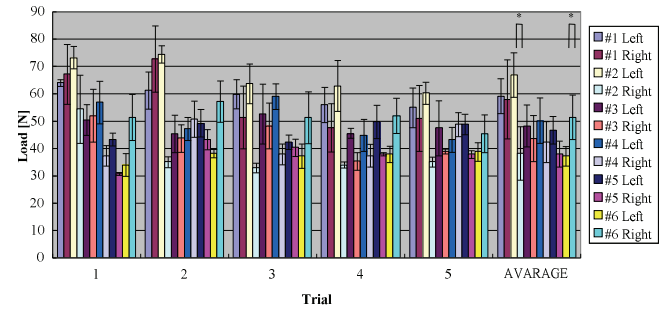


Figure 16. Result of Measured Force during Lachman test

2) Measurement of an expert

Two force changes of time course measured in the experiment are shown in Fig. 17 and Fig. 18. In this Figs, distinctive Chs (Ch4 and Ch5 are channels of the second finger of right hand, Ch 18 and Ch 19 are channels of the thumb of left hand) are picked up. In Fig. 17, the result of firm endpoint is shown. In this Fig., peak of Ch 5 is about 145[N]. In Fig. 18, the result of soft endpoint is shown. In this Fig., peak of Ch 5 is about 70[N]. During Lachman test, even if the ACL is injured or intact, a characteristic of left hand motion should be almost same. In fact, Ch 18 and Ch 19 of both of Fig. 17 and Fig. 18 are almost same. Thus, the result of Fig. 18 is regarded as a result of Soft endpoint.

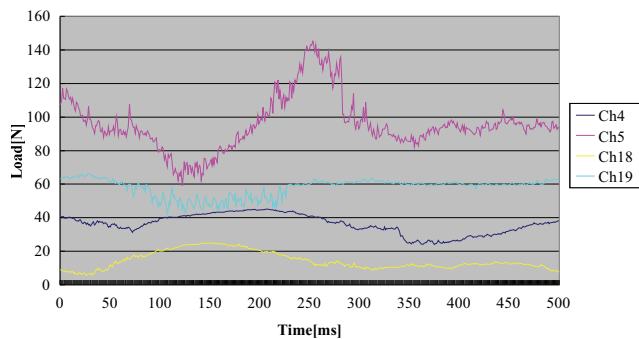


Figure 17. Result of Firm Endpoint

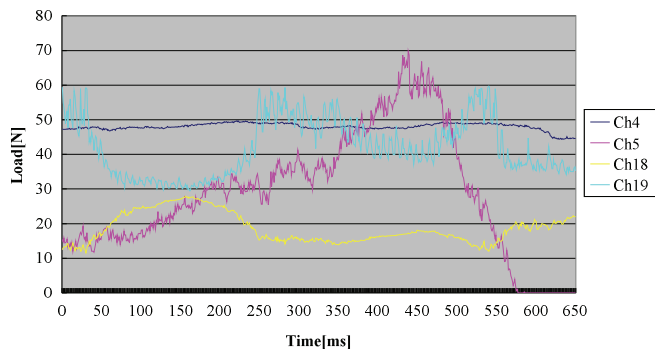


Figure 18. Result of Soft Endpoint

V. DISCUSSION

In the result of measured force during Lachman test by the beginner, both knees of #2 and #6 had significant differences. The difference was related to the injured knee except for the ACL. Both the injured knees of #2 and #6 were left knee. However the distinctive differential values were observed in these knees. We thought a value of the injured knee was lower than the normal knee. The value of the injured knee of #6 was lower than the another knee. However #2 and #6 have a different tendency. In case of #2, subject was thought that he made his injured knee strong tension during Lachman test due to fear for the movement.

In the result of measured force during Lachman test by the expert, the difference was shown in the knee of the ACL injured knee. Because a knee in comparison with a injured knee was a normal knee of another person, a difference was seen in results. However although both of Ch 18 and Ch 19 were almost same, the largest load of Ch 5 became that the normal knee indicated twice loading of the injured knee. The difference was considered to be the difference of "soft endpoint" and "firm endpoint."

VI. CONCLUSION

This study aimed to develop a quantitative measurement system of endpoint during Lachman test using force sensor. The finger force sensor was made by attaching force sensors to finger braces. In the experiments, the developed system was applied to twelve healthy knees of six subjects. Forces of

endpoints during Lachman test were analyzed. The variation of inter-subjects was larger than intra-subjects. Usually, the ACL injured knee had soft endpoint. In this experiment, the developed system showed both of firm and soft endpoint. Future works are to improve the finger force sensors, and to apply more subjects, so that the system could classify an examiner into a skill level.

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