Characteristics of muscle contraction of the rectus femoris using Tensiomyography by sex in healthy adolescents: a Cross-Sectional Study

Yasuaki Kusumoto (kusumoto@fmu.ac.jp)  
Fukushima Medical University School of Health Sciences, Fukushima, Japan  
https://orcid.org/0000-0002-6730-4848

Hayato Goto  
LITALICO Inc

Kouhei Chiba  
Japanese Red Cross Medical Center

Sakiko Onishi  
Tokyo University of Technology School of Health Sciences: Tokyo Koka Daigaku Iryo Hoken Gakubu

Junko Tsuchiya  
Tokyo University of Technology School of Health Sciences: Tokyo Koka Daigaku Iryo Hoken Gakubu

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**Abstract**

**Background**

Tensiomyography (TMG) is a non-invasive instrument for measuring mechanical muscle contraction characteristics, and measures the maximum displacement of the muscle belly in the vertical direction and the time needed to achieve this from electrical stimulation. There have only been few reports of TMG on general healthy adults. A systematic review on TMG reported a low proportion of female participants with a small sample size. Therefore, it is unclear whether there is a difference in TMG parameters by sex and between the dominant and non-dominant feet. Furthermore, the relationship between the TMG parameters and the evaluations commonly used in clinical practice has not been clarified. This study aimed to clarify the characteristics of muscle contraction of the rectus femoris using tensiomyography by sex among healthy adolescents and its relationship with muscle function evaluation, such as lower limb muscle mass and muscle strength. The subjects included 91 healthy university students. The measurement items included TMG, lower limb muscle mass, rectus femoris thickness, isometric knee joint extension torque, and thigh circumference.

**Results**

There was a main effect on sex in all parameters ($p \leq 0.05$). In terms of TMG parameters, maximum displacement ($D_m$) in the non-dominant foot was significantly lower in women. The correlation between TMG parameters for males and females and lower limb muscle mass, muscle thickness, joint torque, and thigh circumference had a significant correlation with some TMG parameters and lower limb muscle mass ($p \leq 0.05$). The absolute value of the correlation coefficient was overall low with 0.27 ~0.45.

**Conclusion**

In healthy adolescents, there was a difference by sex in TMG parameters and a weak correlation between TMG parameters and the lower limb muscle mass. TMG parameter evaluation may indicate a different function compared with the traditional muscle function assessment used in clinical practice. The TMG parameter is considered as a unique evaluation method for neuromuscular function assessment.

**Key Points**

- TMG parameters differed by sex, and there was a weak correlation between TMG parameters and lower limb muscle mass, but not with the muscle function evaluation conventionally used in clinical practice in healthy adolescents.

- Practitioners in the sports medicine field must understand that TMG parameter evaluation differs from muscle function evaluation that is conventionally used in clinical practice.
When using TMG parameter as an evaluation battery, it is necessary to consider the sex-related differences when choosing subjects.

The TMG parameter is a unique evaluation method for neuromuscular function assessment.

**Introduction**

Tensiomyography (TMG-100: TMG manufactured by TMG-BMC) is a non-invasive instrument for measuring mechanical muscle contraction characteristics. TMG determines the muscle contraction time, muscle fatigue, and muscle fitness by measuring the maximum displacement of the muscle belly in the vertical direction (radial direction with respect to the muscle) and the time needed to achieve this from electrical stimulation (1). In recent years, TMG has been utilized mainly in the field of sports in Europe. By understanding the characteristics of muscle contraction before and after training, it is also used to gauge the characteristics of muscle contraction among athletes in specific sports and the effectiveness of training during specific period or competition season to prevent and hasten recovery from injuries (2,3). According to the latest review on TMG, soccer and volleyball athletes have been the most studied. It has been concluded that TMG is useful for determining changes in muscle contraction characteristics between competition and training (4). There have only been few reports of TMG on general healthy adults. Therefore, going forward, it is necessary to accumulate data on healthy individuals for it to be utilized among people with illnesses at general hospitals in the region.

Muscles mass, thickness, and strength are the most common muscle function evaluations performed in geriatric medicine and in general hospitals to evaluate the individual condition of the lower limb muscles (5,6). Sex-based differences in muscle mass, thickness, and strength have been observed, with females having lower values than males. It is also generally known that these values do not vary significantly between the dominant foot and the non-dominant foot within the same subject. On the other hand, a systematic review on TMG reported a low proportion of female participants with a small sample size (7). Therefore, it is unclear whether there is a difference in TMG parameters by sex and between the dominant and non-dominant feet. Furthermore, the relationship between the TMG parameters and the evaluations commonly used in clinical practice has not been clarified. The application of TMG will be broadened to include sick people if it becomes clear whether the TMG parameter is a unique evaluation method for neuromuscular function or an assessment that is useful in clinical practice and can be a possible substitute. In previous studies, TMG in various muscles has been reported. However, the neuromuscular function of the rectus femoris has been measured in many competitive sports and studies by training types (7,8).

Therefore, this study aimed to clarify the muscle contraction characteristics of the rectus femoris using TMG in healthy adolescents by sex and its relationship with common tests for muscle function used in clinical practice.

**Material And Methods**
This study used a cross-sectional design to identify the muscle contraction characteristics of the rectus femoris using TMG in healthy adolescents. Independent variables were sex and dominant and non-dominant feet and dependent variables were TMG parameters and common tests for muscle function used in clinical practice. This study was conducted with the approval of the Tokyo University of Technology Ethics Review Committee, and consent was obtained by oral and written explanation to the subjects (Approval number: E16HS-030), and informed consent was obtained by oral and written explanation to the subjects.

**Subjects**

Inclusion criteria of subjects was healthy university students with no underlying endogenous diseases. The subjects included 105 healthy university students (aged 18-24 years) who provided written consent. Subjects who underwent major trauma or surgery within 6 months, had a history of ligament injury around the knee joint, and could not complete the measurement were excluded. Accordingly, 91 subjects who met the criteria were analyzed (Fig. 1). The dominant foot was defined as the foot used to kick the ball. The dominant foot was right in 83 and left in 8.

**Procedures**

The measurement items included lower limb muscle mass determined with TMG and body composition analyzer, rectus femoris thickness determined with an ultrasonic measuring device, isometric knee extension torque with manual muscular strength meter as the maximum muscle strength, and thigh circumference. Considering the effect of fatigue, the measurement order of each measurement item was randomly determined for each subject using a random number table.

**TMG**

The same inspector performed TMG on the rectus femoris in the dominant and non-dominant feet. All measurements were performed in a resting supine position, with the attached triangular pillow being placed below the knee to slightly flex the knee joint. The TMG sensor rod was placed in the middle of the anterior inferior iliac spine to the upper edge of the patella, perpendicular to the belly of the rectus femoris (Fig. 2). Electrodes for electrical stimulation (5 cm x 5 cm) were attached around the sensor rod, creating a 5-cm distance between the electrodes (9). The starting current was 20 mA, and the pulse stimulation time was 1 ms. The current was increased by 10 mA, and electrical stimulation was repeated until no changes in the waveform were observed or the maximum output of 110 mA was reached (10). The evaluation items were maximum displacement (Dm), delay time (Td), and contraction time (Tc). These have been reported to be highly reliable and recommended for use in previous studies (11).

A typical TMG waveform is shown in Figure 3. Dm, the vertical displacement of the radial waveform, expresses the amount of vertical displacement of the contracted muscle in mm in response to electrical stimulation. A decrease in Dm corresponds to an increase in muscle stiffness (4). Td represents the time required (ms) to reach 10% of Dm after electrical stimulation, reflecting the responsiveness of muscles to...
muscle contraction due to electrical stimulation (4). Tc represents the time needed (ms) to achieve 10–90% of Dm, reflecting the contraction rate from the onset to the end of the muscle contraction. Therefore, Tc is said to be affected by muscle fiber type, and it becomes longer as tendon stiffness decreases (4).

In order to confirm the accuracy of the inspector’s measurement technique, TMG was performed twice within one week in eight healthy university students who were not the subjects of this study. The intraclass correlation coefficients (3,1) were calculated, resulting to 0.75 for Dm, 0.61 for Td, and 0.74 for Tc.

**Body Composition Measurement**

The InBody S20 (manufactured by InBody) was used to measure body composition. With the participants resting in a supine position, a total of 8 contact electrodes were attached, 4 points on the bilateral 1st and 3rd fingers, and 4 points around the medial and lateral malleolus bilaterally. The skin of the measurement part was first cleaned with alcohol to remove the keratin on the skin surface. In this study, the lower limb muscle mass of the dominant and non-dominant legs analyzed.

**Rectus Femoris Thickness**

The rectus femoris thickness was measured in a resting supine position using an ultrasonic image measuring device (ACUSON P300 and 18-6 MHz linear probe, Siemens Japan Co., Ltd.). The probe was applied perpendicularly to the rectus femoris at the midpoint of anterior inferior iliac spine to the upper edge of the patella, and its angle was adjusted to maximize the view of the femur. In addition, all measurements were performed by one inspector after sufficient practice while being careful not to compress the muscles. The image at this time was recorded on a computer, and the muscle thickness of the rectus femoris was measured in mm using the attached software.

**Knee Joint Extension Torque**

The knee joint extension torque was measured using a handheld dynamometer (Mutas F-1, ANIMA) by fixing the belt to the support of the bed while the subjects were seated (12). The belt’s length was adjusted so that the lower leg was in the drooping position, and care was taken not to shift the sensor pad. The subjects were instructed to maintain their trunk in a vertical position with fold both upper limbs in front of it. Knee extension muscle strength was measured with maximum effort for about 3 seconds. Breaks lasting 30 seconds or more were provided for the left and right legs, and each was performed twice. The maximum value was used, and the torque-to-body weight ratio [Nm / kg] was calculated.

**Maximum Thigh Circumference**

The measurement was done in the resting supine position using a cloth measure. The measurement site was located 15 cm from the upper edge of the patella, considered to be strongly related to lower limb muscle strength (13), and was measured once with bare skin without covering.

**Statistical Analysis**
The attributes of the subjects were compared using the unpaired t-test and chi-square test. Each parameter was compared by two-way ANOVA, with sex and dominant/non-dominant foot as the unpaired factors, and Bonferroni's multiple comparison test. The correlation between the TMG parameters and the other parameters was examined by Pearson's product moment correlation coefficient for both males and females. All analyses were performed using the SPSS statistical software for Windows, version 27.0 (IBM, Tokyo). A p-value of <0.05 was considered to be statistically significant.

Results

The characteristics of the subjects, including age, height, and body mass, are shown in Table 1. While the ANOVA results for sex, dominant foot, and non-dominant foot are shown in Table 2. Each parameter is shown in Table 3. In terms of sex, a main effect was observed for all the parameters, and in terms of the TMG parameters, Dm in the non-dominant foot was significantly lower in women.

Table 1 Subject attributes

|                          | Male (n = 51) | Female (n = 40) | P value |
|--------------------------|--------------|-----------------|---------|
| Age (year)               | 21.2(1.0)    | 20.9(1.2)       | 0.15    |
| Height(cm)               | 172.3(5.9)   | 161.4(16.4)     | 0.00 *  |
| Weight(kg)               | 65.5(8.8)    | 50.3(4.9)       | 0.00 *  |
| Dominant foot (right, left; n) | 47, 4      | 36, 4           | 0.72    |
| Exercise frequency of at least 1 hour per day per week (0 days, 1-2 days, 3-4 days, 5 days or more; person) | 36, 13, 0, 2 | 30, 6, 3, 1 | 0.16 |

Average (standard deviation), *: p value <.05
| Parameter                          | Source                           | F-value | Degrees of freedom | p-value |
|-----------------------------------|----------------------------------|---------|--------------------|---------|
|                                   | Sex                              |         |                    |         |
|                                   | Dominant foot                   |         |                    |         |
|                                   | Non-dominant foot               |         |                    |         |
|                                   | sex x dominant foot             |         |                    |         |
|                                   | non-dominant foot               |         |                    |         |
| Dm                                | Sex                              | 5.37    | 1                  | 0.02    |
|                                   | Dominant foot                   | 0.09    | 1                  | 0.76    |
|                                   | Non-dominant foot               | 0.39    | 1                  | 0.53    |
|                                   | sex x dominant foot             | 0.09    | 1                  | 0.76    |
|                                   | non-dominant foot               | 0.39    | 1                  | 0.53    |
| Td                                | Sex                              | 4.65    | 1                  | 0.03    |
|                                   | Dominant foot                   | 1.14    | 1                  | 0.29    |
|                                   | Non-dominant foot               | 0.05    | 1                  | 0.83    |
|                                   | sex x dominant foot             | 0.05    | 1                  | 0.83    |
|                                   | non-dominant foot               | 0.05    | 1                  | 0.83    |
| Tc                                | Sex                              | 5.50    | 1                  | 0.02    |
|                                   | Dominant foot                   | 0.08    | 1                  | 0.77    |
|                                   | Non-dominant foot               | 0.02    | 1                  | 0.90    |
|                                   | sex x dominant foot             | 0.02    | 1                  | 0.90    |
|                                   | non-dominant foot               | 0.02    | 1                  | 0.90    |
| Lower limb muscle mass           | Sex                              | 303.15  | 1                  | 0.00    |
|                                   | Dominant foot                   | 0.26    | 1                  | 0.61    |
|                                   | Non-dominant foot               | 0.11    | 1                  | 0.74    |
|                                   | sex x dominant foot             | 0.11    | 1                  | 0.74    |
|                                   | non-dominant foot               | 0.11    | 1                  | 0.74    |
| Muscle thickness                  | Sex                              | 114.01  | 1                  | 0.00    |
|                                   | Dominant foot                   | 1.05    | 1                  | 0.31    |
|                                   | Non-dominant foot               | 0.05    | 1                  | 0.83    |
|                                   | sex x dominant foot             | 0.05    | 1                  | 0.83    |
|                                   | non-dominant foot               | 0.05    | 1                  | 0.83    |
| Knee joint extension torque      | Sex                              | 32.34   | 1                  | 0.00    |
|                                   | Dominant foot                   | 1.35    | 1                  | 0.25    |
|                                   | Non-dominant foot               | 0.30    | 1                  | 0.58    |
|                                   | sex x dominant foot             | 0.30    | 1                  | 0.58    |
|                                   | non-dominant foot               | 0.30    | 1                  | 0.58    |
| Thigh circumference 20 cm         | Sex                              | 34.51   | 1                  | 0.00    |
|                                   | Dominant foot                   | 0.08    | 1                  | 0.77    |
|                                   | Non-dominant foot               | 0.09    | 1                  | 0.76    |
|                                   | sex x dominant foot             | 0.09    | 1                  | 0.76    |
|                                   | non-dominant foot               | 0.09    | 1                  | 0.76    |
Table 3 Comparison of male and female parameters for dominant and non-dominant feet

| Parameter                          | Dominant foot | Non-dominant foot | P value in dominant and non-dominant feet comparison |
|------------------------------------|---------------|-------------------|------------------------------------------------------|
|                                    | Male (n = 51) | Female (n = 40)   | P value | Male (n = 51) | Female (n = 40) | P value | Male | Female |
| Dm (mm)                            | 6.6 (1.5)     | 6.2 (1.9)         | 0.40    | 6.9 (2.2)     | 6.1 (1.9)       | 0.04    | 0.48 | 0.83   |
|                                    | [6.1-7.2]     | [5.6-6.8]         |         | [6.4-7.4]     | [5.5-6.7]       |         |      |        |
| Td (ms)                            | 26.7 (4.2)    | 28.4 (5.8)        | 0.10    | 26.1 (3.8)    | 27.5 (5.0)      | 0.17    | 0.52 | 0.39   |
|                                    | [25.4-28.0]   | [26.9-29.8]       |         | [24.8-27.4]   | [26.0-28.9]     |         |      |        |
| Tc (ms)                            | 30.5 (5.8)    | 28.6 (5.9)        | 0.12    | 30.9 (5.5)    | 28.8 (5.2)      | 0.08    | 0.76 | 0.91   |
|                                    | [29.0-32.1]   | [26.9-30.4]       |         | [29.3-32.4]   | [27.0-30.5]     |         |      |        |
| Lower limb muscle mass (kg)        | 9.4 (1.5)     | 6.2 (0.9)         | 0.00    | 9.3 (1.4)     | 6.1 (0.9)       | 0.00    | 0.53 | 0.91   |
|                                    | [9.1-9.8]     | [5.8-6.6]         | *       | [8.9-9.6]     | [5.8-6.5]       | *       |      |        |
| Muscle thickness (mm)              | 21.0 (2.3)    | 17.2 (2.6)        | 0.00    | 20.7 (2.3)    | 16.7 (2.6)      | 0.00    | 0.49 | 0.55   |
|                                    | [20.3-21.7]   | [16.4-17.9]       | *       | [20.0-21.4]   | [16.0-17.5]     | *       |      |        |
| Knee joint extension torque (Nm / kg) | 2.64 (1.09) | 1.86 (0.59)      | 0.00    | 2.42 (0.88)  | 1.79 (0.53)     | 0.00    | 0.20 | 0.68   |
|                                    | [2.41-2.87]   | [1.60-2.12]       | *       | [2.20-2.65]   | [1.53-2.05]     | *       |      |        |
| Thigh circumference (cm)           | 49.9 (4.2)    | 46.6 (3.1)        | 0.00    | 49.6 (3.9)    | 46.6 (2.6)      | 0.00    | 0.66 | 0.99   |
|                                    | [49.0-50.9]   | [45.5-47.8]       | *       | [48.6-50.6]   | [45.2-47.8]     | *       |      |        |

Tc: contraction time, Dm: displacement, Td: delay time, average (standard deviation) [95% Confidence interval], *: p < .05
Table 4 presents the correlation coefficients between the TMG parameters and lower limb muscle mass, muscle thickness, joint torque, and thigh circumference for males and females. In males, negative correlations were observed between the non-dominant foot Dm and lower limb muscle mass and between the dominant foot Td and knee extension torque. Meanwhile, a positive correlation between the non-dominant foot Tc and lower limb muscle mass was noted. In females, a negative correlation between the dominant foot Dm and lower limb muscle mass and a positive correlation between the dominant and non-dominant foot Td and lower limb muscle mass were observed.
### Table 4 Correlation coefficient between TMG parameters and each parameter

|       | Lower limb muscle mass | Muscle thickness | Knee joint extension torque | Thigh circumference |
|-------|------------------------|-----------------|----------------------------|--------------------|
| **Male** |                        |                 |                            |                    |
| Dm    |                        |                 |                            |                    |
| Dominant foot | -0.18   | 0.11            | -0.01                      | 0.20               |
| Non-dominant foot | -0.29 * | -0.08           | 0.26                       | 0.15               |
| **Td** |                        |                 |                            |                    |
| Dominant foot | 0.27    | -0.27           | -0.27 *                    | 0.05               |
| Non-dominant foot | 0.08    | -0.16           | -0.01                      | 0.03               |
| **Tc** |                        |                 |                            |                    |
| Dominant foot | 0.13    | 0.16            | 0.14                       | -0.01              |
| Non-dominant foot | 0.28 *  | -0.05           | -0.12                      | 0.27               |
| **Female** |                      |                 |                            |                    |
| Dm    |                        |                 |                            |                    |
| Dominant foot | -0.45 *  | -0.09           | 0.21                       | -0.15              |
| Non-dominant foot | -0.11   | -0.10           | -0.12                      | -0.15              |
| **Td** |                        |                 |                            |                    |
| Dominant foot | 0.42 *   | -0.17           | -0.01                      | 0.12               |
| Non-dominant foot | 0.33 *  | 0.16            | -0.16                      | 0.12               |
| **Tc** |                        |                 |                            |                    |
| Dominant foot | -0.07   | -0.12           | -0.10                      | -0.25              |
| Non-dominant foot | 0.07    | 0.08            | -0.12                      | 0.11               |

Tc: contraction time, Dm: displacement, Td: delay time, *: p <.05

For each of the other parameters, the values of the ipsilateral lower limbs were used in the analysis to correspond to the dominant and non-dominant feet of the TMG parameter.

**Discussion**
Since all the TMG parameters had a main effect by sex, the results of the two-way ANOVA highlighted the sex-based differences of the TMG parameters in healthy adolescents. This results were similar to the evaluation of muscle function frequently used in clinical practice, such as muscle mass and strength. Based on the multiple comparison test, upon examination of the dominant and non-dominant feet, the DM was the only TMG parameter that was different between males and females for the non-dominant foot, indicating that DM is the most likely indicator of sex difference in TMG. In addition, as seen in Table 3, the 95% CIs of Dm, Td, and Tc for both dominant and non-dominant feet overlap between males and females. However, the values for Dm and Tc among females are generally lower, which highlights the possibility that in healthy adolescents, females have a smaller amount of vertical displacement during muscle contraction due to electrical stimulation and the slower contraction rate from the onset to the end of the muscle contraction. In addition, Td’s wider 95% CI among females may result to the muscles’ slower responsiveness of to muscle contraction by electrical stimulation. Therefore, when using this TMG parameter as an evaluation battery, it is necessary to consider the sex-based differences when choosing subjects.

Overall, there was a weak correlation (correlation coefficient: 0.27-0.45) among the items, with a significant correlation between the TMG parameters and each parameter. Specifically, there was a correlation between the multiple TMG parameters and lower limb muscle mass. The Dm and lower limb muscle mass of the non-dominant foot in men (correlation: -0.29) and the dominant foot (correlation: -0.45) in women were negatively correlated, indicating that those with high muscle mass in the lower limbs have low Dm and high muscle stiffness. In addition, there was a correlation of 0.42 for the dominant foot Td and 0.33 for the non-dominant foot Td in women. It is possible that in healthy adolescent females and in those with low muscle mass of the lower limbs, the muscle responsiveness to contraction is quicker, whereas those with a large amount of lower limb muscle may require longer times to muscle contraction from electrical stimulation. The evaluation of muscle functions, such as lower limb muscle mass and joint torque, does not include individual muscles but involved multiple muscle functions working in combination. This is thought to reflect the amount of activity of daily life\(^\text{14}\). In the fields of sports and medicine, muscle strength, thickness, fatigue rate, and risk of injury, including the muscles’ physiological and pathophysiological, are substantially affected by sex\(^\text{15,16}\). Similarly, in this study, the amount of activity of daily living, including the frequency of exercise and the physiological aspects of muscles, differed between men and women. It is possible that lower limb muscle mass was related to the neuromuscular response of muscles in healthy adolescents. Although many subjects in our study did not exercise on a daily basis, they were generally healthy adolescents.

At present, information on the application of the TMG parameters in healthy adolescents and females is limited, making it difficult to determine their characteristics by comparing with findings of previous studies on TMG for athletes. Since the reason for the different correlation between the dominant and non-dominant feet by sex is unclear, it will be necessary to investigate sex, exercise frequency, and motor function in the future. The results of this study provide basic information for future application of TMG in subjects with such diseases.
In the report on the validity of the TMG parameter, the maximum muscle strength and the muscle fatigue rate are often verified. A high correlation is reported \(^{17,18}\), but in this study, the maximum muscle strength by the manual muscular strength meter and femoral circumference had little to do with TMG parameters. This may be due to differences in muscle strength measurement methods or differences in subjects who do not play sports on a daily basis. There was a weak correlation between the TMG parameter and lower limb muscle mass, but not with other muscle function assessments. As such, the TMG parameter may be a unique evaluation method for assessing neuromuscular function.

**Conclusions**

In healthy adolescents, TMG parameters differed by sex, and there was a weak correlation between TMG parameters and lower limb muscle mass, but not with the muscle function evaluation conventionally used in clinical practice. Practitioners in the sports medicine field must understand that TMG parameter evaluation differs from muscle function evaluation that is conventionally used in clinical practice. When using TMG, it is important to consider sex-related differences. It was suggested that the TMG parameter is a unique evaluation method for neuromuscular function assessment.

**Abbreviations**

Tensiomyography: TMG; Maximum displacement: Dm; Delay time: Td; Contraction time: Tc

**Declarations**

**Ethics approval and consent to participate**

This study was conducted with the approval of the Tokyo University of Technology Ethics Review Committee, and consent was obtained by oral and written explanation to the subjects (Approval number: E16HS-030), and informed consent was obtained by oral and written explanation to the subjects.

**Consent for publication**

Not applicable. Participants or the public were not involved in the design, conduct, reporting, or dissemination plans of our research.

**Availability of data and material**

The datasets generated and/or analysed during the current study are available in the [figshare] repository, [10.6084/m9.figshare.16945522].

**Competing interests**

The authors, Yasuaki Kusumoto, Hayato Goto, Kouhei Chiba, Sakiko Onishi, and Junko Tsuchiya, declare that they have no competing interests.
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Authors' contributions

YK, HG, KC, SO, JT Conception and design of the study. YK, HG, KC Data acquisition. YK, SO, JT Data analysis and interpretation. YK Drafting of the manuscript. YK, HG, KC, SO, JT Critical revision of the manuscript. YK, HG, KC, SO, JT Accountability for all aspects of work, ensuring integrity and accuracy. All authors of the submitted manuscript certify that they have sufficiently participated in the work to take responsibility for the manuscript’s content. Furthermore, each author certifies that this material has not been and will not be submitted to or published in any other publication. The authors read and approved the final manuscript.

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Figures
Figure 1

Flow chart of the subjects

Figure 2
TMG measurement in a patient

Figure 3

Typical TMG measurement results