Development of estimation system of knee extension strength using image features in ultrasound images of rectus femoris

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ABSTRACT

The word "Locomotive syndrome" has been proposed to describe the state of requiring care by musculoskeletal disorders and its high-risk condition. Reduction of the knee extension strength is cited as one of the risk factors, and the accurate measurement of the strength is needed for the evaluation. The measurement of knee extension strength using a dynamometer is one of the most direct and quantitative methods. This study aims to develop a system for measuring the knee extension strength using the ultrasound images of the rectus femoris muscles obtained with non-invasive ultrasonic diagnostic equipment. First, we extract the muscle area from the ultrasound images and determine the image features, such as the thickness of the muscle. We combine these features and physical features, such as the patient's height, and build a regression model of the knee extension strength from training data. We have developed a system for estimating the knee extension strength by applying the regression model to the features obtained from test data. Using the test data of 168 cases, correlation coefficient value between the measured values and estimated values was 0.82. This result suggests that this system can estimate knee extension strength with high accuracy.

Keywords: Ultrasound image, Knee extension strength, Rectus femoris, Locomotive syndrome

1. INTRODUCTION

Currently, Japan is a super-aged society and about 26% of the population is elderly [1]. In addition, the rapid aging has become a serious social problem causing an increase of elderly in a condition of need for long-term care such as bedridden. About 20% of the causes of this condition is musculoskeletal disorders such as fractures and falls [2]. Then, in 2007, "Locomotive syndrome" which is a concept meaning a condition that has a high risk of need for long-term care has been proposed and its enlightenment activities are vigorously conducted.

Reduction of knee extension strength is one of the factors of locomotive syndrome. It has been reported that knee extension strength is related to the ability of unassisted walking [3]. Therefore, it is desirable to carry out the measurement and evaluation of knee extension strength, and to provide care such as muscle strengthening exercise in order to prevent the musculoskeletal disorders and the bedridden. Although use of a dynamometer is general when measuring the knee extension strength, it has a problem such as a damage to patient's muscle and joints.

An ultrasound image is often used when checking the status of muscles in orthopedics, and image features such as thickness of muscle, echogenicity of muscle area, and texture features which are related to muscle strength can be examined in ultrasound image [4]. Therefore, we extract image features that are related to knee extension strength and try to develop a system for estimating knee extension strength non-invasively by combining image features and physical features.

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2. METHODS

2.1 Outline

Overall scheme of this system is shown in Fig. 1. As shown in Fig. 2, muscle area of a person whose knee extension strength is weak is whiter than muscle area of a person whose knee extension strength is strong. First, we extract the rectus femoris muscle area from an ultrasound image in order to extract image features. We obtain image features from the muscle area. We perform this process for all data. We perform correlation analysis between obtained features and knee extension strength. Based on the results of the analysis, we build a regression model from the features that had a strong relationship with the knee extension strength. Estimation of knee extension strength is carried out by inputting features of the test data to the regression model.

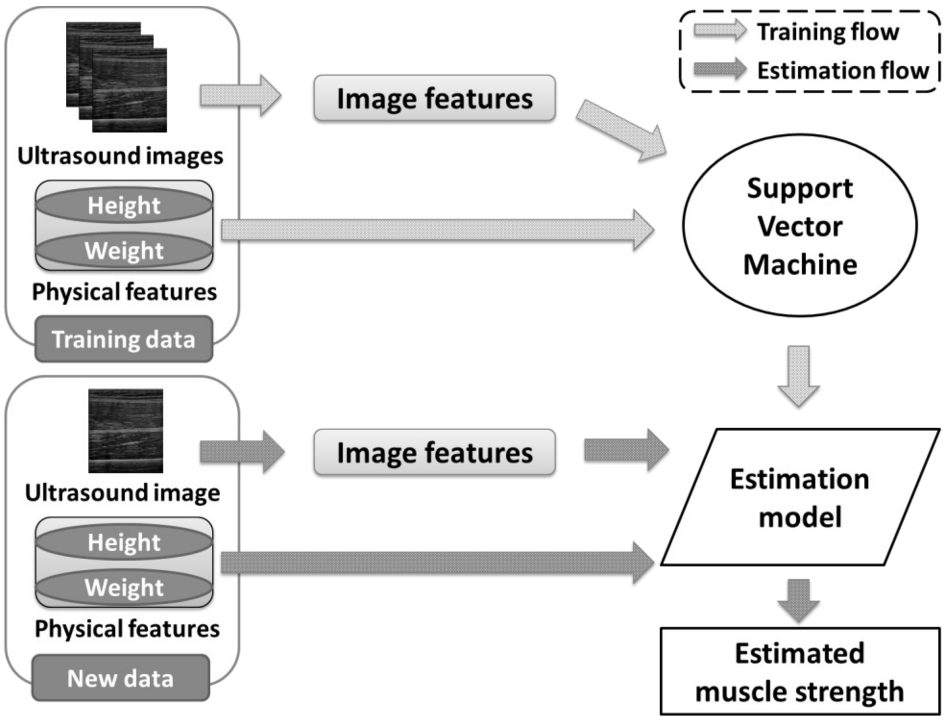


Fig.1 Overall scheme for estimation of knee extension strength

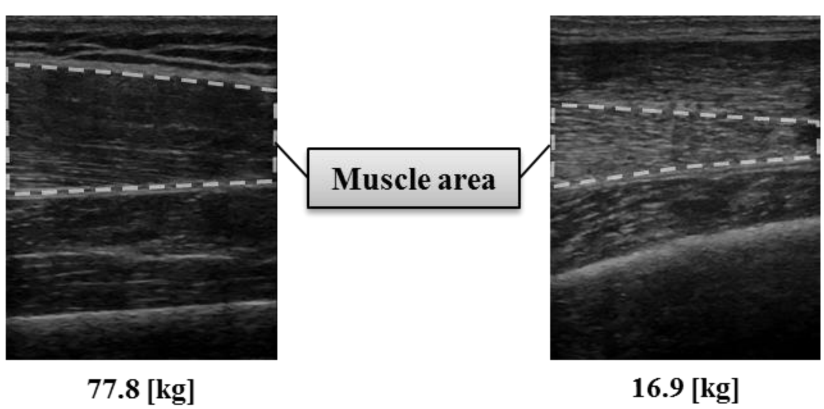
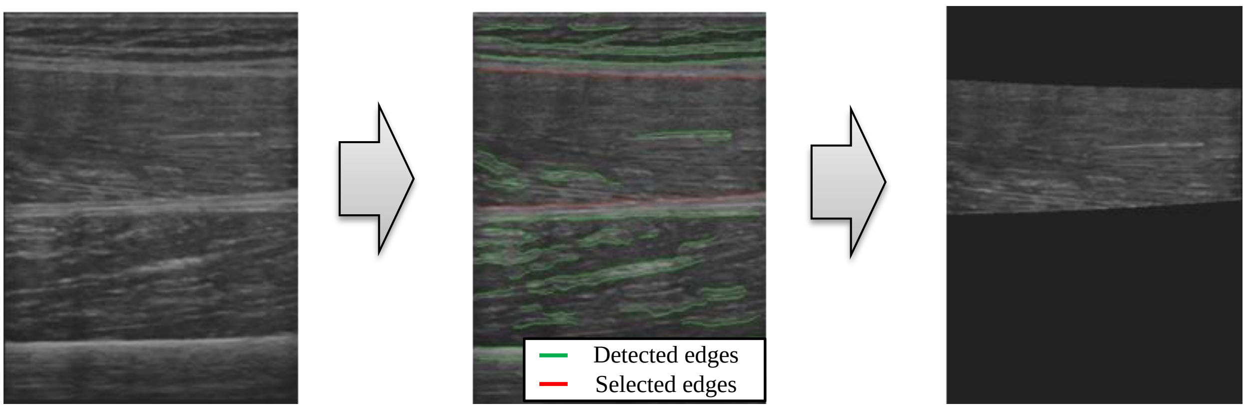


Fig.2 Difference in the images of individuals with different knee extension strength

2.2 Extraction of muscle area

First, we extract the muscle area from ultrasound images. We detect edges from an original image using Canny edge detector [5]. We select the edges close to the boundary of the muscle area manually. The boundary lines of the upper and lower ends of the muscle area are determined by approximating the selected edges with curves. The area between these boundaries is defined as the muscle area. Figure 3 shows the flow of extraction of the muscle area.

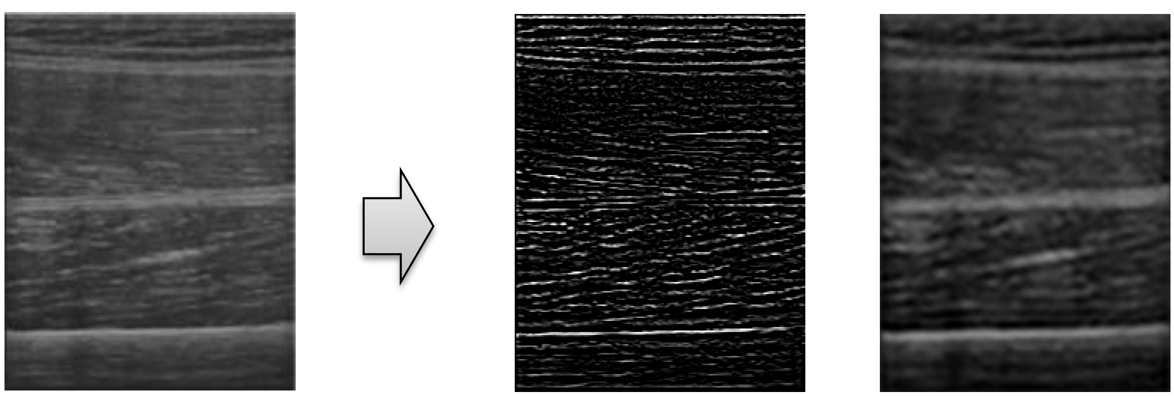


Original image Selection of edges Result image

Fig.3 Flow of extraction of muscle area

2.3 Creation of high-frequency image and low-frequency image

We apply a two-dimensional fast Fourier transform on the original image, and create images constituted by the high-frequency components such as edges and highlights and low-frequency components that represent a pattern of an image. Figure 4 shows the results of applying fast Fourier transform to an original image.



Original image High-frequency image Low-frequency image

Fig.4 Results of fast Fourier transform

2.4 Determination of image features

We obtain image features using gray level co-occurrence matrix (GLCM) and the histograms of echogenicity from the muscle area of the high-frequency image and the low-frequency image. From GLCM, we obtain 10 image features such as angular second moment and entropy. Features were calculated from the GLCMs for four directions (0°, 45°, 90°, and 135°). In the experiment, we use the average value of features calculated from the four directions in order to suppress the influence of rotation of the image. From the echogenicity histograms the average value, standard deviation, skewness, and kurtosis are calculated. In addition, the vertical length at the center of the muscle area is considered as the thickness of the muscle.

2.5 Construction of a regression model

We combine the image features and physical features, such as the patient's height, and build a regression model of the knee extension strength. We construct the regression model using support vector regression (SVR) [6]. The knee extension strength is estimated by entering the feature amounts obtained from test data to the regression model, which is constructed using the learning data.

3. MATERIALS

In this study, we used 168 B-mode ultrasound images of rectus femoris muscles scanned on both legs of 84 subjects. Table 1 shows the breakdown of the subjects. Images were obtained from the subjects in supine position. Figure 5 shows the condition of ultrasound imaging. The image size was 820 × 614 [pixels] and the spatial resolution is 0.07-0.12 [mm/pixel]. Knee extension strength was measured using a dynamometer as shown in Fig.6. Measurements were carried out twice each on the left and right legs. We employed the maximum strength of the two measurements for each knee. We measured the height and weight of the subjects in addition to their muscle strengths.

Table 1 Breakdown of the subjects

	Male	Female	Total
Young 1)	23	13	36
Elderly 2)	14	34	48
Total	37	47	84

1) Young: from 19 to 45 years old, 2) Elderly: from 46 to 86 years old

Fig.5 The condition of ultrasound imaging

Fig.6 Muscle strength dynamometer

4. RESULTS

As a result of correlation analysis between knee extension strength and features, strong correlations were observed in several features. Therefore, we built a regression model of the knee extension strength with these features as explanatory variables by using SVR. Table 2 shows the features used in the regression model. In the experiment, we used leave-one-out cross validation.

As a result of the experiment, the strong positive correlation value of 0.82 was confirmed between the estimated values and measured values. The root mean squared error (RMSE) which represents the deviation degree of the estimated values and measured values was 7.69 [kg]. There were some values that differed significantly from the measured value in the estimated values. These results may be due to the imbalance in the data with small numbers of cases with very strong muscle strength and those with very weak muscle strength, and the regression model was not fitted well for such data. We consider it necessary to suppress the inequality of the database by supplying insufficient data and sampling of database. It is difficult to output the same estimated value every time because of the poor reproducibility of ultrasound imaging, and the difficulty in obtaining the same cross section. Therefore, we consider that it is necessary to verify the reproducibility of the estimate values by obtaining several ultrasound images from the same subject and estimating the knee extension strength from these images.

As a result of this experiment, there were errors of about ±7.69 [kg] between measured values and estimated values calculated by this system. But, it is considered that there are some variations in measured values of knee extension strength using a dynamometer. In the future, we perform a comparison of estimated values and a range of values that a dynamometer may take.

Table 2 Features used in the regression model

Feature	**Correlation value**
Inverse difference moment 1)	0.57
Sum entropy 1)	-0.64
Angular second moment 1)	0.67
Information measurement of correlation 1)	-0.56
Mean of histogram 2)	-0.61
Thickness of quadriceps muscle 2)	0.66
Height	0.61
Weight	0.50

1) Features obtained from high-frequency images, 2) Features obtained from original images

5. CONCLUSION

In this study, we developed a system for estimating the knee extension strength using ultrasound images of rectus femoris muscles. The correlation coefficient value between the measured values and estimated values was 0.82, and RMSE was 7.69 [kg]. These results suggest that the proposed method can estimate knee extension strength with high accuracy. In the future, we will create a regression model considering the gender and age to improve the accuracy of estimation and verify the validity and reproducibility of the estimated values.

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