博士論文

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: characteristics and relations with low back injuries

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柔道選手における体幹筋
：その特徴と腰部損傷との関係

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Abbreviations

CT: computed tomography

CSAs: cross-sectional areas

EAP: excellent athletic performance

LAP: lower athletic performance compared to EAP

LBP: low back pain

LRA: lumbar radiological abnormalities

MRI: Magnetic resonance imaging

nsLBP: nonspecific low back pain

OCU: Osaka city university

SD: standard deviation

sLBP: specific low back pain

TMS: trunk muscle strength

Chapter 1. General introduction

1-1. Judo

Judo is a contact combat sport characterized by the use of grappling techniques. The name judo originated from “budo” which refers to Japanese traditional martial arts with an emphasis on education. Today, judo is widely known in Olympic and Paralympic sports, and the number of judokas is increasing worldwide, with more than one hundred and forty countries now competing in the world judo championship. The purpose of judo is to control an opponent using various techniques, including throwing and ground techniques with grappling movements. According to current regulation, judo is a fierce competition consisting of a 4-minute game and an extra time known as the Golden Score. Despite its short duration, a single match imposes an extremely high burden on the athlete. In international competitions, tournaments are usually held in a single day, and it takes about five to six matches to win a tournament. Hence, the physical and psychological strain on judokas is particularly high. Thus, judokas require strong muscle strength, including trunk muscle strength (TMS). Moreover, judokas suffer from large external and internal forces that pose a high risk of various injuries in the whole body including low back injuries (1, 2), such as low back pain (LBP). Thus, I believe that the trunk region is crucial for enhancing athletic performance and preventing LBP in judokas.

According to the regulation, judokas are divided into seven weight categories as follows: under 60 kg, 66 kg, 73 kg, 81 kg, 90 kg, 100 kg, and over 100 kg for men, and under 48 kg, 52 kg, 57 kg, 63 kg, 70 kg, 78 kg, and over 78 kg for women. Some of the movements in judo are specific for a category (3). Thus, the repertoire of movements of judokas varies according to weight category. The movements of lighter weight judokas are faster and more technically diverse than those in higher weight categories. Specifically, lighter-weight judokas quickly grasp the opponent's jacket and attempt to throw them within a short period. Contrastingly, heavier-weight judokas grasp each other tightly, thus applying a continuous strong force (4). Moreover, heavyweight judokas have not only a high bodyweight but a high body fat percentage as well. Therefore, the load on the trunk region may differ not only in magnitude but also in type of load across weight categories. Thus, the TMS characteristics differ across weight categories. Therefore, judokas should be aware of the characteristics of TMS in relation to weight categories to improve their performance. Moreover, this characteristic might affect LBP depending on the weight category. I consider that it is necessary to investigate the influence of weight category on TMS related to athletic performance and LBP in judokas.

In Japan, collegiate judokas usually have high-quality judo techniques and athletic performance levels, and have Olympic champions and world champions among their ranks. These judokas are optimal for the investigation of trunk conditions related to athletic performance and orthopedic problems in elite judokas.

1-2. Trunk muscles in Judokas

Some researchers have investigated muscle strength under various conditions across various regions (e.g., trunk, arm, knee, neck, and shoulder) in different athletes, including judokas (5-9). It has been shown that TMS is essential in judo (10). Muscle strength is essential for judokas to fight opponents with throwing and grounding techniques as well as intensive grappling. TMS, which is frequently used in all judo situations, is critical. TMS has also been reported to be essential for athletic performance (3, 4).

Body weight has a mechanical impact on the trunk region. There is a strong possibility that the characteristics of TMS depend on the weight category because of the different loads on the trunk region. For example, heavyweight judokas require TMS to a high extent. Moreover, heavyweight judokas should have a large muscle mass because of their large body weight. However, the relative TMS normalized by body weight should be lower in heavyweight judokas because of their significant body weight and fat. Contrastingly, lightweight judokas should have strong relative TMS normalized by body weight because of their extremely low body fat. In other words, judokas in each weight category have different TMS characteristics depending on their body weight and body fat. Thus, there is a strong possibility that the characteristics of TMS depend on the weight category because of the different loads on the trunk region. However, no study has investigated the relationship between weight categories and TMS in judokas.

Different methods and types of equipment have been used to measure the muscle strength of athletes (11-13). Although multiple joints and position setups render an appropriate evaluation difficult, TMS has also been studied using special equipment such as Cybex or Biodex (5, 11, 14, 15). Magnetic resonance imaging (MRI) and computed tomography (CT) are the main methods used to analyze the cross-sectional areas (CSAs) of the trunk muscles (16-20). A careful evaluation of skeletal muscle tissue can be obtained from images of the CSAs of the muscles. Because of the methodological difficulties, there is a shortage of studies on the evaluation of trunk muscle flexor and extensor strength among athletes. Athletes' muscles have higher CSAs and achieve greater TMS as a result of continuous daily training, which can be considered a sport-specific phenomenon. Thus, different muscular characteristics should exist between judokas and other athletes. To the best of our knowledge, sport specificity has never been examined in relation to the trunk region, especially the CSAs of the trunk muscles.

Few studies have addressed the relationship between judo athletic performance and TMS. A previous study (21) described that international level judokas with excellent athletic performance

(EAP) have higher trunk extension strength than national-level judokas with lower athletic performance compared to EAP (LAP). The isokinetic peak torques were measured at 120°/s in a previous study. As a result, international judokas—weight: 75.2 ± 13.1 kg (mean ± standard deviation [SD])—showed a capacity for trunk extension of 460.4 ± 62.9 N・m, and of 212.1 ± 28.6 N・m for trunk flexion. National level judokas (weight: 74.4 ± 9.9 kg) showed a capacity of 399.1 ± 59.6 N・m in the trunk extensor and of 228.2 ± 25.0 N・m in the trunk flexor (21). In contrast, another study described that EAP judokas did not have stronger TMS than LAP judokas (22). Partly because of the differences in the procedures for measuring TMS, level of performance, and weight categories, the results in this regard have been controversial.

For judokas, trunk rotation and lateral flexion motions have been reported to be critically important for the standing and groundwork techniques involved in judo (23-25). Techniques involving trunk rotation and accentuated hip and knee flexion (e.g., Seoi-nage) are more physically demanding than frontal attacks (26). Moreover, judokas require trunk rotation not only during dynamic movements but also in static positions. Judokas must output their TMS rotationally to keep their posture stable when defending against their opponent's attack. The judokas' trunk seems to be static in these situations, but the trunk produces rotational force statically. In addition, judokas must try to achieve an optimal grip of the opponent's judo-gi before attempting a throwing technique. This action is to establish dominant situation for judokas during the match, which is essential. Even in this situation, the trunk rotation movement is critical dynamically and statically, especially the peak isokinetic torque of the trunk rotation, which is associated with the dynamic pulling variable during the pulling motion with change of position (27). There is a strong possibility that the judo-specific motion of the trunk region can affect the trunk muscle function of judokas, including TMS, CSAs, trunk muscle size, and other factors. However, no study has investigated trunk rotation strength in judokas.

In a previous study on TMS, senior judokas (age: 21.6±0.98 years) showed higher hip extension and trunk flexion isometric strength than junior judokas (age: 17.5±0.71 years) and cadet judokas (age: 15.5±0.54 years) (28). In this study, differences between groups could, however, be due to age. Moreover, no relationship between TMS and athletic performance level within groups was found in that study (28). In another study in judokas, the CSAs of the left and right lumbar multifidus muscles were found to be asymmetric (29). However, despite the known asymmetry in the trunk of judokas, no studies have investigated the influence of this (including the rotator muscles) on athletic performance.

I would now like to describe the trunk muscles from the perspective of more detailed movements in internationalized judo. Although Judo is a traditional Japanese martial art, it is widely spread all over the world. Various techniques of close combat, originating from martial arts from other nations, such as Mongolia, Georgia, Russia, Uzbekistan, Brazil, and others, are frequently seen in recent international competitions. These techniques can be a determinant factor in the recent judo match. Close combat means that during the match, the judoka's trunk remains close to the opponent's trunk, while they try to grasp each other’s back through the armpit or over the shoulder. The judoka then tries to lift the opponent and throw them backward with trunk extension and rotation, an essential movement known as Ura-nage. Judokas also bend the trunk and rotate it to throw forward the opponent. This technique is named Soto-makikomi, Koshi-guruma, and others. In these situations, TMS is critical, especially rotation. Therefore, trunk rotation is a decisive factor in international judo competitions. Some international level judokas have thick trunk regions. They are decisive for close combat and have a strong defense against the opponent’s throwing techniques. It is very important to note that information on the anatomy and function of the trunk muscles is available to judokas, and their strength and/or technical training coaches encourage them to understand the judo-specific characteristics of the trunk muscle, so that they can apply the concepts to their practice to strengthen the trunk muscles involved in judo.

1-3. Low back pain in judokas

As mentioned earlier, judo is a martial art that involves a large amount of external force and a significant risk of injury (1, 2). The characteristics of judo-related injuries differ by body weight, favorite technique, judo history, etc. (1, 30, 31). To achieve a better understanding of judo injuries, it is crucial to classify subjects according to their level of athletic performance.

LBP is a common musculoskeletal disorder that affects the general population and athletes (32-36). There are various causes of LBP. According to its cause, LBP is classified into specific LBP (sLBP) and nonspecific LBP (nsLBP). sLBP is relatively uncommon and is caused by malignancies, infections, inflammatory spondyloarthropathies, and fractures (37). Contrarily, nsLBP, back pain that cannot be attributed to a specific cause, is quite common (37). Therefore, nsLBP is an appropriate research target for sports-related LBP.

There are multiple possible causes of nsLBP, which may be confounded. Specifically, not only anatomical changes in the lumbar spine and low TMS, which will be described later, but also alignment, flexibility (38), reaction speed, muscle endurance, and movement characteristics are associated with nsLBP. However, the relationship between these factors and nsLBP has not been clarified. At least in judo, as mentioned above, there are differences among weight categories in the performance of athletic skills, and so if judokas were not classified by weight category, the uniformity of the participants cannot be achieved, which complicates the analysis. This is because judokas range in weight between less than 60 kg in the lightest weight category to the heaviest category of more than 100 kg. Therefore, judokas differ not only in physique parameters such as height, body fat, and BMI but also in the movements and techniques most frequently used according to their category (3, 4).

Previous studies have indicated a prevalence of nsLBP in the range of 40%–60% for the general population and 30%–85% for athletes (32-34, 36, 39). Although the prevalence of nsLBP varies depending on the sport, it is commonly observed in all sports, including judo (40, 41). In judokas, LBP has been reported to occur in 62.4% of practitioners(41). Since such high incidences of LBP have been found among different types of athletes, it is very important that athletes and their coaches work toward prevention so that athletes can continue their sports activities.

In addition, due to the nature of judo as a martial art, judokas often experience back pain during hard practice sessions, which can reduce the quality of the practice. In addition, as LBP worsens, the need to interrupt the practice increases. It is crucial to preserve the high quality of the practice to improve athletic performance. Thus, even LBP that allows judokas to practice should not be overlooked. Moreover, no LBP study has included recent elite judokas.

1-4. Anatomical changes in the lumbar spine in judokas

Although the pathogenesis of nsLBP is extremely complicated, anatomical changes in the lumbar spine (i.e., lumbar radiological abnormalities (LRA) constitute a possible related factor (33, 42). LRA can be detected using plain film radiographs, CT, 99mTc-HMDP bone scans, and MRI. Plain film radiographs and MRI examinations are often used to identify LRA in athletes (33, 36, 43-45). It has been reported that 35%–57% of athletes have some type of LRA (46). In a previous study (47), analysis of plain film radiographs revealed that 33% of judokas suffer from spondylolysis. Min et al. reported that the prevalence of lumbar vertebral disc degeneration was 54% (41/48) by using MRI (48). Because there are no reports that use both plain film radiographs and MRI for the detection of LRA in judokas, there is a possibility of an even higher prevalence of abnormalities in judokas.

There is an obvious causal relationship between LRA and the causes of sLBP (37). However, the relationship between LRA and nsLBP remains unclear. While some authors have found a positive association between LRA and nsLBP (34, 39, 49-53), others have not (33, 37, 54, 55). Cannon and James (56) showed that 11% of athletes with nsLBP had LRA. In wrestlers, the prevalence of nsLBP in athletes with and without LRA was reported to be 40% and 44%, respectively, demonstrating no specific association between nsLBP and LRA (33). Previous studies have reported a high prevalence among individuals without nsLBP (general population: 32% (55), wrestlers: 70% (33) for LRA). To date, no study has examined the possible association between nsLBP and LRA in judokas.

In sedentary individuals as well as athletes, high body weight has been reported to be a risk factor for both nsLBP (42, 52, 57-61) and LRA (53, 57). In most cases, judo competitions are held in weight categories. There is a strong possibility that the stress on the lumbar region differs depending on the weight category of the judokas. However, the influence of body weight on the prevalence of nsLBP and LRA in judokas has not been previously examined.

Thus, the relationship between LRA and nsLBP remains unclear, but the relationship between the acute and chronic phases of LRA or the degree of LRA may differ. In the acute phase of LRA, back pain is expected to be severe, and its relationship with LBP is expected to be robust. Therefore, it may be necessary to separate the acute and chronic phases, but it is difficult to recruit suitable participants. Furthermore, the mechanism of occurrence may differ depending on the type of LRA, and it may be useful to examine each type of LRA separately.

1-5. Trunk muscle strength and low back pain in judokas

It has been shown that TMS is an essential element of judo. More importantly, it has been demonstrated that if TMS is weak in one area, imbalance may occur, and the risk of injury increases (10). The lumbar spine structure is unstable, and TMS is an important stabilizer. Moreover, external forces and body weight are loads on the lumbar region that require the support of TMS.

The weakness of TMS is a strong potential contributor to LBP (62-66), but the relationship between these two variables remains an unresolved issue. Previous studies in non-athletes confirmed that those with LBP had lower TMS (extensor, flexor, and/or rotator) than those without LBP (67-69), but other studies did not draw the same conclusion (33, 70). In collegiate wrestlers, low TMS of the extensor muscles has been found to be correlated with the functional disability level of LBP (33, 71). However, there are no studies regarding the relationship between LBP and TMS in judokas.

The load on the lumbar region varies depending on the weight category. Heavier weight judokas carry greater loads on the lumbar region. In other words, heavyweight judokas need higher TMS. However, relative TMS normalized by body weight should be lower in heavyweight judokas because of their large body weight. This suggests that the load on the lumbar region is expected to be greater in heavyweight judokas. To clarify this, it would be necessary to compare TMS and the prevalence of

LBP and LRA between weight categories. Furthermore, as mentioned above, since the risk factors for LBP are interrelated in a complex manner, TMS and LRA should not be considered independently but rather in an integrated fashion. In addition, such an investigation of the relationship between LBP and TMS is key from the viewpoint of injury prevention, since LBP is a frequent complaint among active athletes including judokas (15, 35).

1-6. Objectives

In judokas, while the trunk region is important for both athletic performance and medical problems, the characteristics of judo-specific trunk muscles and LBP are unclear. Based on this background, this doctoral dissertation aimed to enhance judokas' athletic performance by understanding their trunk muscles and low back injuries. Therefore, the objectives of this study comprised the following two themes.

1. To investigate the characteristics of the trunk muscles and their relationship with athletic performance in elite judokas according to weight categories.

Trunk muscles are crucial for judokas. However, their weight-category-dependent characteristics, associations with athletic performance, and detailed sports-specificities have not been clarified.

I conducted three subsequent studies to accomplish this objective as a functional aspect of the trunk region: 1) characterization of TMS in elite judokas by weight category (Chapter 2), 2) evaluation of the weight category-dependent association of TMS with athletic performance in elite judokas (Chapter 3), and 3) comparisons of the trunk muscles in elite judokas to those of wrestlers (Chapter

4).

2. To investigate the relationship between TMS and low back injuries; namely LBP and LRA, in elite judokas depending on weight categories.

LBP is a common symptom of low back injuries in judokas. Anatomical changes in the lumbar spine, weak TMS, and TMS imbalance are associated with LBP. However, the pathological mechanisms of LBP in judokas remain unclear. Moreover, analysis of these factors according to weight category has never been performed.

I conducted three subsequent studies to accomplish this objective as a medical aspect of the trunk region: 1) assessment of nsLBP and LRA as anatomical changes in the lumbar spine in elite judokas according to weight category (Chapter 5), 2) weight-category-dependent associations of TMS and LBP in elite judokas (Chapter 6), and 3) association of lower TMS with LBP in elite lightweight judokas according to LRA as anatomical changes in the lumbar spine (Chapter 7).

1-7. Significance of this thesis

This study contributes to the athletic performance of judokas. In Japan, judo is a national sport with many medals in the Olympics games. The athletic performance level of Japanese university judokas is exceptionally high, such that university-level judokas often win gold medals at the Olympics. Therefore, enhancing the athletic performance of Japanese university judokas is critical for their continued success in the Olympics games.

However, few studies have assessed the competitive performance of Japanese university-level judokas. More specifically, no study has reported on the trunk muscles, which are considered important in judo, including trunk rotational muscle strength. Understanding the characteristics of the trunk muscles is important to enhance the athletic performance of university-level judokas.

There is also a lack of studies on lower back injuries, which frequently occur among university-level judokas. However, many judokas with back injuries continue to practice, which can make it hard to improve their athletic performance owing to a lack of high-quality practice. Therefore, learning to prevent and improve low back injuries is essential so that judokas can practice hard to enhance their athletic performance. Therefore, this study is a vital topic for judokas.

1-8. Definition of Terms

Elite judokas

The elite judokas enrolled in this study belonged to a Japanese division I university judo club. This club includes judokas with excellent athletic performance such as international competition winners. The participants also had a long judo history of approximately 10 years; thus, they possessed the representative physical characteristics of elite judokas.

Lightweight, middleweight, and heavyweight categories

Judokas are categorized according to their body weight. In this study, the lightweight category refers to athletes up to 60 kg and 66 kg. The middleweight category includes athletes up to 73 kg and 81 kg. Finally, the heavyweight category refers to athletes up to 90 kg, 100 kg, and those over 100 kg. The Japanese athletes were classified based on their physical characteristics. Athletes weighing more than 90 kg have significant body fat (72).

TMS

In this study, TMS refers to the peak torques of trunk extension, flexion, left rotation, and right rotation obtained from an isokinetic dynamometer with some angular velocities. I utilized the absolute (N・m) and the relative (N・m/kg) values of TMS. The relative values are shown as TMS per body weight and were calculated from the absolute values of TMS normalized to body weight.

LBP

In this study, LBP was defined as the subjective pain from the lumbar region reported by the judokas. Pain was confirmed using a questionnaire that assessed LBP-related ADL.

Anatomical changes in the lumbar spine

This study detected anatomical changes in the lumbar spine by two orthopedic surgeons from plain film radiographs and magnetic resonance imaging (MRI). Anatomical changes in the lumbar spine were considered indicative of LRA.

Chapter 2. Characteristics of trunk muscle strength depending on weight category in elite judokas

2-1. Abstract

Purpose: TMS, especially rotator, is an important factor for both athletic performance and injury risks in judokas. However, the characteristics of TMS that depend on weight categories are still unclear. The present Chapter investigated weight category-dependent associations of TMS in elite judokas.

Methods: The subjects were 66 male collegiate judokas, who were classified into lightweight (n=14), middleweight (n=29) and heavyweight (n=23) category. The peak torques of extensor, flexor and rotator were measured.

Results: The absolute TMS in the heavier weight category showed higher in comparison with other categories. In the absolute TMS, not significant differences were observed in flexor (60, 90 and 120deg/s). On the contrary, the relative TMS (normalized by body weight) in the heavier weight category showed lower tendency than other categories, except for rotator strength. In the relative TMS, significant differences were observed in the extensor (90 and 120deg/s; $p<0.05$) and flexor (60, 90 and 120deg/s; $p<0.01$).

Conclusions: The absolute TMS of all directions was stronger in a heavier weight category than in a lighter weight category. The relative TMS of judokas decreased in heavyweight, except for rotations. It suggests that the rotator will become more vital for judokas.

2-2. Introduction

Judo is an intensive grappling martial art. It has been reported that TMS is an essential element and important for athletic performance of judokas (73). Movements involving trunk rotation are seen frequently in throwing and groundwork techniques. Also, judokas output their trunk rotator strength to keep their posture stable for defense against their opponent’s attack. However, there is no study investigating the trunk rotator strength in judokas.

Weight category-dependent movement specificity exists in judo (3). Judokas move differently based upon each weight category. Lighter weight judokas’ movements are faster (4) and more diverse. On the other hand, heavyweight judokas are the opposite. Thus, there is a strong possibility that judokas' TMS characteristics depend on their weight category. However, no study has ever investigated the relationships between weight categories and TMS in judokas. Judokas must know these characteristics of TMS depending on weight category to strengthen their performance.

Moreover, the body weight had a mechanical impact on the lumbar region in judokas. Therefore, the load on the trunk region would be different depending on each weight category. Further, heavyweight judokas have not only bodyweight but also body fat percentage. In other words, stronger

TMS is needed for heavyweight judokas. However, relative TMS normalized by body weight should be lower in heavyweight judokas because of their significant body weight and fat.

Thus, the present Chapter investigates variations in TMS (flexion, extension, and rotation) in judokas across different weight categories. This chapter hypothesized that judokas in the heavyweight category show higher absolute TMS but lower relative TMS normalized by body weight.

2-3. Methods

Participants

Approval was obtained from the university's ethics committee, and the study conformed with the tenets of the Declaration of Helsinki (74). All the subjects gave written informed consent before participating. I informed all the participants and their coaches of the purpose and potential risks of this study. The subjects were 66 male elite collegiate judokas (mean ±SD: age, 20.2 ± 0.9 years; height, 172.7 ± 6.3 cm; weight, 84.3 ± 17.3 kg). In this study, I classified judokas into three weight categories as follows; the lightweight category (under 60, 66kg, n=14), the middleweight category (under 73, 81kg, n=29), and the heavyweight category (under90, 100, over100kg, n=23) (Figure 2-1). The characteristics of the subjects are shown in Table 2-1. All the subjects participated in judo practice for a total of 3 hours a day, with sessions happening twice a day, 6 days a week.

Measurement of TMS

TMS was measured isokinetically using the Biodex System3 with the back attachment and torso rotation attachment (Biodex Medical Systems, Inc. Shirley, NY) (Figure 2-1 and 2-2). The peak torques of the trunk extensor, flexor, left-rotator, and right-rotator muscles were measured at angular velocities of 60, 90, and 120°/s. Additionally, I calculated the extensor/flexor ratio and the dominant/non-dominant rotator ratio. Two preliminary movements were performed before each measurement. Reciprocal movements such as extension-flexion and left rotation-right rotation were performed three times for each velocity being tested, and 60-second rest intervals were taken between each velocity being tested. For measuring extension-flexion cycle of the trunk, the participants were placed in a semi-standing posture with their knees flexed at 15°. To determine the trunk extension and flexion movement axes, I first identified L5-S1. I decided that the height of L5-S1 was 3.5 cm below the top of the iliac crest, and the extension and flexion movement axis was a horizontal line passing through the axillary midline on both sides at the height of L5-S1. The range of motion was set at 90°. Based on the instruction manual, full extension was set at 15° from the upright position. The chest, axillae, and dorsal surface of the sacrum were fixed with straps and pads. In the measurement of the left-right rotation cycle of the trunk, the participants were placed in a sitting posture with their feet free above the floor. Trunk left rotator and right rotator movements occurred along the vertical axis, which passed through the center of the cranial bone. The range of motion was set at 90°. I set the median trunk position to 0°. From this position, 45° was set on each side was set. The chest, axillae, bilateral surface of the pelvis, and thighs were fixed with straps and pads.

Statistical analyses

I compared with the parameters of TMS (N･m and N･m/kg) between three weight categories (Figure 2-1). A one-way analysis of variance (ANOVA) followed by a Bonferroni‐Dunn post-hoc test was used for statistical evaluation. The level of significance was set to 5%. All analyses were performed using IBM SPSS Statistics version 25 (IBM Corporation, Armonk, NY, USA). All experimental designs are shown in Figure 2-3

Table 2-1. Physical characteristics of 66 male collegiate judokas

	All subjects (n=66)	Lightweight (n=14)	Middleweight (n=29)	Heavyweight (n=23)
Age (years)	20.2±0.9	20.1±0.9	19.9±0.8	20.6±0.9
Height (cm)	172.7±6.3	166.7±4.6	172.9±5.3	176.2±5.7
Weight (kg)	84.3±17.3	66.0±4.3	78.6±4.8	102.6±15.5
BMI (kg/m^2)	28.1±4.7	23.7±1.0	26.4±2.0	33.0±4.3
Judo history (years)	10.9±3.0	10.6±3.3	10.4±2.8	11.7±3.1

Data are presented as mean ± SD.

Lightweight, under 60kg and 66kg judokas.

Middleweight, under 73kg and 81kg judokas.

Heavyweight, under 90kg, 100kg, and over 100kg judokas.

Figure 2-1. Measurement of extension and flexion trunk muscle strength.

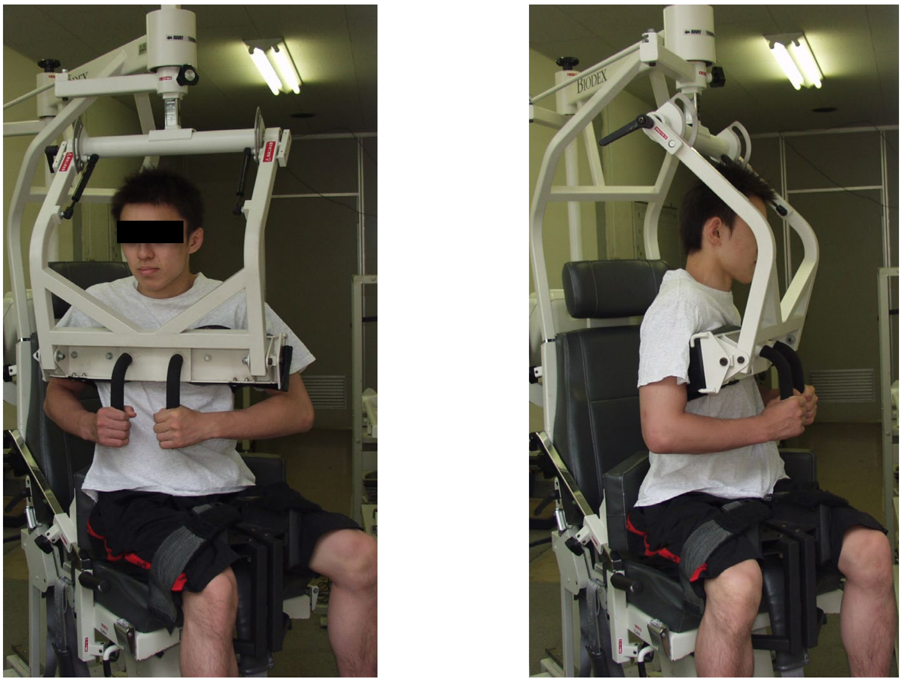


Figure 2-2. Measurement of rotation trunk muscle strength.

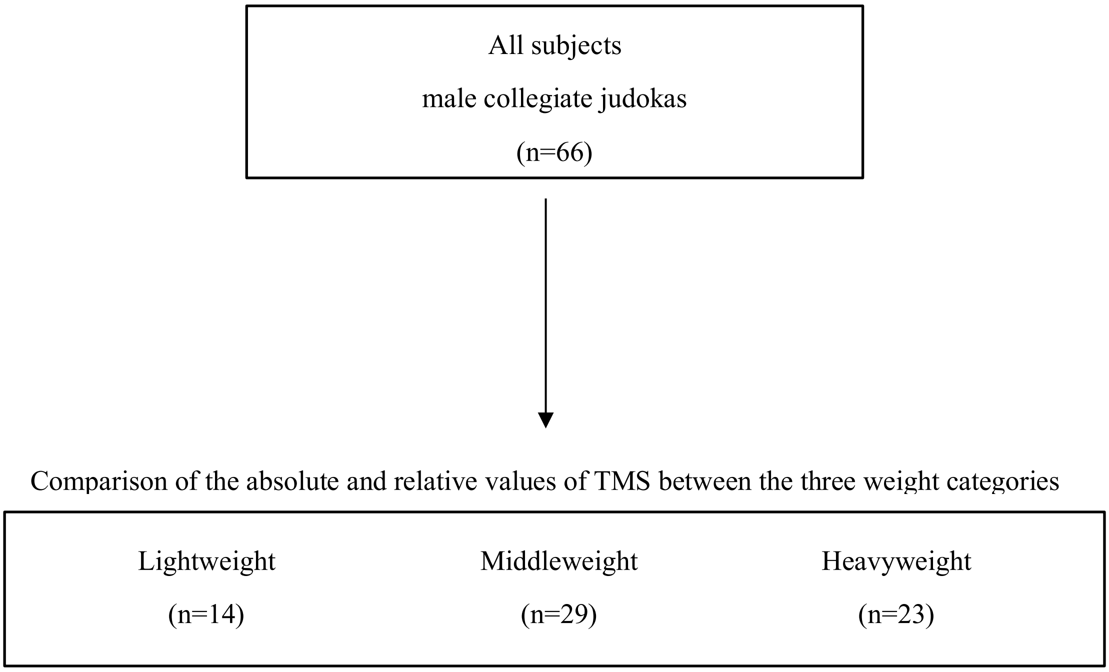


Figure 2-3. Classification of participants.

2-4. Results

Comparison of the physical characteristics among different weight categories

I first compared physical characteristics among different weight categories (Table 2-1). There were significant differences in height, weight, and BMI, as expected. The heavyweight category showed significant higher values than those of lighter weight categories.

Comparison of TMS among different weight categories

This chapter has hypothesized that high absolute TMS would be observed in heavyweight judokas. The comparison of absolute TMS and its ratios among different weight categories was shown in Table 2-2 and 2-3. As expected, absolute values of TMS were significantly higher in the heavyweight category than in the lighter weight categories. Significances were all angular velocities of extensor, and both sides of rotators, except for flexor in middleweight vs heavyweight. The absolute values of TMS ratios were not significantly different. P values are shown in Table 4.

The comparison of relative TMS among different weight categories was shown in Table 2-5. Relative values of TMS were significantly lower in the heavyweight category than in lighter weight categories. Significances were 60°/s of flexor in middleweight vs heavyweight ($p<0.005$), 90°/s of extensor in lightweight vs middleweight ($p<0.05$), 90°/s of flexor in middleweight vs heavyweight ($p<0.01$), and 120°/s of extensor in lightweight vs heavyweight ($p<0.05$). In the rotators, there was no significance. P values are shown in Table 2-6.

Table 2-2. Comparison of absolute peak torques of trunk muscles among weight categories.

Variables	Lightweight (n=14)	Middleweight (n=29)	Heavyweight (n=23)
Extensor (N･m)			
60°/s	447.4±106.3	508.8±75.6	609.5±92.7
90°/s	439.3±83.1	496.5±58.7	597.8±95.8
120°/s	421.9±81.6	481.2±68.9	575.8±107.4
Flexor (N･m)			
60°/s	215.9±57.3	270.2±47.8	290.7±75.4
90°/s	199.5±48.6	252.0±41.1	277.3±68.5
120°/s	182.9±48.0	226.6±36.4	239.9±55.2
Dominant side rotator (N･m)			
60°/s	159.8±21.4	190.2±22.1	237.0±36.7
90°/s	155.9±22.2	178.6±20.4	223.9±34.5
120°/s	147.8±22.8	175.8±19.8	217.8±30.8
Non-Dominant side rotator (N･m)			
60°/s	147.0±19.0	175.1±21.0	212.7±33.1
90°/s	143.8±20.2	168.6±22.0	206.6±30.5
120°/s	140.5±18.9	164.5±18.3	197.9±28.4

Data are presented as mean ± SD.

The absolute values of TMS were significantly higher in the heavier weight category than those in lighter weight categories by one-way ANOVA followed by Bonferroni–Dunn post-hoc test. P values are shown in Table 4.

Table 2-3. Comparison of peak torques ratios of trunk muscles among weight categories.

Variables	Lightweight (n=14)	Middleweight (n=29)	Heavyweight (n=23)
Extensor/ Flexor ratio			
60°/s	2.16±0.59	1.93±0.43	2.18±0.45
90°/s	2.32±0.70	2.02±0.43	2.26±0.57
120°/s	2.44±0.74	2.17±0.43	2.47±0.56
Dominant/non-dominant rotator ratio			
60°/s	1.09±0.07	1.09±0.07	1.12±0.07
90°/s	1.08±0.05	1.06±0.06	1.08±0.05
120°/s	1.05±0.07	1.07±0.06	1.10±0.07

Data are presented as mean ± SD.

The absolute values of TMS ratios were not significantly different by one-way ANOVA.

Table 2-4. P values of the comparison of absolute peak torques among weight categories.

Variables	Lightweight (n=14) VS Middleweight (n=29)	Lightweight (n=14) VS Heavyweight (n=23)	Middleweight (n=29) VS Heavyweight (n=23)
Extensor			
60°/s	0.112	0.000	0.000
90°/s	0.086	0.000	0.000
120°/s	0.119	0.000	0.001
Flexor			
60°/s	0.023	0.002	0.694
90°/s	0.011	0.000	0.289
120°/s	0.015	0.002	0.917
Dominant side rotator			
60°/s	0.004	0.000	0.000
90°/s	0.032	0.000	0.000
120°/s	0.003	0.000	0.000
Non-Dominant side rotator			
60°/s	0.004	0.000	0.000
90°/s	0.010	0.000	0.000
120°/s	0.005	0.000	0.000

Data are presented p values calculated by one-way ANOVA followed by Bonferroni–Dunn post-hoc test.

There were significant differences excepted the extensor of lightweight VS middleweight and the flexor of middleweight VS heavyweight. Moreover, all rotators showed a significant difference.

Table 2-5. Comparison of peak torques of trunk muscles normalized by body weight as relative TMS among weight categories.

Variables	Lightweight (n=14)	Middleweight (n=29)	Heavyweight (n=23)
Extensor (N・m)			
60°/s	6.7±1.3	6.5±1.0	6.0±0.7
90°/s	6.6±1.0*	6.3±0.8	5.8±0.7*
120°/s	6.4±1.0*	6.1±0.8	5.6±0.8*
Flexor (N・m)			
60°/s	3.3±0.7	3.4±0.6††	2.8±0.5††
90°/s	3.0±0.7	3.2±0.5††	2.7±0.6††
120°/s	2.8±0.7	2.9±0.4††	2.4±0.5††
Dominant side rotator (N・m)			
60°/s	2.42±0.25	2.42±0.28	2.32±0.27
90°/s	2.35±0.22	2.28±0.26	2.20±0.30
120°/s	2.23±0.23	2.24±0.25	2.14±0.23
Non-Dominant side rotator (N・m)			
60°/s	2.22±0.20	2.23±0.26	2.08±0.24
90°/s	2.17±0.20	2.15±0.27	2.03±0.24
120°/s	2.12±0.20	2.09±0.22	1.94±0.24

Data are presented as mean ± SD.

The relative values of TMS were significantly higher in the heavyweight category than those in lighter weight categories by one-way ANOVA followed by Bonferroni–Dunn post-hoc test. However, all rotators did not show a significant difference. P values are shown in Table 6.

*: The lightweight vs. the heavyweight is statistically different ($p<0.05$).

††: The middleweight vs. the heavyweight is statistically different ($p<0.01$).

Table 2-6. P values of the comparison of relative peak torques among weight categories.

Variables	Lightweight (n=14) VS Middleweight (n=29)	Lightweight (n=14) VS Heavyweight (n=23)	Middleweight (n=29) VS Heavyweight (n=23)
Extensor			
60°/s	1.000	0.073	0.195
90°/s	0.716	0.014	0.098
120°/s	1.000	0.035	0.115
Flexor			
60°/s	1.000	0.133	0.002
90°/s	0.978	0.326	0.008
120°/s	1.000	0.058	0.001
Dominant side rotator			
60°/s	1.000	0.944	0.544
90°/s	1.000	0.284	0.951
120°/s	1.000	0.768	0.392
Non-Dominant side rotator			
60°/s	1.000	0.280	0.107
90°/s	1.000	0.256	0.256
120°/s	1.000	0.066	0.061

Data are presented p values calculated by one-way ANOVA followed by Bonferroni–Dunn post-hoc test.

There were significant differences, extensor of lightweight VS middleweight and the flexor of middleweight VS heavyweight. Also, all rotators did not show a significant difference.

2-5. Discussions

The present Chapter is the first trial to evaluate the relationship between judokas' TMS including rotator strength. This chapter hypothesized that judokas with heavier bodyweight possess higher absolute TMS but lower relative TMS. As expected, the absolute TMS of all directions showed higher values for those in a heavier weight category than those in a lighter eight category. On the contrary, the relative extensor and flexor TMS showed lower values for those in a heavier weight category than those in a lighter weight category. However, the relative rotator TMS of the heavier weight category was not weaker than that of a lighter eight category.

The characteristics of weight-dependent TMS have not been previously reported. This chapter found higher absolute TMS in the heavyweight category compared to those in the other two weight categories. TMS of all directions were stronger in a heavier weight category than those in a lighter eight category. On the other hand, this chapter found that the relative TMS in the heavyweight category was lower in the extensor and flexor muscles. It was reported during a judokas' handgrip strength test that those in a heavier weight category had a lower relative muscle strength than those in a lighter category (75), suggesting that relative muscular strength is low in heavyweight judokas. I now suspect that this is because their body weight may be too heavy for their TMS.

To my knowledge, this is the first study to investigate rotator TMS in elite judokas. In the first trial, this chapter found that relative rotator TMS of the heavyweight category was not significantly different from that of the other two categories. However, the tendency is clearly different with extensor and flexor TMS strength. These results that only rotators were not weaker in a heavier weight category than those in a lighter eight category. Heavyweight judokas have enough rotator strength for their significant bodyweight like other lighter-weight judokas. As mentioned in the introduction, the rotator strength of TMS is important in judo techniques (76). Moreover, I will mention Chapter 4, judokas had thicker trunk rotator muscles than those of wrestlers who have similar sports specificity (22). Since high rotator TMS strength is demanded for judokas, relative rotator strength is independent of weight categories. The results also suggested that rotator strength should be evaluated and enhanced in judokas.

In ratios of TMS, there was no significant difference inter weight categories. Even the dominant/non-dominant rotator ratios were not different inter weight categories. It would suggest that the development rate of each trunk muscle has the same tendency in all weight categories. Judokas would need appropriate trunk muscles development to be an elite competitor regardless of weight category.

There are some limitations in this chapter. One of the most important points is a small sample size. Although total of 66 judokas are relatively small sample size, most of all participants in this chapter practiced judo for more than 10 years. Thus, the cohort of this chapter accurately represents the characteristics of judokas. In addition, the TMS measurement of rotation is horizontal plane movement; hence judokas were less likely to load their upper bodyweight during its measurement. It is the difference from the TMS measurement of extension and flexion, which are likely loaded their body weight in sagittal plane movement. However, these situations are similar conditions in actual judo situations. So, these measurements will have evident meaning for the investigation of judokas' TMS.

2-6. Conclusions

The present Chapter examined the characteristics of TMS including rotators in judokas across the weight categories. The absolute TMS of all directions, including rotations, was higher in the heavier weight category than other weight categories. On the contrary, the relative extensor and flexor TMS showed lower values for those in a heavier weight category than those in a lighter weight category. However, the relative TMS of rotators were not significantly different. The present Chapter concluded that weight categories characterize the TMS of judokas. Heavier weight judokas had stronger absolute TMS of all directions and weaker relative TMS, not rotators but extensors and flexors than lighter weight judokas. It suggests that the rotator will become more vital for judokas.

Chapter 3. Weight category-dependent association of trunk muscle strength with athletic performance in elite judokas

3-1. Abstract

Purpose: The purpose of this chapter was to examine the relationship between athletic performance level and trunk muscle strength (TMS) in elite collegiate judokas.

Methods: Fifty-four elite collegiate judokas were divided into two groups based on their athletic performance (excellent athletic performance: EAP (N=27); lower athletic performance compared to EAP: LAP, (N=27)). This Chapter also divided the participants into three weight categories (<60, <66 kg: lightweight (N=15), <73, <81 kg: middleweight (N=17), and <90, <100, and >100 kg: heavyweight (N=22)). I measured the isokinetic peak torque of the trunk extensors, flexors, and rotators. The participants performed movements twice, at angular velocities of 60°/s and 180°/s.

Results: Judokas in the EAP group showed a higher TMS than those in the LAP group. Among all participants, significant differences were observed in the TMS values for extensor, flexor, dominant rotator, and non-dominant rotator movements. Among those in the middle weight category, significant differences (180°/s) were observed in the absolute and TMS per body weight values for extensor

movements ($p<0.01$), along with the extensor/flexor ratio ($p<0.05$). In the heavyweight category, significant differences (60°/s: $p<0.05$) were observed in the TMS for dominant and non-dominant rotator movements. However, no significant TMS differences were observed in the lightweight category.

Conclusions: The present Chapter concluded that TMS is associated with athletic performance in elite judokas, except in lightweight judokas. Development of TMS for trunk extension and rotation movements is essential for middleweight and heavyweight judokas, respectively.

3-2. Introduction

Chapter 2 confirmed the weight category-dependent TMS characteristics. Mainly, rotational TMS depending on weight category of elite judokas was revealed for the first time. Japanese collegiate judokas usually have high-level athletic performance. There even exist Olympic champions among them. Thus, it is precious evidence concerning judo athletic performance. However, Chapter 2 did not investigate the relationship between TMS and athletic performance directly, which is one of the primary purposes of this doctoral dissertation.

Judokas are divided into seven weight categories for men in the competition. The difference in sports specificity exists between each weight category (21). Specific movements and techniques are associated with each weight category (3). Lighter-weight judokas perform a large amount of rapid and flexible movements. Moreover, lighter-weight judokas grasp the opponent's “judo-gi” jacket quickly and attempt to throw and defeat the opponent within a short period. In contrast, heavier-weight judokas grasp each other tightly and statically apply strong force (4).

Muscle strength is essential for judokas. Trunk muscle strength (TMS), which is frequently used in all judo situations, is critical. In judo, TMS has also been reported to be essential for athletic performance (10, 77). However, few studies have been conducted regarding the relationship between athletic performance and TMS in judo, and controversial results exist as follows. A previous study (21) described that international-level judokas with EAP have a higher trunk extension strength compared to that of national-level judokas with a LAP. In contrast, the study described that EAP-judokas did not have a higher TMS than LAP-judokas (22).

Trunk rotation and lateral flexion have been reported to be essential for judokas (23, 24, 78). Techniques involving trunk rotation and accentuated hip and knee flexion (e.g., “Seoi-nage”) are more physically demanding than frontal attacks (26). The trunk rotation movement is dynamically and statically critical, particularly the peak isokinetic torque of the trunk rotation, which is associated with dynamic pulling during the pulling motion with change position (27). Moreover, judokas must output their rotational TMS statically to maintain a stable posture for a dominant situation and defense.

In previous studies on TMS, senior judokas showed higher hip extension and trunk flexion isometric strength than junior and cadet judokas (28). However, no relationship between TMS and athletic performance was found within the groups in this study (28). Another study involving judokas found that the cross-sectional areas of the left and right lumbar multifidus muscles are asymmetric (29). However, despite the asymmetry found in the trunks of judokas, few studies have investigated athletic performance while including the trunk rotators (79, 80).

Currently, judo is practiced globally. Recently, several fighting techniques originating from ethnic martial arts from some nations, such as Mongolia, Central Asia, Georgia, Russia, Brazil, and others, are seen international competitions. These techniques, especially close combat techniques, are likely to be determinant factors for matches. In a close combat situation, a judoka fights against an opponent such that the judoka's trunk remains close to the opponent's trunk, to help grasp the opponent's back under or over the shoulder. Subsequently, the judoka tries to lift the opponent and throw them backward using trunk extension and rotation movements; this is called the Ura-nage. In these situations, TMS is critical. Therefore, trunk rotation has become more important in recent judo competitions.

Therefore, the present Chapter aimed to investigate the relationship between athletic performance and TMS, including rotators, based on the weight categories, in elite judokas. I hypothesized that judokas with EAP possess higher TMS, in terms of both absolute and relative values, and each weight category has different TMS characteristics.

3-3. Methods

Participants

Approval was obtained from the university's ethics committee, and the study conformed with the tenets of the Declaration of Helsinki (74). All participants provided written informed consent before participating in the study. In addition, I informed all participants and their coaches of the purpose and potential risks of this study. Herein, 54 male collegiate judokas were classified into two athletic performance groups based on their performance in a national-level collegiate judo championship: the EAP group (n=27) and LAP group (n=27) (Figure 3-1). Moreover, I classified judokas into three weight categories as follows: lightweight (under 60, 66 kg; n=15), middle weight (under 73, 81 kg; n=17), and heavyweight (under 90, 100, over 100 kg; n=22). The characteristics of the participants are presented in Tables 3-1 and 3-2. All participants practiced judo for 3 hours daily; sessions occurred twice a day for six days a week.

Measurement of TMS

TMS was measured isokinetically using the Biodex System3 with the back attachment and torso rotation attachment (Biodex Medical Systems, Inc. Shirley, NY). The peak torques of the trunk extensor, flexor, left-rotator, and right-rotator muscles were measured at angular velocities of 60 and 180°/s. Additionally, I calculated the extensor/flexor ratio and the dominant/non-dominant rotator ratio. Two preliminary movements were performed before each measurement. Reciprocal movements such as extension-flexion and left rotation-right rotation were performed three times for each velocity being tested, and 60-second rest intervals were taken between each velocity being tested. For measuring extension-flexion cycle of the trunk, the participants were placed in a semi-standing posture with their knees flexed at 15°. To determine the trunk extension and flexion movement axes, I first identified L5-S1. I decided that the height of L5-S1 was 3.5 cm below the top of the iliac crest, and the extension and flexion movement axis was a horizontal line passing through the axillary midline on both sides at the height of L5-S1. The range of motion was set at 90°. Based on the instruction manual, full extension was set at 15° from the upright position. The chest, axillae, and dorsal surface of the sacrum were fixed with straps and pads. In the measurement of the left-right rotation cycle of the trunk, the participants were placed in a sitting posture with their feet free above the floor. Trunk left rotator and right rotator movements occurred along the vertical axis, which passed through the center of the cranial bone. The range of motion was set at 90°. I set the median trunk position to 0°. From this position, 45°

was set on each side was set. The chest, axillae, bilateral surface of the pelvis, and thighs were fixed with straps and pads.

Statistics analyses

I compared the absolute values of TMS (N・m) and TMS normalized by body weight as the relative values of TMS (N・m/kg) between the EAP and LAP groups and for each weight category. Unpaired Student's t-test was used for statistical evaluation. The level of significance was set to 5%. All analyses were performed using IBM SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, N.Y., USA). All classification of participants and experimental designs are shown in Figure 3-1.

Table 3-1. Physical characteristics of 54 male elite collegiate judokas classified with two athletic performances

	Excellent athletic performance group (n=27)	Lower athletic performance group (n=27)
Age (years)	20.5±1.0	20.1±0.8
Height (cm)	175.0±5.7*	170.7±6.9
Weight (kg)	91.2±19.8*	79.6±14.4
BMI (kg/m^2)	29.6±5.0	27.3±4.4

Data are presented as mean ± SD.

Height and Weight were significantly higher in the excellent athletic performance group than those in the lower athletic performance group.

*: Statistically different by unpaired Student's t-test ($p<0.05$).

Table 3-2. Physical characteristics of 54 male elite collegiate judokas categorized with three weight categories

	Lightweight		Middleweight		Heavyweight	
	EAP (n=5)	LAP (n=10)	EAP (n=8)	LAP (n=9)	EAP (n=14)	LAP (n=8)
Age (years)	20.6±0.9	20.1±0.9	21.3±0.7	20.0±0.9	20.1±0.9	20.1±0.6
Height (cm)	167.0±2.6	166.4±5.7	174.4±2.8	173.2±6.4	178.1±4.7	173.3±7.0
Weight (kg)	68.2±1.4	65.5±5.4	80.8±2.7	79.4±4.3	105.4±17.2	97.4±8.3
BMI (kg/m^2)	24.5±0.4	23.7±1.3	26.6±0.7	26.5±1.5	33.1±4.6	32.6±3.8

Data are presented as mean ± SD.

Lightweight, under 60kg and 66kg judokas.

Middleweight, under 73kg and 81kg judokas.

Heavyweight, under 90kg, 100kg, and over 100kg judokas.

EAP, excellent athletic performance.

LAP, lower athletic performance compared to EAP.

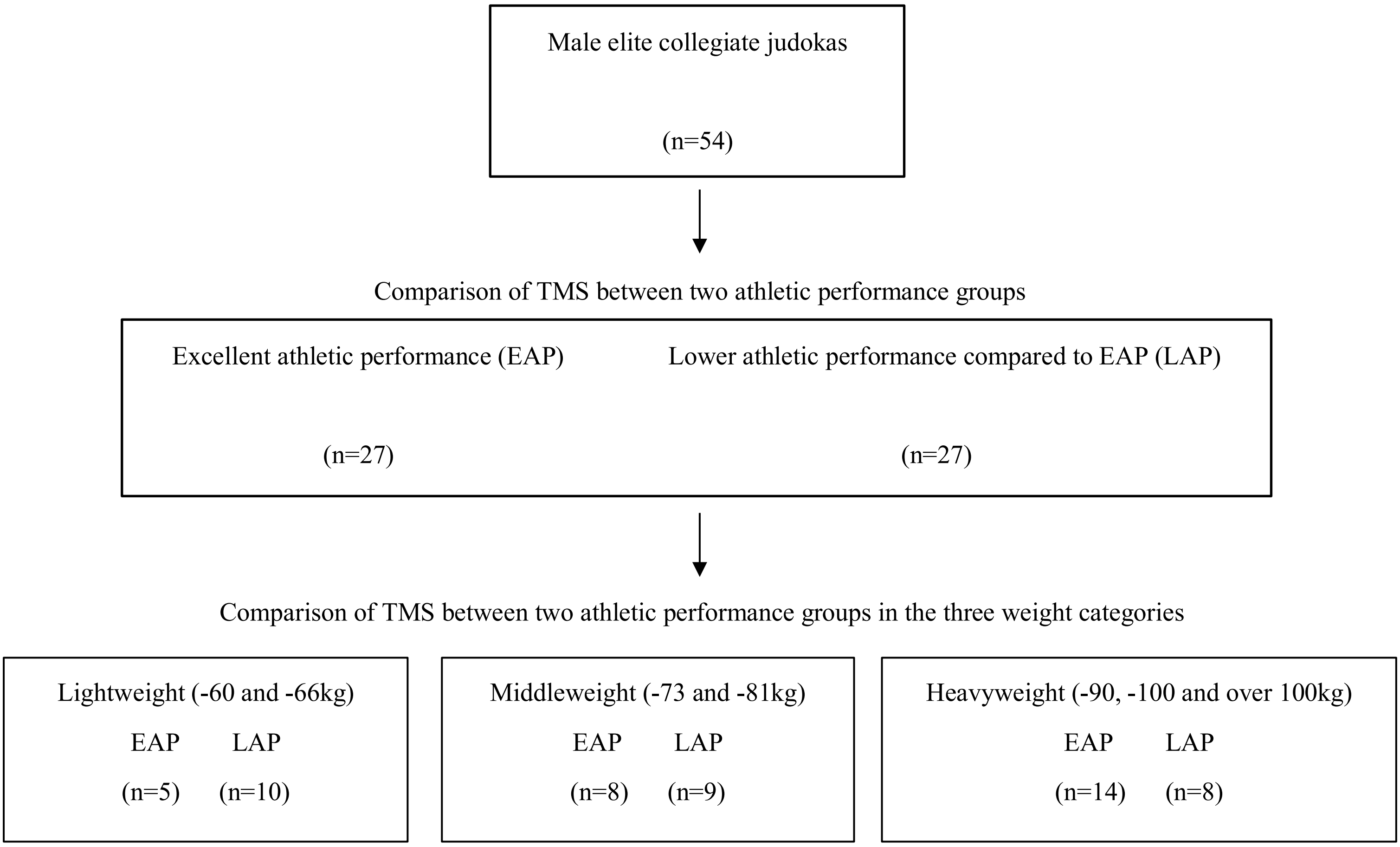


Figure 3-1. Classification of participants and experimental designs

3-4. Results

Comparison of TMS between athletic performances

A comparison of TMS between the different athletic performance groups is shown in Table 3-3. The absolute values of TMS were significantly higher in the EAP group than in the LAP group.

Significant between-group differences were found in the extensor (180°/s: p=0.019), flexor (180°/s:pP=0.038), dominant rotator (60°/s: p=0.001, and 180°/s: p=0.048), and non-dominant rotator (60°/s: p=0.000, and 180°/s: p=0.036). Unexpectedly, no significant differences were observed in the relative values of TMS, i.e., TMS per body weight.

Comparison of TMS between athletic performances with regard to weight category

The comparison of TMS among different athletic performances in the same weight category is presented in Tables 3-4. TMS was observed to be significantly higher in the EAP group than in the LAP group.

Comparison of the middle weight and heavyweight categories revealed a similar tendency to that of the comparison of TMS values of all the participants by athletic performance. In the middleweight category, significant differences were observed in the absolute value (180°/s: p=0.002) and TMS per body weight value (180°/s: $p=0.002$) for extensor movements, along with the extensor/flexor rotator (60°/s: $p=0.038$). In the heavyweight category, significant differences were observed in the dominant rotator (60°/s: $p=0.038$), and non-dominant rotator (60°/s: $p=0.02$) movements. However, no significant difference in TMS was observed in the lightweight category.

Table 3-3. Comparison of peak torques of trunk muscles among athletic performances in all participants. Values inside the parentheses shown relative TMS normalized by body weight.

Variables	Excellent athletic performance group (n=27)	Lower athletic performance group (n=27)
Extensor (N・m) (N・m/kg)		
60°/s	550.0±108.1 (6.02±0.77)	500.3±81.6 (6.34±0.81)
180°/s	489.9±129.1* (5.36±1.21)	414.3±74.7 (5.27±0.91)
Flexor (N・m) (N・m/kg)		
60°/s	264.0±73.9 (2.87±0.53)	234.8±61.8 (2.96±0.64)
180°/s	224.1±58.7* (2.44±0.44)	192.7±40.2 (2.46±0.54)
Dominant side rotator (N・m) (N・m/kg)		
60°/s	159.3±26.6** (2.08±0.27)	187.0±29.3 (2.02±0.28)
180°/s	145.5±28.1* (1.62±0.31)	130.3±26.0 (1.65±0.27)
Non-Dominant side rotator (N・m) (N・m/kg)		
60°/s	172.2±23.5*** (1.92±0.28)	145.8±25.6 (1.85±0.27)
180°/s	133.7±26.5* (1.49±0.29)	118.1±25.6 (1.49±0.26)
Extensor/Flexor ratio		
60°/s	2.16±0.42	2.25±0.56
180°/s	2.23±0.53	2.22±0.52

Dominant/non-dominant rotator ratio		
60°/s	1.09±0.08	1.10±0.06
180°/s	1.09±0.05	1.11±0.08

Data are presented as mean ± SD.

TMS, trunk muscle strength.

TMS were significantly higher in the excellent athletic performance group than those in the lower athletic performance group.

*: Statistically different by unpaired Student's t-test ($p<0.05$).

**: Statistically different by unpaired Student's t-test ($p<0.01$).

***: Statistically different by unpaired Student's t-test ($p<0.001$).

Table 3-4. Comparison of peak torques of trunk muscles among athletic performances in each weight categories. Values inside the parentheses shown relative TMS normalized by body weight.

Variables	Lightweight		Middleweight		Heavyweight	
	EAP (n=5)	LAP (n=10)	EAP (n=8)	LAP (n=9)	EAP (n=14)	LAP (n=8)
Extensor (N・m) (N・m/kg)						
60°/s	409.8±32.8 (6.00±0.37)	439.8±54.9 (6.72±0.66)	538.4±71.0 (6.64±0.81)	517.9±79.6 (6.47±0.90)	598.5±99.5 (5.75±0.71)	558.4±64.4 (5.74±0.58)
180°/s	327.2±63.1 (4.79±0.89)	379.9±68.2 (5.78±0.72)	552.7±46.8** (6.82±0.48**)	426.7±65.2** (5.34±0.80**)	511.0±131.7 (4.87±0.97)	444.7±82.4 (4.58±0.86)
Flexor (N・m) (N・m/kg)						
60°/s	204.5±57.0 (2.99±0.79)	188.6±43.2 (2.87±0.59)	237.7±35.5 (2.93±0.35)	263.8±54.7 (3.30±0.64)	294.4±78.5 (2.80±0.54)	263.5±57.3 (2.72±0.65)
180°/s	149.3±19.6 (2.18±0.25)	171.5±28.3 (2.64±0.52)	209.6±39.7 (2.58±0.42)	202.6±37.4 (2.53±0.44)	253.7±51.3 (2.45±0.48)	209.3±47.7 (2.18±0.61)
Dominant side rotator (N・m) (N・m/kg)						
60°/s	150.2±8.7 (2.20±0.11)	137.5±19.9 (2.09±0.16)	184.7±15.5 (2.28±0.19)	169.3±23.3 (2.12±0.31)	201.2±27.9* (1.93±0.25)	176.4±18.8* (1.83±0.32)
180°/s	119.7±14.1 (1.76±0.23)	111.8±19.9 (1.70±0.24)	144.4±23.9 (1.78±0.29)	136.2±23.4 (1.70±0.26)	155.3±28.9 (1.50±0.29)	147.5±22.1 (1.53±0.31)
Non-Dominant side rotator (N・m) (N・m/kg)						
60°/s	143.3±11.4 (2.10±0.14)	125.0±20.1 (1.90±0.21)	168.3±16.0 (2.08±0.22)	155.4±20.4 (1.94±0.25)	184.5±20.2* (1.78±0.27)	162.2±19.3* (1.68±0.29)
180°/s	111.5±13.9 (1.64±0.22)	97.9±18.1 (1.49±0.25)	132.3±25.1 (1.63±0.31)	124.4±22.6 (1.55±0.26)	142.3±27.0 (1.37±0.26)	137.0±19.4 (1.42±0.28)
Extensor/Flexor ratio						
60°/s	2.10±0.45	2.45±0.62	2.28±0.24	2.01±0.42	2.12±0.48	2.23±0.58
180°/s	2.15±0.24	2.25±0.45	2.72±0.44*	2.16±0.47*	2.04±0.51	2.24±0.69
Dominant/non-dominant rotator ratio						

60°/s	1.05±0.05	1.11±0.07	1.10±0.09	1.09±0.06	1.09±0.09	1.09±0.06
180°/s	1.08±0.04	1.15±0.10	1.10±0.06	1.10±0.06	1.09±0.04	1.08±0.03

Data are presented as mean ± SD.

TMS, trunk muscle strength.

Lightweight, under 60kg and 66kg judokas.

Middleweight, under 73kg and 81kg judokas.

Heavyweight, under 90kg, 100kg, and over 100kg judokas.

EAP, excellent athletic performance.

LAP, lower athletic performance compared to EAP.

TMS were significantly higher in the EAP than those in the LAP in the same weight category.

*: Statistically different by unpaired Student's t-test ($p<0.05$).

**: Statistically different by unpaired Student's t-test ($p<0.01$).

3-5. Discussion

This Chapter the first to evaluate the association of the TMS in Japanese elite judokas with athletic performance and weight categories, including trunk rotator strength evaluation. I hypothesized that judokas with an EAP may possess a higher TMS, in terms of both absolute and relative values, than that of judokas with LAP. However, this Chapter observed that the relative TMS values were not significantly different among the participants. Judokas with EAP were observed to have higher absolute TMS values, in all directions, compared to those of judokas with LAP. High-speed extension and flexion and high-and low-speed rotations were significantly stronger in the EAP group than in the LAP group. In middle weight judokas with EAP, the TMS in the extension with high speed movement was particularly high. Moreover, the TMS in both-sided rotations at low speed was highest among heavyweight judokas with EAP. However, in the lightweight category, no significant differences were observed in the absolute and relative TMS.

Trunk rotation strength has been considered essential for judo, including for dynamic techniques, such as those involving throwing and groundwork with trunk rotation, and for static techniques, such as those involving grasping their opponent’s judo-gi, to create dominant situations and defend themselves from the opponent’s' attacks (23, 24, 78). However, the importance of trunk rotation strength has remained unelucidated, particularly in terms of the dynamic trunk muscle characteristics of elite judokas. Therefore, in the present study, I confirmed the relationship between the dynamic TMS of elite judoka men and their athletic performance.

The EAP-judokas possessed a higher absolute TMS than the LAP-judokas. The TMS was high during high-speed extension and flexion movements; however, it was also high while performing both low- and high-speed rotation movements, suggesting that trunk rotation is essential for more movements than just those comprising extension and flexion. In contrast, the relative values of TMS did not differ significantly between EAP judokas and LAP judokas. The EAP judokas were taller and weighed more than the LAP judokas. These physical characteristics might have caused the aforementioned differences in the absolute TMS. Therefore, the relative value of TMS, calculated by dividing muscular strength by body weight, is crucial for athletic performance measurements. However, judo training does not take body weight into consideration; therefore, EAP judokas, whose body size is larger and TMS is higher than those of the LAP judokas, perform the same training for judo competitions as LAP judokas, without weight reduction (81). This suggests that EAP judokas are at an advantage during judo training, which might be associated with the athletic performance. Thus, I believe that it was essential to compare the absolute values of TMS. It was also essential to compare

TMS in each weight category because judokas compete for judo competitions based on their weight categories.

In lightweight judokas, no significant differences were observed between the relative and absolute TMS values. Lightweight judokas cannot afford to put on body fat, because their body weight needs to maintain at a low level. Thus, their body fat levels were deficient compared to those of judokas in higher weight categories. I hypothesized that even if there was no significant difference in absolute values of TMS, the relative TMS values are significantly difference between EAP- and LAP-judokas. However, the relative and absolute values were not significantly different between the two groups, indicating that it is difficult to compete under the lightweight category if the judokas' TMS does not reach the upper limit of the absolute values. Accordingly, the relative values that this Chapter observed had reached their upper limits. Therefore, lightweight judokas practice judo depending on factors other than TMS, including a variety of judo techniques, rapid reactions to the opponent's movement, etc. The athletic performance characteristics of lightweight judokas comprise more rapid, flexible, and unexpected movements compared to that of judokas in heavier weight categories (3, 4). There is seldom a situation in which force is applied using slow movements, and lightweight judokas decide on a match with complicated techniques. Therefore, it is necessary to examine flexibility, rapid reaction time, and others rather than the TMS to make the relationship between lightweight judokas' trunk function and their athletic performance more apparent.

In middle weight judokas, the absolute and relative TMS values for high-speed extension and flexion movements were significantly higher in the EAP group than in the LAP group. In particular, only in the middle weight category, the relative TMS, which was measured by dividing peak torque by body weight, was significantly stronger in the EAP group than in the LAP group. Relative TMS should be measured in middle weight judokas because they cannot afford to put on body fat to maintain an appropriate body weight for their weight category. The absolute TMS value also needs to be measured for these judokas because in some situations, middle weight judokas need to maintain the application of strong force, similar to the techniques used by heavyweight judokas. Thus, the middleweight category requires measurement of both the relative and absolute values of TMS. Among heavyweight judokas, significant differences were observed in the TMS during low-speed rotation movements between the EAP and LAP groups. This is the main difference in TMS characteristics between the middle and heavyweight categories. In the middleweight category, the extension/flexion ratio in EAP-judokas was significantly higher than that of LAP-judokas. Therefore, TMS being higher during trunk extension than during flexion is characteristic of middle weight judokas with EAP. This suggests that it is crucial to selectively strengthen the trunk extensors in middleweight judokas. This consideration can be applied to other body parts in a limited weight situation.

In heavyweight judokas, the TMS in those with EAP was significantly higher than that in those with LAP. Significant differences were observed only in the absolute TMS values of low-speed and side-rotation movements; this finding was different from that of the TMS in the middleweight category, which was significantly different for the EAP and LAP groups. In general, trunk rotation is essential for dynamic trunk rotational movements such as the Seoi-nage (77). However, in the present study, the trunk rotational strength did not differ among lightweight judokas who attempt the Seoi-nage frequently, while it differed significantly among heavyweight judokas who do not attempt the Seoi-nage frequently. This may be because heavyweight judokas frequently use trunk rotational movement by utilizing their body weight to throw an opponent, rather than to perform the Seoi-nage. It is also expected that the heavyweight category requires more groundwork actions (82) and consequently, a higher TMS related to groundwork actions than for the other categories of actions. This weight category-dependent athletic movement specificity causes the significant differences in trunk rotational strength in lighter-weight judokas and heavyweight judokas. Moreover, there were significant differences in the absolute value of TMS among those in the heavyweight category, indicating that trunk rotational strength per body weight must be improved to enhance athletic performance in heavyweight judokas. In the present study, I obtained different results for TMS depending on the athletic performance level for each weight category. These tendencies may be influenced by the movement specificity for each weight category. Therefore, further studies examining the movement and TMS of judokas are necessary to clarify the relationship between athletic performance and TMS.

In terms of the practical application of the present study, most judokas do not have to gain body weight to pass the weigh-in procedure, except for those in the over 100 kg category. Judokas should focus on particular trunk regions, based on their weight category, to strengthen the TMS accompanying muscular hypertrophy. Determining the critical TMS for judokas in each weight category is crucial to strengthen TMS and improve athletic performance. Based on our findings, those in the middle weight category, which has relatively severe body weight limitations, should selectively strengthen their TMS for high-speed trunk extension movements. Judokas in the heavyweight category can strengthen the TMS for low-speed trunk rotation movements selectively; however, they easily can strengthen TMS for other movements since they have relatively mild body weight limitations. Judokas in the lightweight category should focus on the technical and tactical approaches rather than on their TMS.

In terms of the limitations to the present study, although judo requires the use of various physical fitness elements such as rapid reaction time, muscular endurance, and flexibility, this Chapter did not examine these elements. It may be necessary to evaluate these elements to understand the associations between athletic performance and trunk function, especially for lightweight judokas who had no positive findings in the present study. Moreover, it is crucial to divide judokas based on movement specificity for further investigation.

3-6. Conclusions

The present Chapter examined the relationship between TMS and athletic performance in elite male judokas. This Chapter confirmed that EAP-judokas possessed strong TMS, in all directions, when I did not divide the judokas based on their weight categories. Significantly, high-speed extension and low-speed rotation strength are vital for middle and heavyweight judokas, respectively. However, there was no association between TMS and the athletic performance among lightweight judokas. Thus, TMS is associated with athletic performance in elite judokas depending on the weight category, except for lightweight judokas.

Chapter 4. Characteristics of trunk muscles in elite judokas are different with wrestlers

4-1. Abstract

Purpose: The present Chapter evaluated the sport-specific characteristics of CSAs of trunk muscles and TMS of judo by comparing with wrestling.

Methods: The participants were 14 male elite collegiate judokas and 14 wrestlers. MRI was used to assess the trunk muscle CSAs at the L3/L4 level parallel to the lumbar disc space. A Biodex System3 was used to measure isokinetic trunk flexor and extensor muscle strength of peak torque, work, average torque, and average power.

Results: The absolute and relative CSAs of the trunk muscles in the judokas and wrestlers were significantly different (Rectus abdominis: judo < wrestling, $p<0.05$; Obliques: judo > wrestling, $p<0.05$; Quadratus lumborum: judo > wrestling, $p<0.01$). I confirmed that the absolute and relative trunk extensor and flexor strength of peak torque, work, and average torque were significantly lower in the judokas than in judokas wrestlers.

Conclusions: These findings indicated that the characteristics of the CSAs of the trunk muscles and TMS of judo obviously differed even from wrestling having athletic similarity. Athletes should

practice the sport-specific training of trunk muscles and develop sport specificity in their sports. Particularly, judokas need to strengthen trunk rotation and lateral flexion motions, and wrestlers must train in trunk flexion and extension motions.

4-2. Introduction

One of the primary purposes of the present doctoral dissertation is to obtain the findings of elite judokas' TMS for helping to enhance judokas' athletic performance. Therefore, I investigated the characteristics of TMS depending on each weight category in Chapter 2 and its relation with athletic performance in Chapter 3. However, understanding more detailed characteristics of elite judokas' TMS are helpful to strengthen judoka efficiently.

Judo is similar in certain aspects of wrestling —both involve grappling, contact sports and combat sports, and use the weight category system. In judokas and wrestlers, some researchers have published several articles on measuring their muscle strength under various conditions at various regions (5-9). Similar to the case of other sports, the importance of the trunk region, in particular, was indicated in both these sports. I consider that the one of the ways to obtain the detailed characteristics of judokas' TMS is to comparing judokas to wrestlers having certain athletic similarities. However, there is limited research on the trunk muscles of athletes, and no studies have deeply compared the trunk muscles of judokas and wrestlers.

The evaluation of skeletal muscle volume can be obtained from the muscles CSAs. Of course, CSAs is valid for the evaluation of TMS. Athletes' muscles have higher CSAs and they gain greater

TMS, as a result of muscular hypertrophy and neural adaptation inducing from continuous daily training. This tendency can be considered as a sport-specific phenomenon, i.e., different muscular characteristics should exist between judokas and wrestlers. These morphological and functional adaptations of trunk muscles have vital information to understand their sports specificity. However, as far as I know, I have never seen to examine the characteristics of the trunk muscles CSAs of judokas and wrestlers.

Regarding the trunk motions during judo, the trunk rotation and lateral flexion motions have been reported to be very important for the standing and groundwork techniques involved (23, 24, 83). On the other hand, wrestlers are required to strengthen sagittal movements such as the flexion and extension motions to assume the low posture that is unique to wrestling and tackle and lift an opponent during practice and competitions (15, 84-86). There is a strong possibility that the differences in the specific characteristics of the trunk muscles resulting from the differences in the motion of the trunk region that are crucial to the two similar competitive sports can affect the morphology and function of the trunk muscle of judokas and wrestlers. It is very important to note that the information on the morphology and function of the trunk muscles is available to these athletes and their strength and technical training coaches to enable them to understand the sport-specific trunk muscle characteristics, and to allow them to apply the concepts that strengthen the trunk muscles involved in each sport.

The present Chapter hypothesized that the characteristics of the trunk muscles of elite judokas are different, even with wrestlers having athletic similarity by the sport-specific characteristics in each sport. To prove my hypothesis, the CSAs of trunk muscles were measured as the muscular hypertrophy of trunk region resulting adaptation for each sport. Moreover, various isokinetic TMSs were measured as practical parameters. This chapter compared all of the parameters to confirm the sport specify of the CSAs of trunk muscles and TMS in judokas and wrestlers.

4-3. Methods

Participants

Approval was obtained from the university's ethics committee, and this chapter conformed with the tenets of the Declaration of Helsinki (74). Signed informed consent was obtained from all subjects prior to their participation. Further, the participants were briefed about the objective of this study and its potential risks. Twenty-eight elite male elite collegiate athletes volunteered to participate in this study (mean ± SD: age, 19.7 ± 1.2 years; height, 169.4 ± 4.5 cm; weight, 68.9 ± 4.8 kg) (Table 4-1). These participants comprised 14 judokas and wrestlers, none of whom had experienced any lower back problems at least 6 months prior to the study. The 14 participants of two groups were determined as similar conditions of body weight. All the participants regularly spent a total of approximately 3 h practicing the sport; usually, they had two training sessions per day for 6 days a week.

Physical Characteristics

Anthropometric data of the participants was recorded (height, to the nearest 0.1 cm; weight, to the nearest 0.1 kg). The age of the participants and their sport history were also recorded. Sport history is defined as the period of time for which a participant practiced the sport before participating in this chapter.

CSAs of Trunk Muscles

To evaluate the CSAs of trunk muscles, MRI was performed using a 0.3-T magnetic resonance system that uses surface coils with a body coil (AIRIS, Hitachi Medical Corp., Tokyo, Japan). The participants lay on a bed in the MR imager in a comfortable relaxed supine position. Transverse MR spin-echo T1-weighted images were obtained at the L3/L4 level parallel to the lumbar disc space [repetition time (TR), 760 ms; echo time (TE), 20 ms; matrix, 256 × 265; field of view (FOV), 320 mm; slice thickness, 5.0 mm)].

In order to measure the CSAs, the image was traced onto a paper, as shown in Figure 4-1; the traced image was transferred to a computer. The CSAs were calculated using an image analysis software (Scion Image Beta 4.02, Scion Corp., Frederick, MD, USA). In this chapter, I grouped the CSAs of the trunk muscles into five areas because they had poorly defined borderlines. As shown in Figure 1, each of the five areas comprised the same CSAs on the left and right sides (RA, rectus abdominis; OB, oblique muscles; PS, psoas; QL, quadratus lumborum; PA, paraspinal muscles). Two of these areas included multiple muscles; OB included the internal and external obliques and the transversus abdominis muscles, and PA included the erector spinae and the multifidus muscles (3, 6, 24). Both the absolute and relative values were included in the CSAs parameters and were normalized by dividing them by the participant's body weight.

Measurement of TMS

TMS was measured isokinetically using the Biodex System3 with the back attachment (Biodex Medical Systems, Inc. Shirley, NY). The isokinetic of trunk flexor and extensor strength with peak torque, work, average torque, and average power of the trunk extensor and flexor muscles were measured at angular velocities of 60, 90, and 120°/s. Additionally, I calculated the extensor/flexor ratio. Two preliminary movements were performed before each measurement. Reciprocal movements such as extension-flexion and left rotation-right rotation were performed three times for each velocity being tested, and 60-second rest intervals were taken between each velocity being tested. For measuring extension-flexion cycle of the trunk, the participants were placed in a semi-standing posture with their knees flexed at 15°. To determine the trunk extension and flexion movement axes, I first identified L5-S1. I decided that the height of L5-S1 was 3.5 cm below the top of the iliac crest, and the extension and flexion movement axis was a horizontal line passing through the axillary midline on both sides at the height of L5-S1. The range of motion was set at 90°. Based on the instruction manual, full extension was set at 15° from the upright position. The chest, axillae, and dorsal surface of the sacrum were fixed with straps and pads. In the measurement of the left-right rotation cycle of the trunk, the participants were placed in a sitting posture with their feet free above the floor.

Statistical Analyses

The TMS parameters as well as the CSAs parameters were evaluated as the absolute and relative values. The data are expressed as mean ± SD. The physical characteristics, the CSAs values of trunk muscles, and TMS in both the judokas and wrestlers were compared by using the unpaired Student's t test. All analyses were performed using IBM SPSS Statistics version 25 (IBM Corporation, Armonk, NY, USA). The statistical significance level was selected as 5%.

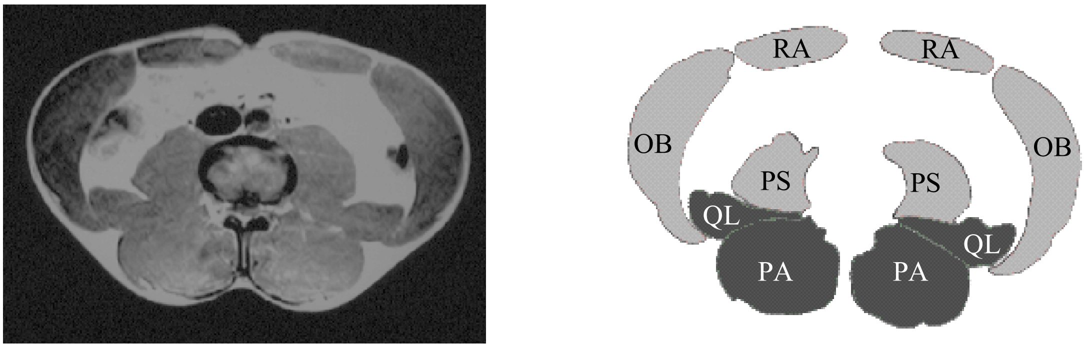
Table 4-1. Physical characteristics of wrestlers and judokas.

Variable	Judokas (n=14)	Wrestlers (n=14)
Age (years)	19.9 ± 1.1	19.4 ± 1.2
Height (cm)	169.0 ± 3.4	169.9 ± 5.5
Weight (kg)	68.9 ± 5.0	68.9 ± 4.7
Sport history[a] (years)	11.9 ± 3.5**	5.1 ± 3.2

Data are mean ± SD.

**Significant difference on comparing wrestlers and judokas ($P < 0.01$).

[a]Sport history is defined as the period of time for which a participant has practiced the sport prior to participating in this chapter.



(a) A transverse image of the trunk muscles

(b) The traced image along with the muscle group assignments

Figure 4-1. Measurement of trunk muscle cross-sectional area.

A transverse image of the trunk muscles (a) and the traced image along with the muscle group assignments (b). In this study, the transverse section was evaluated at the L3/L4 level. The areas obtained in the traced image were grouped into five areas that comprised the same trunk muscle areas on the left and right sides (RA, rectus abdominis; OB, oblique muscles; PS, psoas; QL, quadratus lumborum; PA, paraspinal muscles).

4-3. Results

Physical Characteristics

The parameters describing the physical characteristics of the judokas and wrestlers are listed in Table 4-1. The sport history period of the judokas was significantly longer than that of the wrestlers ($P < 0.01$). No significant differences were observed between the judokas and wrestlers with regard to the other parameters.

CSAs of Trunk Muscles

The absolute and relative CSAs of the trunk muscles of the collegiate wrestlers and judokas are compared in Table 4-2 to assess the development of the trunk muscles. Concerning both the absolute and relative values, a significantly larger RA was observed in the case of the wrestlers ($p<0.05$ and $p<0.05$; absolute and relative, respectively). The absolute and relative trunk muscle CSAs of the judokas were statistically revealed to be significantly higher than those of the wrestlers [OB ($p<0.05$ and $p<0.05$; absolute and relative, respectively) and QL ($p<0.01$ and $p<0.01$; absolute and relative, respectively)].

Comparison of TMS

To evaluate TMS, isokinetic TMS was measured in the collegiate judokas and wrestlers. Tables 4-3 (extensor strength) and 4-4 (flexor strength) provide the differences between the judokas and wrestlers with regard to the absolute and relative values of the isokinetic TMS parameters.

In the absolute trunk extensor strength (Table 4-3), the values of peak torque at 60°/s ($p<0.01$), work at 60°/s, 90°/s and 120°/s ($p<0.01$, $p<0.01$, $p<0.05$, respectively), and average torque at 60°/s and 90°/s ($p< 0.05$, $p< 0.05$, respectively) were significantly higher in the wrestlers than in the judokas. In the relative trunk extensor strength (Table 4-3), the values of peak torque at 60°/s ($p<0.01$), work at 60°/s, 90°/s and 120°/s ($p<0.01$, $p<0.01$, $p<0.01$, respectively), and average torque at 60°/s and 90°/s ($p<0.05$, $p<0.05$, respectively) were significantly higher in the wrestlers than in the judokas.

In the absolute and relative trunk flexor strength (Table 4-4), the values of peak torque at 120°/s ($p<0.01$) and work at 90°/s and 120°/s ($p<0.05$, $p<0.01$, respectively) were significantly higher in the wrestlers than in the judokas. About the absolute and relative values of the trunk flexor and extensor strength parameters, most of the values were higher in the wrestlers than in the judokas.

Table 4-2. Absolute and relative values of the CSAs of trunk muscles.

Muscle	Absolute value (cm^2)		Relative value (cm^2/kg)	
	Judokas (n=14)	Wrestlers (n=14)	Judokas (n=14)	Wrestlers n=14)
RA	18.9 ± 2.9	21.7 ± 4.0*	0.27 ± 0.04	0.31 ± 0.05*
OB	76.5 ± 7.6*	70.4 ± 7.8	1.11 ± 0.12*	1.02 ± 0.11
PS	29.2 ± 5.9	32.2 ± 5.6	0.43 ± 0.09	0.47 ± 0.07
QL	24.5 ± 3.4**	17.6 ± 3.9	0.36 ± 0.05**	0.26 ± 0.05
PA	63.7 ± 7.6	63.4 ± 5.8	0.93 ± 0.11	0.92 ± 0.08

Data are mean ± SD.

RA, rectus abdominis; OB, oblique muscles; PS, psoas; QL, quadratus lumborum; PA, paraspinal muscles.

*Significant difference on comparing judokas and wrestlers ($p<0.05$).

**Significant difference on comparing judokas and wrestlers ($p<0.01$).

Table 4-3. Absolute and relative values of trunk extensor strength parameters.

Velocity	Absolute value		Relative value (/kg)	
	Judokas (n=14)	Wrestlers (n=14)	Judokas (n=14)	Wrestlers (n=14)
Peak torque (N·m)				
60°/s	365.8 ± 57.4	448.2 ± 79.0**	5.3 ± 0.8	6.5 ± 1.2**
90°/s	366.6 ± 85.3	426.3 ± 70.7	5.3 ± 1.3	6.2 ± 1.0
120°/s	364.7 ± 82.3	404.4 ± 66.1	5.3 ± 1.3	5.9 ± 0.9
Work (J)				
60°/s	387.0 ± 39.8	471.5 ± 65.6**	5.6 ± 0.6	6.8 ± 0.8**
90°/s	390.5 ± 50.8	457.0 ± 68.0**	5.7 ± 0.8	6.6 ± 0.8**
120°/s	371.0 ± 38.7	422.7 ± 62.7*	5.4 ± 0.6	6.1 ± 0.7**
Average torque (N·m)				
60°/s	336.9 ± 46.7	392.7 ± 66.1*	4.9 ± 0.7	5.7 ± 0.9*
90°/s	337.8 ± 65.1	389.6 ± 56.5*	4.9 ± 1.0	5.7 ± 0.8*
120°/s	334.8 ± 74.3	372.0 ± 57.8	4.9 ± 1.1	5.4 ± 0.9
Average power (W)				
60°/s	230.8 ± 23.5	252.4 ± 45.2	3.4 ± 0.4	3.7 ± 0.5
90°/s	330.8 ± 39.6	335.5 ± 63.4	4.8 ± 0.6	4.9 ± 0.7
120°/s	394.7 ± 58.2	371.8 ± 74.2	5.7 ± 0.9	5.4 ± 1.0

Data are mean ± SD.

*Significant difference on comparing judokas and wrestlers ($p<0.05$).

**Significant difference on comparing judokas and wrestlers ($p<0.01$).

Table 4-4. Absolute and relative values of trunk flexor strength parameters.

Velocity	Absolute value		Relative value (kg^{-1})	
	Judokas (n=14)	Wrestlers (n=14)	Judokas (n=14)	Wrestlers (n=14)
Peak torque (N·m)				
60°/s	182.9 ± 25.6	193.6 ± 29.7	2.7 ± 0.4	2.8 ± 0.4
90°/s	181.0 ± 30.7	199.3 ± 19.3	2.6 ± 0.5	2.9 ± 0.2
120°/s	171.5 ± 25.0	203.5 ± 14.1**	2.5 ± 0.4	3.0 ± 0.2**
Work (J)				
60°/s	205.4 ± 30.8	215.6 ± 29.3	3.0 ± 0.5	3.1 ± 0.4
90°/s	199.8 ± 28.5	211.1 ± 25.3	2.9 ± 0.5	3.1 ± 0.4
120°/s	185.1 ± 27.9	199.1 ± 23.2	2.7 ± 0.4	2.9 ± 0.4
Average torque (N·m)				
60°/s	171.3 ± 23.8	182.4 ± 24.4	2.5 ± 0.4	2.6 ± 0.3
90°/s	168.6 ± 27.3	190.0 ± 18.6*	2.5 ± 0.4	2.8 ± 0.2*
120°/s	161.4 ± 23.7	193.7 ± 14.5**	2.4 ± 0.4	2.8 ± 0.3**
Average power (W)				
60°/s	120.8 ± 17.6	123.3 ± 16.9	1.8 ± 0.3	1.8 ± 0.2
90°/s	170.1 ± 25.3	165.2 ± 27.2	2.5 ± 0.4	2.4 ± 0.4
120°/s	200.6 ± 29.3	188.9 ± 34.0	2.9 ± 0.5	2.8 ± 0.5

Data are mean ± SD.

*Significant difference on comparing judokas and wrestlers ($p<0.05$).

**Significant difference on comparing judokas and wrestlers ($p<0.01$).

4-5. Discussions

This chapter was to investigate the sport-specific characteristics of the trunk muscles of elite judokas. To accomplish this investigation, I compared the CSAs of trunk muscles with wrestlers having athletic similarities. In addition, TMS consisted of extension and flexion were compared. I observed obvious differences in the sport-specific characteristics of the CSAs of trunk muscles and TMS, even in the two competitive sports, which are similar with regard to certain aspects. Trunk rotators and lateral flexors are crucial for judokas. On the contrary, trunk flexion and extension motions are crucial for wrestlers. Obviously, this result does not imply that judokas never exert to exert trunk flexion and extension motions; similarly, it does not imply that wrestlers never required trunk rotators and lateral flexors. I believe that this study is the first to describe the sport-specific characteristics of the CSAs of trunk muscles and TMS of judo by comparing with similar sports wrestling.

Significant differences were observed between the two sports with regard to the absolute and relative CSAs values of the RA, OB, and QL muscles in the sportspersons. OB and QL were larger in judokas than in the wrestlers. On the contrary, RA was smaller in judokas than in the wrestlers. I wish to discuss the correlation between the specific trunk motions involved in these sports and the three trunk muscle groups (RA, OB, and QL).

The CSAs of the OB was significantly larger in the judokas than in the wrestlers. In this chapter, the OB muscles were defined as comprising the internal and external obliques as well as the transversus abdominis muscles; these muscles were divided by a poorly defined borderline. In addition, the actions of both the internal and the external oblique muscles will result in the flexion of the vertebral column. However, one side of the activated muscles rotates and laterally flexes the vertebral column; the internal oblique rotates the vertebral column to the same side, and the external oblique rotates it to the opposite side (87). There is a strong possibility that judokas have higher trunk rotator and lateral flexor strengths because it was observed that the OB in these athletes has a higher CSAs and lower trunk flexor strength. Some studies have revealed that the trunk rotator and lateral flexor strengths are crucial for judokas(23, 24, 83). Judokas will demonstrate the remarkable ability to throw an opponent during practice and competitions. This throwing motion would aid in the development of trunk rotator and lateral flexor muscles and improve their strength, which play an important role in the throwing motion. Further, when an opponent grasps the judo uniform referred to as "judogis," particularly its collar and sleeves, the judoka attempts to force the opponent to release the judogis by simultaneously exerting various trunk rotation and lateral flexion motions in order to prevent the opponent from gaining advantage. If the judoka does not permit the opponent to grasp the judogis, it is possible that the judoka will not be thrown. It is therefore expected that the CSAs of the OB may be larger in judokas than in wrestlers because judokas use the trunk rotation and lateral flexion motions. In both the standing and groundwork techniques, trunk rotations and lateral flexions are very important for judokas.

Moreover, the judokas were observed to have a QL with a significantly larger CSAs. One side of the QL laterally flexes the vertebral column, and both sides stabilize the vertebral column (87). The significantly larger CSAs observed in judokas may be attributed to the considerable use of lateral flexions, and the importance of QL is similar to that of OB, as described above. Thus, the specific characteristic of the trunk muscle was observed to differ between the collegiate judokas and wrestlers. The sport-specific trunk motions involved in each sport can induce muscular hypertrophy in the corresponding trunk muscles.

In this chapter, the CSAs of the RA was significantly smaller in the judokas than in the wrestlers. It suggests that RA is more important for wrestlers than judokas. Actually, Kubo et al. also have reported that the CSAs of the RA in elite wrestlers was significantly larger than that in elite junior wrestlers (84). It is very important for wrestlers to strengthen their trunk flexor and extensor because wrestlers are often required to assume the low posture that is unique to wrestling, and they are also required to lift an opponent during practice and competitions. While assuming this unique low posture and lifting an opponent, wrestlers are required to firmly stabilize their trunk region; because of this, wrestlers should require a larger RA since the RA muscles are antagonistic to the trunk extensor muscles. On the contrary, judokas require to make their upper body upright. Thus, judokas need to hardly stay the posture mentioned above. Therefore, I believe that the RA indicated a significant difference between the judokas and wrestlers by the sport-specific characteristic.

This section will discuss the fact that these findings indicate a necessity for judokas to strengthen their trunk rotation and lateral flexion motions, while wrestlers are required to strengthen their sagittal movements such as trunk flexion and extension motions. In this chapter, the absolute and relative values of the TMS parameters of elite competitive judokas and wrestlers were compared. The results indicated that the wrestlers had significantly higher isokinetic trunk extensor and flexor strength than the judokas (in extension peak torque at 60°/s, work at 60°/s, 90°/s, 120°/s, and average torque at 60°/s, 90°/s, and in flexion peak torque at 120°/s, and average torque at 90°/s, and 120°/s). The other values of trunk flexor and extensor strength were also higher in the wrestlers; however, these values were not significantly different from those of the judokas. I considered that the wrestlers would require greater trunk flexor and extensor strength than the judokas. One reason for this greater requirement is that wrestlers frequently tackle and lift an opponent in competitions and during practice in order to score points, and the aim of the game is to pin down an opponent. Additionally, wrestlers have nothing to grasp anything such as judogis like judokas. It is necessary for wrestlers to close grapple with an opponent. Consequently, the approach to the opponent would make wrestlers demand greater trunk flexor and extensor strength.

The TMS parameters in this chapter were examined using the isokinetic trunk flexor and extensor strength with peak torque, work, average torque, and average power. This study particularly focused on TMS during sagittal movements. However, only a few previous studies, including Chapter 2 and 3, have shown that trunk rotator and lateral flexor strengths are some of important elements with regard to TMS in judokas and are also key points from the viewpoint of obtaining a flexible body (23, 24, 83). It appears that the trunk rotator and lateral flexor strengths observed in a competitive judo are relative to those observed in judo performance and play an important role in the standing and groundwork judo techniques. This was confirmed by the MRI performed in this study. In my future study, I would like to examine the trunk rotator and lateral flexor strength in athletes, particularly judokas and wrestlers. The simultaneous testing of trunk rotator and lateral flexor strengths is very interesting.

The finding of this chapter is that obvious differences are present in the sport-specific characteristics of the CSAs of trunk muscles and TMS between the elite collegiate athletes of the two similar sports, namely, judo and wrestling. I will try to mention the practical application for strengthening these two sports. On the sports scene, it is very important to adopt the sport-specific training programs and to develop the trunk muscles of athletes involved in these two sports. These athletes should strengthen trunk rotation and lateral flexion exercises for judokas and trunk flexion and extension exercises for wrestlers.

4-6. Conclusions

In conclusion, the present Chapter examined the sport-specific characteristics of the trunk muscles of elite judokas. The CSAs of the trunk muscles and TMS in the judokas were significantly different, even in the wrestlers having athletic similarity. For judokas, trunk rotators and lateral flexors are crucial. On the contrary, trunk flexors and extensors are crucial for wrestlers. The results of this chapter thus indicates that even in the two similar competitive sports—judo and wrestling—different sport-specific characteristics are exhibited by the trunk muscles of the athletes.

Chapter 5. Nonspecific low back pain and anatomical changes in the lumbar spine in elite judokas with weight category

5-1. Abstract

Purpose: nsLBP and LRA occur frequently in judokas. High body weight has been reported to be associated with both nsLBP and LRA. To investigate the prevalence and coprevalence of nsLBP and LRA in judokas.

Methods: The participants comprised 82 male judokas (mean ± SD age, 20.1 ± 0.9 years) from three weight categories: lightweight (n= 29), middleweight (n=31), and heavyweight (n=22). The presence of nsLBP was evaluated using a questionnaire. LRA were examined using plain film radiographs and MRI. The prevalence of nsLBP and LRA were compared among weight categories.

Results: The prevalence of nsLBP in the lightweight, middleweight, and heavyweight categories was 34.5%, 32.3%, and 40.9%, respectively. For LRA, prevalence for the three weight categories was 65.5%, 90.3%, and 90.9%, respectively (middleweight and heavyweight greater prevalence than lightweight, $p < 0.05$). The prevalence of LRA in judokas with nsLBP in each category was 50.0%, 100%, and 88.9%, respectively (middleweight greater prevalence than lightweight, $p < 0.05$). The

prevalence of LRA in judokas without nsLBP in each category was 73.7%, 85.7%, and 92.3%, respectively.

Conclusions: The prevalence of LRA was over 90% in the middle and heavy weight categories compared to 65.5% in the lightweight category. There was a large coprevalence of nsLBP and LRA. The prevalence of LRA in those with nsLBP (79.3%) was similar to the prevalence of LRA for those without nsLBP (83.0%), suggesting a lack of direct association between nsLBP and LRA. However, the prevalence of LRA in judokas with nsLBP in each category was 50.0%, 100%, and 88.9%, respectively, hence there was the obvious difference between lightweight and other two heavier categories.

5-2. Introduction

Chapters 2–4 focused on the relation of TMS with athletic performance as an aspect of physical fitness in elite judokas. Chapters 5–7 investigate LBP as a medical aspect of the trunk region in elite judokas.

LBP is a common musculoskeletal disorder affecting the general population as well as athletes (32-36). LBP is classified into sLBP and nsLBP. sLBP is relatively uncommon and is caused by malignancies, infections, inflammatory spondyloarthropathies, and fractures (37). There is an obvious cause and effect relationship between LRA and causes of sLBP. Conversely, nsLBP is quite common and cannot be attributed to a specific cause (37). The relationship between LRA and nsLBP is unclear. The prevalence of nsLBP varies depending on the sport, it is commonly observed in all sports, including judo (40, 41). 62.4% of judokas suffered from nsLBP (41). Because nsLBP is a common complaint among athletes, prevention of ns LBP is essential to continue their sports activities.

The pathogenesis of nsLBP is very complicated, though anatomical changes in the lumbar spine, i.e., LRA, could be one possible factor (33, 42). In a previous study conducted by Kuroki (47), 33% of judokas suffered from spondylolysis by the analysis of plain film radiographs. Moreover, analysis of MRI revealed that the prevalence of lumbar vertebral disc degeneration was 54% (41/48) (48). No reports are using both plain film radiographs and MRI to detect LRA in judokas. Hence, there is a possibility of an even higher prevalence of abnormalities in judokas.

The association between LRA and nsLBP is still controversial (33, 34, 37, 39, 49-55). A previous study (56) showed that 11% of the athletes with nsLBP had LRA. For combat sports, the prevalence of nsLBP in wrestlers with and without LRA has been reported to be 40% and 44%, respectively (33). Moreover, this previous study reported that wrestlers without nsLBP had high prevalence for LRA (70%). Thus, there was no specific association between nsLBP and LRA in wrestlers (33). However, for judokas, there has been no report that has examined the possible association between nsLBP and LRA.

High body weight would be a risk factor for both nsLBP (42, 52, 57-61) and LRA (53, 57) in general populations and athletes. In current competitive regulation, judokas compete into seven weight categories. Chapter 2 suggested a strong possibility that the stress on the lumbar region differs depending on the weight category. However, no study examined the influence of body weight on the prevalence of nsLBP and LRA in judokas.

The present Chapter hypothesized that individuals in the heavier weight categories would have a greater prevalence of nsLBP and LRA among judokas. To verify this hypothesis, this chapter examined the prevalence and coprevalence of nsLBP and LRA in three weight categories of collegiate judokas.

5-3. Methods

Participants

Approval was obtained from the university's ethics committee, and the study conformed with the tenets of the Declaration of Helsinki (74). All participants were recruited from an elite collegiate judo club. All judokas provided a written informed consent prior to their participation. Information regarding the purpose of the study, the potential risks, and the protection of the rights of the participants was provided to all the judokas and their coaches.

Individuals were excluded from the study if they presented with radiological findings suggesting a cause of sLBP: malignancies, infections, inflammatory spondyloarthropathies, and fractures (37). These abnormalities were assessed with both plain film radiographs and MRI. Two judokas were excluded from the study, one due to a fracture of a transverse process and another due to the fracture of an inferior articular process of vertebra.

The participants consisted of 82 elite male collegiate judokas (mean ± SD: age, 20.1 ± 0.9 years; height, 171.6 ±6.2 cm; weight, 79.8 ± 14.5 kg) (Table 5-1). Subsequently, I classified the judokas into three weight categories as follows: the lightweight category (those competing in the under 60 kg and under 66 kg weight classes; n = 29), the middleweight category (those competing in the under 73 kg and under 81 kg weight classes; n = 31), and the heavyweight category (those competing in the under 90 kg, under 100 kg, and over 100 kg weight classes; n = 22). All judokas practiced judo 6 days per week for approximately 3 hours per day (divided into 2 daily sessions).

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Evaluation of nsLBP

Following the protocol of a previous study (33), the presence of nsLBP was evaluated using the questionnaire the Osaka city university (OCU) test and modified by Kuroki and Tajima (88) (Table 5-2). The OCU test is composed of 10 questions about LBP related to activities of daily living. For each question, points were assigned based on the perceived ability to do each activity: possible without pain, 0 point; possible with pain, 1 point; and impossible, 2 points. For the purpose of this study, any subject with a total of 1 or more points on the OCU test, was considered to have nsLBP. All participants were instructed to base their answer on their current status.

Radiological examination

Two experienced orthopedic surgeons examined the plain film radiographs and MRI (Hitachi Medical Corporation, Tokyo, Japan) to determine the presence of abnormalities of the lumbar vertebrae and the intervertebral discs. The radiographic films were obtained with anteroposterior, lateral, and right and left anterior oblique views. MRI was performed with a 0.3-T unit by using surface coils with a body coil in the supine position. T2-weighted fast spin-echo was used to obtain sagittal images of the lumbar spine and lumbar intervertebral discs. I modified the definitions of LRA presented by Iwamoto et al. (51) LRA detected by MRI, such as lumbar intervertebral disc degeneration and disc protrusion, were added to the definitions (Table 5-3). Some congenital abnormalities such as transitional vertebra and spina bifida occulta were excluded because these are not caused by engaging in sports activities. Additionally, the definition of spinal instability was excluded because it indicated malalignment of the lumbar spine during trunk flexion and extension and not anatomical changes in the lumbar vertebrae. The evaluation of images to determine the presence of LRA was independently performed by two orthopedic surgeons without knowledge of nsLBP status of the individual. In the event of a discrepancy for the presence of LRA, between the two orthopedic surgeons, disagreements were resolved by consensus. LRA were considered to be present when a judoka exhibited at least one abnormal finding.

Statistical analyses

All data were compared among the three weight categories. The characteristics of the judokas were analyzed by using either a 1-way analysis of variance (ANOVA) or Kruskal-Wallis test followed by Scheffe test or Mann-Whitney U test for multiple comparisons as appropriate. The prevalence and coprevalence of nsLBP and LRA were analyzed by using chi-square and Fisher's exact tests. Significance was accepted at the 5% level. All analyses were performed using IBM SPSS Statistics version 25 (IBM Corporation, Armonk, NY, USA).

Table 5-1. Physical characteristics of 82 male elite judokas.

Variables	All judokas (n=82)	Lightweight (n=29)	Middleweight (n=31)	Heavyweight (n=22)
Age (years)*	20.1 ± 0.9	19.8 ± 0.8	20.0 ± 0.9	20.6 ± 1.0
Height (cm)†	171.6 ± 6.2	167.0 ± 4.7	173.1 ± 5.2	175.7 ± 5.6
Body Weight (kg)†	79.8 ± 14.5	66.8 ± 4.6	78.8 ± 4.7	98.6 ± 11.8
BMI (kg/m^2)	26.9 ± 3.8	23.9 ± 1.3	26.4 ± 1.9	31.7 ± 3.5
Judo history (years)	11.0 ± 2.9	10.9 ± 2.9	10.7 ± 2.8	11.5 ± 3.2

Data are presented as mean ± SD.

Lightweight, under 60kg and 66kg judokas.

Middleweight, under 73kg and 81kg judokas.

Heavyweight, under 90kg, 100kg, and over 100kg judokas.

* The heavyweight category is older than the other 2 categories ($p<0.05$).

† Significant difference for height and body weight between each pair of weight categories ($p<0.01$).

Table 5-2. The Osaka City University test for nsLBP.

No.	Item
1	Lying face up with leg extended.
2	Rising from the bed in the morning.
3	Washing your face in the morning.
4	Wearing and removing trousers and socks while standing.
5	Using a Japanese-style toilet.
6	Sitting on a chair.
7	Standing.
8	Walking.
9	Ascending and descending stairs.
10	Lifting or holding heavy objects.

1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
Total	

Points
0: possible without pain
1: possible with pain
2: impossible

nsLBP, nonspecific low back pain.

nsLBP is defined as a total of 1 or more points.

Modified from Kuroki and Tajima (88).

Table 5-3. Definitions of LRA.

LRA	Definition
Balloon disc	More than 20% reduction in the central vertebral height when compared with the anterior and posterior vertebral heights above or below the affected disc.
Disc protrusion	Protrusion or extrusion of the nucleus pulposus within the annulus into the vertebral canal.
Disc space narrowing	More than 20% reduction in the affected disc space when compared with the disc space above and below the affected disc. The normal disc space of the L5-S1 intervertebral disc was assumed to normally be two-thirds of the space of the L4-5 disc.
Facet arthropathy	Joint-space narrowing, subchondral sclerosis, or osteophyte formation of the facet joints of the spine.
Limbus vertebrae	Separative, sclerotic, triangular ossicle adjacent to but separate from the vertebral endplate. The affected endplate contains an adjacent, irregular, focal, and sclerotic defect (secondary to chronic herniation of the disc material through the attachment of the annulus fibrosis).
Lumbar intervertebral disc degeneration	Non-homogeneous white structure of the lumbar intervertebral disc, possibly horizontal bands. Findings of severe degeneration of the intervertebral disc: unclear distinction between the nucleus pulposus and annulus fibrosis, or collapsed disc space(89).
Scheuermann's disease	Irregularities in the anterior portion of the endplates of 3 consecutive vertebral bodies with at least 5° of anterior wedging in each vertebral body.
Schmorl's nodule	Sharply marginated, sclerotic indentation in the vertebral endplate (secondary to chronic herniation of the nucleus pulposus through the affected endplate).
Scoliosis	Lateral curvature of the spine in the frontal plane greater than 10°, as estimated by Cobb's method of measuring the angle of scoliosis(90).
Spondylolysis	Defect of the pars interarticularis.
Spondylolisthesis	Ventral slipping of 1 vertebral body over another as measured by the Meyerding grading system(91).
Spurring	Osteophyte(s) arising from the anterior or posterior aspect of the affected vertebral body.

LRA, lumbar radiological abnormality.
Modified from Iwamoto et al (51).

5-4. Results

Participants

The characteristics of the participants are listed in Table 5-1. The height for the judokas in the heavyweight and middleweight categories was significantly higher than for those in the lightweight category ($p<0.0001$, 1-way ANOVA and Scheffe test). As expected, body weight was significantly different among the three weight categories ($p<0.0001$, Kruskal-Wallis test and Mann-Whitney's U test). The age of those in the heavyweight category was significantly higher than for those in the lightweight and middleweight categories ($p<0.05$, and $p<0.001$, respectively, Kruskal-Wallis test and Mann-Whitney's U test). There was no statistical difference between the three weight categories for the number of years practicing judo. Therefore, the significant difference in age for the heavyweight category was independent of judo experience.

Prevalence of nsLBP

The prevalence of nsLBP in the lightweight, middleweight, and heavyweight categories was 34.5% (10 of 29), 32.3% (10 of 31), and 40.9% (9 of 22), respectively (Table 5-4). The mean ± SD functional disability level (score on the OCU test) of those with nsLBP was 1.9 ± 0.9 (range, 1–3), 2.5

± 2.1 (1–8), and 3.7 ± 2.3 (1–7) for the participants in the lightweight, middleweight, and heavyweight categories, respectively. There was no statistical difference between categories for the prevalence of nsLBP and the OCU test score.

Prevalence of LRA

The prevalence of LRA in the lightweight, middleweight, and heavyweight categories was 65.5% (19 of 29), 90.3% (28 of 31), and 90.9% (20 of 22), respectively (Table 5-5). The prevalence of LRA in the middleweight and heavyweight categories was significantly higher than that in the lightweight category ($p<0.05$).

Details regarding the LRA are shown in Table 5-6. Lumbar intervertebral disc degeneration and spondylolysis were frequently identified (56.1% and 34.1%, respectively). The prevalence of the lumbar intervertebral disc degeneration in the heavier weight categories was significantly higher than that in the lighter weight categories (heavyweight > middleweight and lightweight, $p<0.05$ and $p<0.001$, respectively; middleweight > lightweight, $p<0.01$).

Prevalence of LRA in judokas with and without nsLBP

In the judokas with nsLBP, the prevalence of LRA in the lightweight, middleweight, and heavyweight categories was 50.0% (5 of 10), 100% (10 of 10), and 88.9% (8 of 9), respectively (Table 5-7). The coprevalence of nsLBP and LRA in the middleweight category was significantly higher than that in the lightweight category ($p<0.05$).

In the judokas without nsLBP, the prevalence of LRA in the lightweight, middleweight, and heavyweight categories was 73.7% (14 of 19), 85.7% (18 of 21), and 92.3% (12 of 13), respectively (Table 5-8). There was no statistical difference in the prevalence of LRA in the judokas without nsLBP.

Table 5-4. The prevalence of nsLBP in judokas.

	All judokas (n=82)	Lightweight (n=29)	Middleweight (n=31)	Heavyweight (n=22)
No nsLBP	64.6% (n=53)	65.5% (n=19)	67.7% (n=21)	59.1% (n=13)
nsLBP	35.4% (n=29)	34.5% (n=10)	32.3% (n=10)	40.9% (n=9)

nsLBP, nonspecific low back pain.

Lightweight, under 60kg and 66kg judokas.

Middleweight, under 73kg and 81kg judokas.

Heavyweight, under 90kg, 100kg, and over 100kg judokas.

There was no significant difference in prevalence between the 3 weight categories ($p>0.05$).

Table 5-5. The prevalence of LRA in judokas.

	All judokas (n=82)	Lightweight (n=29)	Middleweight (n=31)	Heavyweight (n=22)
No LRA	18.3% (n=15)	34.5% (n=10)	9.7% (n=3)	9.1% (n=2)
LRA	81.7% (n=67)	65.5% (n=19)*†	90.3% (n=28)*	90.9% (n=20)†

LRA, lumbar radiological abnormality.

Lightweight, under 60kg and 66kg judokas.

Middleweight, under 73kg and 81kg judokas.

Heavyweight, under 90kg, 100kg, and over 100kg judokas.

*† Prevalence significantly greater in the heavyweight and middleweight categories compared to the lightweight category ($p<0.05$).

Table 5-6. The prevalence of various LRA.

Details of LRA	All judokas (n=82)	Lightweight (n=29)	Middleweight (n=31)	Heavyweight (n=22)
Lumbar intervertebral disc degeneration*	56.1% (n=46)	24.1% (n=7)	61.3% (n=19)	90.9% (n=20)
Spondylolysis	34.1% (n=28)	37.9% (n=11)	32.3% (n=10)	31.8% (n=7)
Balloon disc	13.4% (n=11)	13.8% (n=4)	19.4% (n=6)	4.5% (n=1)
Disc space narrowing	12.2% (n=10)	0% (n=0)	16.1% (n=5)	22.7% (n=5)
Schmorl's nodule	6.1% (n=5)	0% (n=0)	9.7% (n=3)	9.1% (n=2)
Spurring	4.9% (n=4)	3.4% (n=1)	0% (n=0)	13.6% (n=3)
Disc protrusion	4.9% (n=4)	0% (n=0)	6.5% (n=2)	9.1% (n=2)
Limbus vertebra	1.2% (n=1)	3.4% (n=1)	0% (n=0)	0% (n=0)

LRA, lumbar radiological abnormality.

Lightweight, under 60kg and 66kg judokas.

Middleweight, under 73kg and 81kg judokas.

Heavyweight, under 90kg, 100kg, and over 100kg judokas.

* Significant difference between each pair of weight categories ($p<0.05$).

Table 5-7. The prevalence of LRA in judokas with nonspecific low back pain.

	All judokas (n=29)	Lightweight (n=10)	Middleweight (n=10)	Heavyweight (n=9)
No LRA	20.7% (n=6)	50.0% (n=5)	0% (n=0)	11.1% (n=1)
LRA*	79.3% (n=23)	50.0% (n=5)*	100% (n=10)*	88.9% (n=8)

LRA, lumbar radiological abnormality.

Lightweight, under 60kg and 66kg judokas.

Middleweight, under 73kg and 81kg judokas.

Heavyweight, under 90kg, 100kg, and over 100kg judokas.

* Significant difference between the lightweight and middleweight categories ($p<0.05$).

Table 5-8. The prevalence of LRA in judokas without nonspecific low back pain.

	All judokas (n=53)	Lightweight (n=19)	Middleweight (n=21)	Heavyweight (n=13)
No LRA	17.0% (n=9)	26.3% (n=5)	14.3% (n=3)	7.7% (n=1)
LRA	83.0% (n=44)	73.7% (n=14)	85.7% (n=18)	92.3% (n=12)

LRA, lumbar radiological abnormality.

Lightweight, under 60kg and 66kg judokas.

Middleweight, under 73kg and 81kg judokas.

Heavyweight, under 90kg, 100kg, and over 100kg judokas.

No significant difference between the 3 weight categories ($p>0.05$).

5-5. Discussions

In elite collegiate judokas, this chapter noted a higher prevalence of LRA in the middleweight (90.3%) and heavyweight (90.9%) categories than the lightweight category (65.5%) ($p<0.05$). Moreover, the prevalence of LRA in judokas with nsLBP was 50.0% in the lightweight category, 100% in the middleweight category, and 88.9% in the heavyweight category, with the difference in coprevalence being significant ($p<0.05$) between the middle and lightweight categories. On the other hand, the prevalence of LRA in judokas without nsLBP was 73.7% in the lightweight category, 85.7% in the middleweight category, and 92.3% in the heavyweight category.

The prevalence of nsLBP in judokas was 35.4%. Previous studies have estimated the prevalence of nsLBP in judokas to range from 30% to 85% (32, 36, 39). While these data are at the lower end of that range, comparisons are difficult because of the various criteria used to define nsLBP in those studies. In a study using the same questionnaire and definition of nsLBP, Iwai et al (33) demonstrated that 41.5% of collegiate wrestlers had nsLBP. Further, by using the same questionnaire test and nsLBP criteria (i.e., at the time of evaluation), this chapter found that nsLBP was present in approximately 30% to 45% of collegiate athletes engaging in sports activities involving high load on the lumbar region.

In this chapter, the prevalence of nsLBP in the three weight categories was similar (approximately 30%–40%). This finding was contrary to my initial hypothesis, and may indicate that internal (generated by the individual) and external (generated by the opponent or judo surface) forces applied to the lumbar region during judo are proportional to the size of the individual. Judokas seem to have a proportionally similar ability to sustain these forces across weight categories.

High body weight has previously been reported to be a risk factor for LRA (53, 57) as well as LBP (42, 52, 57, 59-61). In this chapter, 81.7% of the judokas had some type of LRA. In previous studies, 35% of soccer players, 42% of gymnasts, and 57% of wrestlers were found to have LRA (46). The higher prevalence in this chapter may be due to methodological differences. In previous studies only plain film radiographs were used, compared to both plain film radiographs and MRI in this chapter. The prevalence of LRA based on plain film radiographs only was 57.3% in this chapter, and the prevalence is similar to that of wrestlers reported previously (46). My colleagues Iwai et al (33), also using a combination of radiographs and MRI, reported a 66% prevalence of LRA in wrestlers. The apparent higher prevalence of LRA in the judokas may have been due to a longer exposure to the sport (an average of 11.0 years versus 5.3 years for the wrestlers).

The prevalence of LRA in the middleweight and heavyweight categories was greater than 90% compared to 65.5% in the lightweight category. These results are partially consistent with the hypothesis that judokas with higher body weight tend to develop LRA and the results of previous reports that high body weight is associated with LRA (53, 57). In judo, it is possible that the greater body weight of the judoka and his opponents participate in creating greater loads on the anatomical structures of the spine. However, it is noteworthy that prevalence of LRA was not different between the 2 heavier weight categories. The high prevalence of LRA in these judokas of relatively young age, for all weight categories, is also noteworthy.

I considered the two types of LRA with higher prevalences in this chapter: lumbar intervertebral disc degeneration and spondylolysis. This chapter identified that the prevalence of lumbar intervertebral disc degeneration in the heavier weight categories was significantly higher than in the lighter weight categories. However, the same was not found for the prevalence of spondylolysis.

In this chapter, the prevalence of LRA in judokas when evaluated by plain film radiographs alone was 57.3% with spondylolysis being the most frequently observed (34.1%) type of LRA. This high prevalence of spondylolysis in judokas is consistent with the prevalence (33%) previously reported (47). During adolescence, repetitive movements during sports activities have been reported as a cause of fatigue fracture, and spondylolysis has been regarded as a fatigue fracture at the pars interarticularis (92, 93). It has been noted that high stress on the lumbar spine, particularly repetitive trunk hyperextension and rotation, results in spondylolysis during adolescence (43, 45, 93). The judokas in this chapter started practicing judo at approximately 10 years of age. Hyperextension, extension with high load, and rotation of the lumbar spine are frequently observed in judo competitions and practice.

Approximately 80% of the judokas with nsLBP had some form of LRA. Interestingly, approximately 80% of judokas without nsLBP also had some form of LRA. This is consistent with previously reported findings that individuals without nsLBP have a high prevalence of LRA (wrestlers: 70% (33); general population: 32% (55)). These findings are in agreement with earlier findings. Therefore, while judokas with nsLBP frequently have LRA, similar prevalence in the judokas without nsLBP suggests that a direct association does not exist between LRA and nsLBP. However, the prevalence of LRA in judokas with nsLBP in each category was 50.0%, 100%, and 88.9%, respectively, hence there was the obvious difference between lightweight and other two heavier categories. Especially, this chapter confirmed that half of the lightweight judokas' nsLBP did not accompany LRA. Thus, it suggested that the association of LRA in LBP differs depending on the weight category. Moreover, it becomes lower, especially for lightweight judokas.

5-6. Conclusions

In this group of 82 judokas, the prevalence of nsLBP was between 30 and 40% with no difference between the light, middle, and heavy weight categories. In this same group, the prevalence of LRA was over 90% in the middle and heavy weight categories compared to 65.5% in the lightweight category. The prevalence of LRA in those with nsLBP (79.3%) was similar to the prevalence of LRA for those without nsLBP (83.0%), suggesting a lack of direct association between nsLBP and medical imaging findings. However, the prevalence of LRA in judokas with nsLBP in each category was 50.0%, 100%, and 88.9%, respectively, hence there was the obvious difference between lightweight and other two heavier categories. The present Chapter concluded that the association of LRA in LBP differs depending on the weight category. Moreover, it becomes lower, especially for lightweight judokas.

Chapter 6. Weight category-dependent associations of trunk muscle strength and low back pain in elite judokas

6-1. Abstract

Purpose: TMS, especially rotator, is an important factor in judokas' athletic performance and injury risks. Chapter 2 and 3 confirmed that the characteristics of TMS depending on weight categories and their relation with athletic performance. Although inadequate TMS might cause LBP, the relationship between these two variables is not fully understood. In the present Chapter, the relationship between weight category-dependent TMS and LBP was investigated in Japanese elite judokas.

Methods: The participants were 66 male collegiate judokas, who were classified into the lightweight (n=14), middleweight (n=29) and heavyweight (n=23) category. The peak torques of extensor, flexor and rotator were measured. LBP group and non-LBP group were defined by questionnaire.

Results: Only in the TMS (normalized by body weight) of the heavier weight category, the LBP group (n=9) showed significantly lower extensor (60°/s; $p<0.05$) and both sides of rotators (60°/s; $p<0.05$), compared to the non-LBP group (n=14).

Conclusions: The present Chapter concluded that low trunk extensor and rotator strengths are risk factors for LBP in heavyweight judokas. Primarily, both sides of rotators are associated with not only athletic performance but also LBP.

6-2. Introduction

Chapter 5 confirmed the weight category-dependent prevalence of LBP and LRA and their relation in elite judokas. Moreover, Chapter 2 revealed the characteristics of TMS depending on weight category in elite judokas. It has been shown that TMS is an essential element of judo, and more importantly, if TMS is weak in one area, imbalance may occur and the risk of injury increases (10). However, although TMS is one of the factors related to LBP, earlier chapters have not investigated the relationship between TMS and LBP yet.

Judo is classified as a contact or combat sport and seven weight categories are used in the current competitive regulation. In judo, it has also been reported that TMS is very important for athletic performance (10, 73). There is a strong possibility that the characteristics of one's TMS depends on their weight category because of the different loads on the lumbar region. Chapter 2 confirmed TMS depending on weight category. Heavyweight judokas had stronger absolute TMS but weaker relative TMS (normalized by body weight) than lighter weight judokas.

LBP is a frequent injury among athletes (39, 94), especially in judokas, wherein LBP has been reported to be occur in 62.4% (41). In Chapter 5 (95), there is no significant difference in the incidence of LBP by weight category between lightweight (34.5%), middleweight (32.3%), and heavyweight

(40.9%). Since such high incidences of LBP have been found among different types of athletes, it is very important that athletes and their coaches work toward its prevention.

The weakness of TMS has strong possibility to contribute for LBP (62-66). However, the relationship between LBP and low TMS is still unresolved issue. Previous studies on ordinary people confirmed that those with LBP had lower TMS (extensor, flexor, and/or rotator) than those without LBP (67-69), but other studies did not conclude samely (70, 96). For combat sports, low extension TMS of collegiate wrestlers correlated to the LBP severity deduced from the functional disability level of LBP (33, 71). However, in judokas, there is no study regarding the relationship between LBP and TMS.

Chapter 5 have already reported that LBP in middle- and heavyweight categories tended to accompany LRA, conversely about half of the LBP cases (50%) in the lightweight category were not accompanied by any LRA (95), suggesting that the body weight clearly had a mechanical impact on the lumbar region in judokas. In other words, stronger TMS is needed for heavyweight judokas. However, relative TMS normalized by body weight was lower in heavyweight judokas because of their large body weight in Chapter 2. Thus, the present Chapter hypothesized the relationship between LBP and low TMS to be more evident in the heavyweight category.

6-3. Methods

Participants

Approval was obtained from the university's ethics committee and the study meets the ethical standards in sport and exercise science research (97). All the participants gave written informed consent before participating. I informed all the participants and their coaches of the purpose and potential risks of this study. The participants were 66 male collegiate judokas (mean ± SD: age, 20.2 ± 0.9 years; height, 172.7 ±6.3 cm; weight, 84.3 ± 17.3 kg). In this chapter, I classified judokas into three weight categories as follows; the lightweight category (under 60, 66kg, n=14), the middleweight category (under 73, 81kg, n=29), and the heavyweight category (under90, 100, over100kg, n=23). The characteristics of the participants are shown in Table 6-1. All the participants participated in judo practice for a total of 3 hours a day, with sessions happening twice a day, 6 days a week.

Measurement of TMS

TMS was measured isokinetically using the Biodex System3 with the back attachment and torso rotation attachment (Biodex Medical Systems, Inc. Shirley, NY). The peak torques of the trunk extensor, flexor, left-rotator, and right-rotator muscles were measured at angular velocities of 60, 90, and 120°/s. Additionally, I calculated the extensor/flexor ratio and the dominant/non-dominant rotator ratio. Two preliminary movements were performed before each measurement. Reciprocal movements such as extension-flexion and left rotation-right rotation were performed three times for each velocity being tested, and 60-second rest intervals were taken between each velocity being tested. For measuring extension-flexion cycle of the trunk, the participants were placed in a semi-standing posture with their knees flexed at 15°. To determine the trunk extension and flexion movement axes, I first identified L5-S1. I decided that the height of L5-S1 was 3.5 cm below the top of the iliac crest, and the extension and flexion movement axis was a horizontal line passing through the axillary midline on both sides at the height of L5-S1. The range of motion was set at 90°. Based on the instruction manual, full extension was set at 15° from the upright position. The chest, axillae, and dorsal surface of the sacrum were fixed with straps and pads. In the measurement of the left-right rotation cycle of the trunk, the participants were placed in a sitting posture with their feet free above the floor. Trunk left rotator and right rotator movements occurred along the vertical axis, which passed through the center of the cranial bone. The range of motion was set at 90°. I set the median trunk position to 0°. From this position, 45° was set on each side was set. The chest, axillae, bilateral surface of the pelvis, and thighs were fixed with straps and pads.

Evaluation of LBP

The presence of LBP was evaluated by using the questionnaire the OCU test modified by Kuroki and Tajima (88). The OCU test consisted of 10 questions about LBP-related activities of daily living (Table 5-2): lying face up with an extended leg, rising from the bed in the morning, washing of the face in the morning, attaching and detaching trousers and socks while standing, using a Japanese-style toilet, sitting on a chair; standing, walking, going up and down the stairs, and lifting or holding heavy objects. The participants graded each question according to the following criteria: possible without pain (0 points), possible with pain (1 point), impossible (2 points). Based on the test, I grouped the judokas into the non-LBP group and the LBP group when they scored 0 points and 1 or more points, respectively. In all the participants, the non-LBP group and the LBP group had 43 and 23 participants, respectively. In the lightweight category, there were 9 and 5 participants, respectively. In the middleweight category, there were 20 and 9 participants, respectively. Lastly, in the heavyweight category, there were 14 and 9 participants, respectively.

Statistical analyses

I compared with the parameters of TMS (N･m/kg) between the non-LBP group and the LBP group within all participants and weight categories, respectively (Figure 6-1). Unpaired Student's t-test was used for statistical evaluation. The level of significance was set to 5%. All analyses were performed using IBM SPSS Statistics version 25 (IBM Corporation, Armonk, NY, USA).

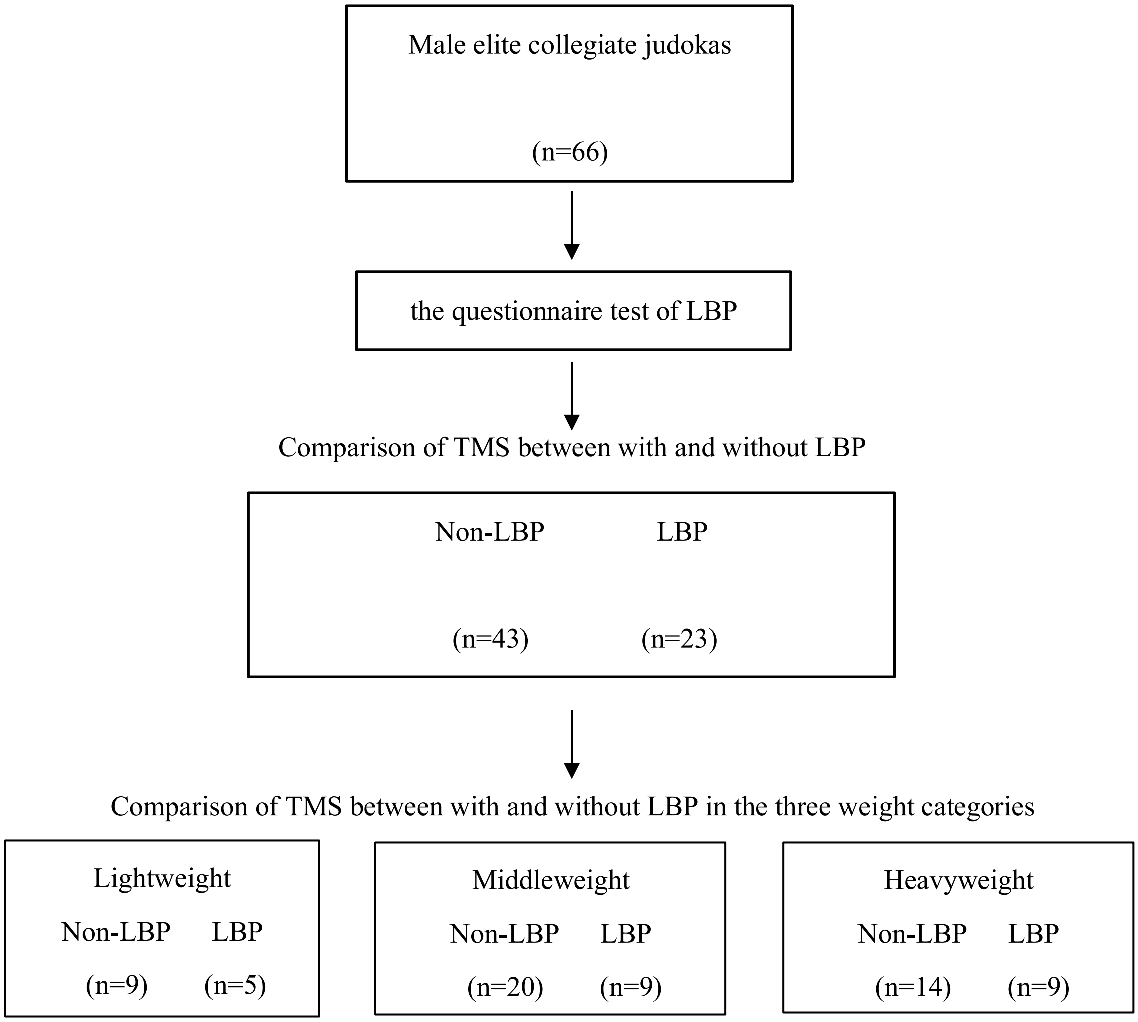

Figure 6-1. Classification of participants and experimental designs.

Table 6-1. Physical characteristics of 66 male collegiate judokas

	All judokas (n=66)	Lightweight (n=14)	Middleweight (n=29)	Heavyweight (n=23)
Age (years)	20.2±0.9	20.1±0.9	19.9±0.8	20.6±0.9
Height (cm)	172.7±6.3	166.7±4.6	172.9±5.3	176.2±5.7
Weight (kg)	84.3±17.3	66.0±4.3	78.6±4.8	102.6±15.5
BMI (kg/m^2)	28.1±4.7	23.7±1.0	26.4±2.0	33.0±4.3
Judo history (years)	10.9±3.0	10.6±3.3	10.4±2.8	11.7±3.1

Data are presented as mean ± SD.

Lightweight, under 60kg and 66kg judokas.

Middleweight, under 73kg and 81kg judokas.

Heavyweight, under 90kg, 100kg, and over 100kg judokas.

6-4. Results

Comparison of the physical characteristics among different weight categories

I first compared physical characteristics among different weight categories (Table 6-2). There were significant differences in height, weight, and BMI, as expected. The heavyweight category showed significant higher values than those of lighter weight categories.

Comparison of the physical characteristics among different weight categories with regard to LBP

I then investigated the physical characteristics of all participants, both in the non-LBP and the LBP groups. As shown in Table 6-2, there are no significant differences of physical characteristics between the non-LBP and LBP groups regardless of weight categories.

Comparison of TMS with regard to LBP

I hypothesized that low TMS in judokas with LBP should be observed especially in those with heavy weight. At the beginning, I compared all judokas with and without LBP (Table 6-3). There was no statistical difference between the non-LBP and LBP groups across all participants. Since I suspected that the relation between LBP and TMS would be highlighted depending on weight category, I further divided judokas into three weight categories (Table 6-4). As expected, in the heavyweight category, extensor at 60°/s and both the dominant side rotator and non-dominant side rotator at 60°/s of the LBP group were significantly lower than that of the non-LBP group ($p<=0.05$, $P<0.01$, and $P<0.05$, respectively; Table 4).

Table 6-2. Physical characteristics of the non-LBP group and the LBP group across all subjects in the three weight categories

Variables	All judokas		Lightweight		Middleweight		Heavyweight	
	Non-LBP (n=43)	LBP (n=23)	Non-LBP (n =9)	LBP (n =5)	Non-LBP (n =20)	LBP (n =9)	Non-LBP (n =14)	LBP (n =9)
Age (years)	20.2±0.9	20.2±0.9	20.2±1.0	20.0±1.0	20.0±0.9	19.9±0.6	20.6±0.8	20.6±1.0
Height (cm)	172.6±5.2	172.9±8.1	168.3±3.3	163.8±5.4	172.1±4.5	174.5±6.8	176.0±4.9	176.4±7.0
Weight (kg)	83.2±15.1	86.4±21.1	67.5±3.7	63.3±4.4	78.8±5.0	78.2±4.7	99.4±14.3	107.6±16.7
BMI (kg/m^2)	27.8±4.1	28.7±5.7	23.8±1.0	23.6±1.0	26.6±1.9	25.7±2.0	32.0±4.0	34.5±4.7
Judo history (years)	11.1±2.8	10.6±3.5	11.4±2.8	9.0±4.0	10.7±2.9	10.0±2.6	11.5±2.7	12.0±3.8

Data are presented as mean ± SD.

LBP, low back pain.

Lightweight, under 60kg and 66kg judokas.

Middleweight, under 73kg and 81kg judokas.

Heavyweight, under 90kg, 100kg, and over 100kg judokas.

Table 6-3. Comparison of peak torques normalized by body weight of trunk muscles as relative TMS between subjects with and without LBP

Variables	Non-LBP (n =43)	LBP (n =23)
Extensor (N・m/kg)		
60°/s	6.52±1.10	6.06±0.75
90°/s	6.35±0.89	6.00±0.68
120°/s	6.11±0.95	5.80±0.74
Flexor (N・m/kg)		
60°/s	3.24±0.63	3.09±0.74
90°/s	3.03±0.58	2.92±0.64
120°/s	2.74±0.56	2.55±0.55
Extensor/Flexor ratio		
60°/s	2.08±0.51	2.05±0.44
90°/s	2.18±0.59	2.14±0.48
120°/s	2.32±0.58	2.37±0.53
Dominant side rotator (N・m/kg)		
60°/s	2.41±0.27	2.35±0.27
90°/s	2.28±0.28	2.25±0.26
120°/s	2.22±0.25	2.17±0.23
Non-Dominant side rotator (N・m/kg)		
60°/s	2.18±0.25	2.17±0.25
90°/s	2.13±0.26	2.08±0.23
120°/s	2.07±0.24	2.02±0.23

Dominant/non-dominant rotator ratio		
60°/s	1.11±0.07	1.08±0.08
90°/s	1.07±0.05	1.08±0.06
120°/s	1.08±0.06	1.08±0.08

Data are presented as mean ± SD.

LBP, low back pain.

Table 6-4. Comparison of peak torques normalized by body weight of trunk muscles as relative TMS between subjects with and without LBP in the three weight categories

Variables	Lightweight		Middleweight		Heavyweight	
	Non-LBP (n=9)	LBP (n=5)	Non-LBP (n=20)	LBP (n =9)	Non-LBP (n=14)	LBP (n=9)
Extensor (N･m/kg)						
60°/s	6.99±1.50	6.29±0.49	6.51±1.08	6.43±0.80	6.24±0.69	5.57±0.58*
90°/s	6.85±1.04	6.24±0.84	6.33±0.86	6.33±0.53	6.05±0.71	5.54±0.48
120°/s	6.51±1.14	6.12±0.72	6.14±0.95	6.08±0.51	5.80±0.76	5.34±0.76
Flexor (N･m/kg)						
60°/s	3.18±0.80	3.40±0.70	3.47±0.60	3.39±0.68	2.96±0.45	2.61±0.62
90°/s	2.90±0.80	3.25±0.45	3.22±0.49	3.19±0.56	2.86±0.52	2.47±0.60
120°/s	2.71±0.84	2.89±0.33	2.93±0.43	2.78±0.48	2.50±0.46	2.12±0.47
Extensor/Flexor ratio						
60°/s	2.30±0.66	1.91±0.37	1.93±0.46	1.95±0.38	2.16±0.42	2.23±0.51
90°/s	2.53±0.80	1.93±0.23	2.02±0.47	2.04±0.35	2.19±0.54	2.37±0.62
120°/s	2.61±0.87	2.14±0.33	2.14±0.44	2.24±0.42	2.38±0.49	2.61±0.65
Dominant side rotator (N･m/kg)						
60°/s	2.36±0.19	2.51±0.33	2.41±0.31	2.45±0.21	2.43±0.26	2.15±0.18*
90°/s	2.36±0.23	2.34±0.22	2.24±0.28	2.36±0.22	2.27±0.31	2.09±0.26
120°/s	2.25±0.24	2.19±0.21	2.22±0.26	2.28±0.23	2.19±0.24	2.05±0.20
Non-Dominant side rotator (N･m/kg)						
60°/s	2.18±0.21	2.30±0.19	2.19±0.29	2.32±0.16	2.17±0.23	1.95±0.19*
90°/s	2.17±0.22	2.17±0.19	2.13±0.30	2.18±0.19	2.09±0.24	1.94±0.24
120°/s	2.10±0.23	2.18±0.14	2.10±0.24	2.09±0.20	2.00±0.25	1.86±0.22
Dominant/non-dominant rotator ratio						
60°/s	1.09±0.07	1.09±0.07	1.10±0.07	1.06±0.06	1.12±0.06	1.11±0.09
90°/s	1.09±0.06	1.08±0.04	1.05±0.05	1.08±0.08	1.09±0.06	1.08±0.04
120°/s	1.08±0.06	1.00±0.07	1.06±0.05	1.09±0.08	1.10±0.06	1.11±0.08

Data are presented as mean ± SD.

LBP, low back pain.

*: The Non-LBP vs. the LBP is statistically different by unpaired Student's t-test in the heavyweight category ($p<0.05$).

6-5. Discussions

This chapter is the first trial to evaluate the relationship between judokas' TMS including rotator strength and LBP. Regarding the relations between TMS and LBP, significant associations between TMS and LBP were observed only in the heavyweight category, as expected. Extensor and rotators at 60°/s of heavyweight judokas having LBP were significantly weaker than those of judokas not having LBP. Other weight categories did not show the same tendency.

Many previous studies involving ordinary people with LBP have shown significantly low strength of both the extensor and flexor muscles in the trunk, and that extensor strength has higher impact for LBP than flexor strength (62-66). However, other previous studies did not point out the same tendencies (70, 96). Moreover, it is also unclear whether flexor or extensor muscle strength contribute to the LBP of athletes, but these reflect the characteristics of their sport (e.g., extension strength for wrestling, trunk rotation strength for golfers) (33, 98). In this chapter, significance was confirmed only for extensor and both sides of rotator in the heavyweight category. As expected, a relationship between peak torque of extensor and rotators, and LBP should exist because extensor and rotator strength are relatively more needed in judokas. However, as a result, significant relations of low TMS and LBP existed only in the heavyweight category; this suggests that the relationship between TMS and LBP varies among cases.

The relationship between low TMS and LBP was more apparent in judokas with heavier body weight. It is conceivable that the result was caused by higher load on the lumbar region caused by heavy body weight. This is consistent with my results in Chapter 2 showing that the absolute values of TMS were significantly larger in heavyweight judokas than those of the other two groups, although the ratio of TMS to body weight was lower in the heavyweight category than in other weight categories. The trunk muscle group has the role of not only agonist trunk movements, but it is also the dynamic stabilizer of lumbar region. LBP-related weakness of the trunk muscle group may be induced by high loads on the lumbar region brought about by sports activities (99). Thus, the possibility of LBP occurring is higher in situations wherein there is the high load on the lumbar region caused by heavy body weight and the relative weakness of TMS.

My colleagues Iwai et al. reported that low trunk extension muscle strength is associated with chronic LBP among wrestling athletes (33). However, in term of extensor/flexor ratio, extension muscle strength is higher than flexion strength, indicating that this represents the characteristics of their sport. There are a few studies that involved neither ordinary people nor athletes, which found that the LBP of judokas has characteristics that are not associated with the abnormal agonist/antagonist ratio in TMS regardless of the weight categories. It seems that judokas with LBP show overall lower TMS, and the strengths of trunk extensors and rotators, which are frequently employed in judo specifically, show much lower value.

Chapter 5 has reported that LBP in middle- and heavyweight judokas almost always accompanies LRA (95). Therefore, this chapter hypothesized that LBP in the lightweight category is more impacted by low TMS compared to other weight categories. However, the influence of low TMS is more apparent in the heavyweight category as shown in this chapter. Although there was no significant difference, the average body weight of the heavyweight LBP group was heavier than that of the non-LBP group. Trunk muscle CSAs is related to LBP, and in the heavyweight category, the lack of muscle strength per body weight may indicate this result (100). It is conceivable that this chapter obtained contradictory results because this chapter did not assess the differential diagnosis of LBP regarding LRA. In the lightweight category, the assignment by the presence of LRA which is a major related factor of LBP is needed because about half of all LBP cases do not accompany any LRA. In the lightweight category specifically, there is a higher necessity to further investigate and remove the influence of LRA.

As mentioned above, this is the first trial to investigate the relationships between rotator TMS and LBP in judokas. Chapter 2 and 3 have found that rotator TMS was not the same among different weight categories and athletic performances. This chapter found here that low rotator TMS was associated with LBP. There are a few studies that investigated the relationship between trunk rotator strength and LBP. Many previous studies have found that the rotation of the trunk affects lumbar disk disease (101, 102). These previous studies that involved ordinary people with LBP did not obtain the same results about the relationship between trunk rotator strength and LBP (103, 104). Other studies have also shown that endurance is more important to prevent LBP than trunk rotation strength in elite male golfers (98). On the other hand, this chapter could point out the relationship between significantly lower trunk rotator strength and LBP related to sports activities. This chapter suggested that the relationship between the low strength of the trunk muscles and LBP is caused by intense sports activity, wherein demands vary per weight category, and/or a higher load on the lumbar region. This consideration was supported in this chapter by confirming the relationship between low TMS and LBP only in the heavyweight category judokas.

My colleagues Iwai et al. pointed out a strong relationship between LBP and low trunk extensor strength, which is particularly important for wrestlers (33). Judo and wrestling have many similarities of sports specificities; thus, trunk extensor strength is also crucial in judokas (22). Also, torso rotation movement plays an essential role in all judo situations, particularly in throwing the opponent, defending throws made by the opponent, and releasing the opponent's hand grasping the sleeve of one's judo-specific uniform called judogi (22). Moreover, Iwai et al. compared the lumbar muscle CSAs and lumbar intervertebral disc degeneration in combat sports (wrestler and judo), and found that the lumbar intervertebral disc degeneration group had small CSAs (100). This study indicated that the lumbar intervertebral disc degeneration group was asymmetrical. The left muscle group in the lumbar intervertebral disc degeneration group was significantly larger than right side. However, this chapter could not confirm similar results, wherein significance was confirmed both sides of rotators. It is considered that this result is caused by the differences between right- and left-handed users, and/or the dominant direction of rotation.

In this chapter, heavyweight judokas having LBP showed significantly weaker TMS of low-speed extension and both sides of rotations. Today, judokas frequently use various fighting techniques originated from ethnic martial arts into judo competition, such as Brazilian Jiu-Jitsu, Sambo of Russia, Chidaoba of Georgia, Bukh of Mongolia, Kurash of central Asia, and others. Fighting techniques of the close combat from these martial arts have become vital to winning the international judo competition. Close combat means that a judoka fights against an opponent in the closed distance to stay close to an opponent's upper body. And then, a judoka tries to lift and throw an opponent by trunk extension and rotation. Thus, judokas consider that trunk extension and rotation strength are more crucial, especially in modern judo. This chapter confirmed the importance of the trunk extension and rotation only in the heavyweight judokas at low-speed movements concerning LBP. These findings are similar results in Chapter 3. Heavyweight judokas with EAP possessed stronger TMS of low-speed on both sides of rotations than LAP in Chapter 3. This chapter revealed that TMS features, which is low-speed on both sides of rotations, would be crucial for heavyweight judokas' not only athletic performance but also LBP. It suggests that strengthening these TMS is a way to improve LBP and athletic performance in heavyweight judokas.

The limitation of this chapter is that LBP was not divided into subgroups diagnosed according to differences in pathology. There is a possibility that the role of TMS in the development of LBP varies among different pathologies. Lumbar radiological abnormal findings make the diagnosis of LBP. Chapter 5 reported that almost all cases of LBP in the middle- and heavyweight categories were accompanied by at least one LRA (95). Thus, in these two categories, it may be unnecessary to divide LBP into subgroups according to the presence of lumbar radiological abnormal findings. However, about half of the LBP cases in the lightweight category were not accompanied by any LRA (95). Thus, for the lightweight category, it may be necessary to divide LBP into subgroups according to the presence of LRA, and further investigation is needed to remove the influence of these abnormalities on the study results. I speculated that the low TMS and LBP relationship is apparent after I investigate the lightweight category.

6-6. Conclusions

The present Chapter examined TMS characteristics in judokas across the weight categories and for those with and without LBP. This chapter concluded that the TMS of heavyweight judokas with LBP is characterized by lower trunk extensor and rotator strength. The relatively high load on the lumbar region caused by heavier bodyweight is the probable reason for its relationship with LBP and low TMS, especially for rotator muscles.

Chapter 7. Association of lower trunk muscle strength with low back pain in elite lightweight judokas is dependent on anatomical changes in the lumbar spine

7-1. Abstract

Purpose: LRA and low TMS are major causes of LBP. Chapter 5 has previously reported that the prevalence of LRA was approximately 90% in the middle- and heavyweight judokas, independent of the occurrence of LBP. However, low TMS, especially rotators, plays a key role in LBP occurrence in heavyweight judokas in Chapter 6. In the present Chapter examined the impact of TMS and LRA on LBP occurrence in lightweight elite judokas.

Methods: The participants were 32 lightweight elite male judokas. The peak torques of the extensor, flexor, and rotators of the TMS were measured. LBP and LRA were defined using a questionnaire and radiological examination (X-ray and MRI), respectively.

Results: The occurrence rate of LBP and LRA were 40.6% and 62.5%, respectively, without any significant correlation. Among judokas without LRA, TMS of those with LBP were significantly lower than those without LBP ($p<0.05$, the extensor 60°/s, 90°/s, and 120 °/s, flexor 60°/s, dominant rotator 60°/s, and 90 °/s, non-dominant rotator 90 °/s, and dominant/non-dominant rotator ratio 90 °/s).

Moreover, there were significant negative correlations between LBP severity and TMS ($p<0.05$, the extensor; 90°/s: $r=-0.63$, dominant rotator; 90°/s: $r=-0.648$, and dominant/non-dominant rotator ratio; 90°/s: $r=-0.621$) in judokas without LRA.

Conclusions: This chapter concluded that weak TMS has an impact on LBP occurrence in lightweight judokas without LRA.

7-2. Introduction

One of the primary purposes of the present doctoral dissertation is to obtain the findings of elite judokas' TMS for helping to prevent and improve judokas' LBP. Therefore, Chapters 5 and 6 investigated TMS, LBP, and LRA characteristics depending on each weight category. As a result, Chapters 5 and 6 obtained some findings related to LBP for middle- and heavyweight categories elite judokas. However, there was less suggestion related to LBP in the lightweight category. Thus, the lightweight category LBP remains more unclear than other weight categories.

In competitive regulation, judokas are divided into seven weight categories. Weight category-dependent sport specificity exists between each weight category, such as techniques, speed, strength, flexibility, reaction time, and others. Lighter weight judokas' movements are faster (4) and more diverse. On the other hand, heavyweight judokas are the opposite. For the trunk region, Chapter 2 revealed that TMS differed depending on weight category. The absolute TMS of all directions was stronger in a heavier weight category than in a lighter weight category. The relative TMS of judokas decreased in heavyweight, except for rotations. Moreover, the characteristics of judo-related injuries differ according to body weight, favorite technique, judo history, etc. (1, 30, 31). These findings suggest that it is necessary to investigate more closely for a better understanding of the relationship between LBP and TMS in judokas.

In Chapter 5 regarding specified ongoing LBP, 30%–40% of elite judokas experienced LBP regardless of weight categories (95). Although the pathogenesis of LBP is very complicated, TMS weakness is strongly implicated in contributing to LBP (62, 65, 66, 105). TMS is also an essential element of judo, and if TMS is weak in one area, imbalance may occur, thus increasing the risk of injury (10). Furthermore, anatomical changes in the lumbar spine detected by LRA are another major cause of LBP. Previous study reported a high prevalence of LRA related to LBP in judokas (47).

Chapter 5 confirmed that LRA occurred in 65.5% of judokas in the lightweight, 90.3% in the middleweight, and 90.9% in the heavyweight categories (95). LBP accompanied by LRA was observed in 50%, 100%, and 88.9% of judokas in the lightweight, middleweight, and heavyweight categories, respectively. Therefore, almost all LBPs occurring in middleweight and heavyweight judokas were accompanied LRA; however, half of the LBPs in lightweight judokas were not. Therefore, there is a possibility that the LBP in lightweight judokas has different characteristics from that in the two heavier weight categories.

Chapter 6 showed low TMS of extension and rotation only in the heavyweight category with LBP (79). However, Chapter 6 could not reveal such associations of LBP among lightweight judokas. My colleagues Iwai et al. added LRA as a factor related to LBP to clarify the relationship between LBP and TMS in collegiate wrestlers. Consequently, wrestlers with LBP not accompanied by LRA had more severe LBP and weaker TMS (33). The average body weight of these wrestlers was 68.7 kg, which is close to that of lightweight judokas. Therefore, it is vital to evaluate TMS by considering LRA for LBP in lightweight judokas.

The present Chapter hypothesized that the relationship between LBP and TMS would become clear when limiting participants to lightweight judokas without LRA. Therefore, this chapter aimed to investigate the relationship between LBP and TMS, including rotators in judokas, and limited participants to elite lightweight judokas and defined LBP with or without LRA using the lumbar radiological examination. Moreover, this chapter investigated the correlation between the severity of LBP and TMS to clarify the different relationships between judokas' LBP and TMS.

7-3. Methods

Participants

Approval was obtained from the university's ethics committee, and the study conformed with the tenets of the Declaration of Helsinki (74). This chapter recruited all the judokas belonging to the university judo club who could participate. All participants provided written informed consent before participating in the study. All participants and their coaches were informed of the purpose and potential risks of the study. The participants were 32 male collegiate lightweight judokas in the 60 and 66 kg categories (mean ± SD: age, 19.9 ± 0.8 years; height, 166.7 ±4.7 cm; weight, 66.9 ± 4.4 kg). The participants' characteristics are presented in Table 7-1. All participants participated in judo practice for 3 hours a day, with sessions twice a day, 6 days a week.

LBP evaluation using questionnaires regarding associated functional disability levels

The presence of LBP was evaluated using a questionnaire the OCU test modified by Kuroki and Tajima (88). The OCU test comprised 10 questions about LBP-related activities of daily living (Table 5-2): lying face up with an extended leg, rising from the bed in the morning, washing the face in the morning, attaching and detaching trousers and socks while standing, using a Japanese-style toilet, sitting on a chair, standing, walking, going up and down stairs, and lifting or holding heavy objects. The participants graded each question according to the following criteria: possible without pain (0 points), possible with pain (1 point), and impossible (2 points); resultantly, I grouped the judokas into the non-LBP group and the LBP group when they scored 0 points and 1 or more points, respectively (95). The sum of the total points of all 10 items (range 0–20) was calculated as the functional disability level of LBP as LBP severity, with a higher value indicating a more severe level of LBP in the OCU test (33).

Radiological Examination

Two experienced orthopedic surgeons examined the plain film radiographs and MRI (Hitachi Medical Corporation, Tokyo, Japan) to determine abnormalities of the lumbar vertebrae and intervertebral discs. The radiographic films were obtained with anteroposterior, lateral, and right and left anterior oblique views. MRI was performed with a 0.3-T unit using surface coils with a body coil in the supine position. T2-weighted fast spin-echo was used to obtain sagittal images of the lumbar spine and lumbar intervertebral discs. I modified the definitions of LRA presented by Iwamoto et al. (51) MRI-detected LRA, such as lumbar intervertebral disc degeneration and disc protrusion, were added to the definitions (Table 5-3) (95). Some congenital abnormalities, such as transitional vertebra and spina bifida occulta, were excluded because they were not caused by engaging in sports activities. The definition of spinal instability was excluded because it indicated malalignment of the lumbar spine during trunk flexion and extension and not anatomical changes in the lumbar vertebrae. The image assessment to determine the presence of LRA was independently performed by two orthopedic surgeons without knowledge of the LBP status of the individual. Disagreements were resolved by consensus between the two orthopedic surgeons in the event of a discrepancy in the presence of LRA. Disagreements between the two orthopedic surgeons were resolved by consensus. LRA was considered to be present when an athlete exhibited at least one abnormal finding (95).

Measurement of TMS

TMS was measured isokinetically using the Biodex System3 with the back attachment and torso rotation attachment (Biodex Medical Systems, Inc. Shirley, NY). The peak torques of the trunk extensor, flexor, left-rotator, and right-rotator muscles were measured at angular velocities of 60, 90, and 120°/s. Additionally, I calculated the extensor/flexor ratio and the dominant/non-dominant rotator ratio. Two preliminary movements were performed before each measurement. Reciprocal movements such as extension-flexion and left rotation-right rotation were performed three times for each velocity being tested, and 60-second rest intervals were taken between each velocity being tested. For measuring extension-flexion cycle of the trunk, the participants were placed in a semi-standing posture with their knees flexed at 15°. To determine the trunk extension and flexion movement axes, I first identified L5-S1. I decided that the height of L5-S1 was 3.5 cm below the top of the iliac crest, and the extension and flexion movement axis was a horizontal line passing through the axillary midline on both sides at the height of L5-S1. The range of motion was set at 90°. Based on the instruction manual, full extension was set at 15° from the upright position. The chest, axillae, and dorsal surface of the sacrum were fixed with straps and pads. In the measurement of the left-right rotation cycle of the trunk, the participants were placed in a sitting posture with their feet free above the floor. Trunk left rotator and right rotator movements occurred along the vertical axis, which passed through the center of the cranial bone. The range of motion was set at 90°. I set the median trunk position to 0°. From this position, 45° was set on each side was set. The chest, axillae, bilateral surface of the pelvis, and thighs were fixed with straps and pads.

Statistics

All classification of participants and experimental designs are shown in Figure 7-1. Based on the evaluation of LBP, I classified judokas into two groups: the non-LBP group (n=19) and the LBP group (n=13). I classified judokas into two groups based on the radiological examination: the non-LRA group (n=12) and the LRA group (n=20).

I compared the TMS (N･m) parameters between the non-LBP and LBP groups and the non-LRA and LRA groups. I compared TMS between the non-LBP (N=13) and the LBP (N=7) group with LRA and between the non-LBP (N=6) and the LBP (N=6) group without LRA. Unpaired Student's t-test was used for statistical evaluation.

Moreover, correlations between the functional disability level of LBP as LBP severity and TMS in judokas with and without LRA were analyzed using Spearman's rank correlation coefficient (r). LBP severity was calculated from the OCU test scores, which is the sum of the total points related to the ADL (range 0–20, higher the values more severe the LBP). The level of significance was set to 5%. All analyses were performed using IBM SPSS Statistics version 25 (IBM Corporation, Armonk, NY, USA).

Table 7-1. Physical characteristics of 32 male collegiate lightweight judokas consisted of under 60kg and 66kg categories.

	Lightweight Judokas (n=32)
Age (years)	19.9±0.8
Height (cm)	166.7±4.7
Weight (kg)	66.9±4.4
BMI (kg/m^2)	24.1±1.3
Judo history (years)	11.0±3.3

Data are presented as mean ± SD.

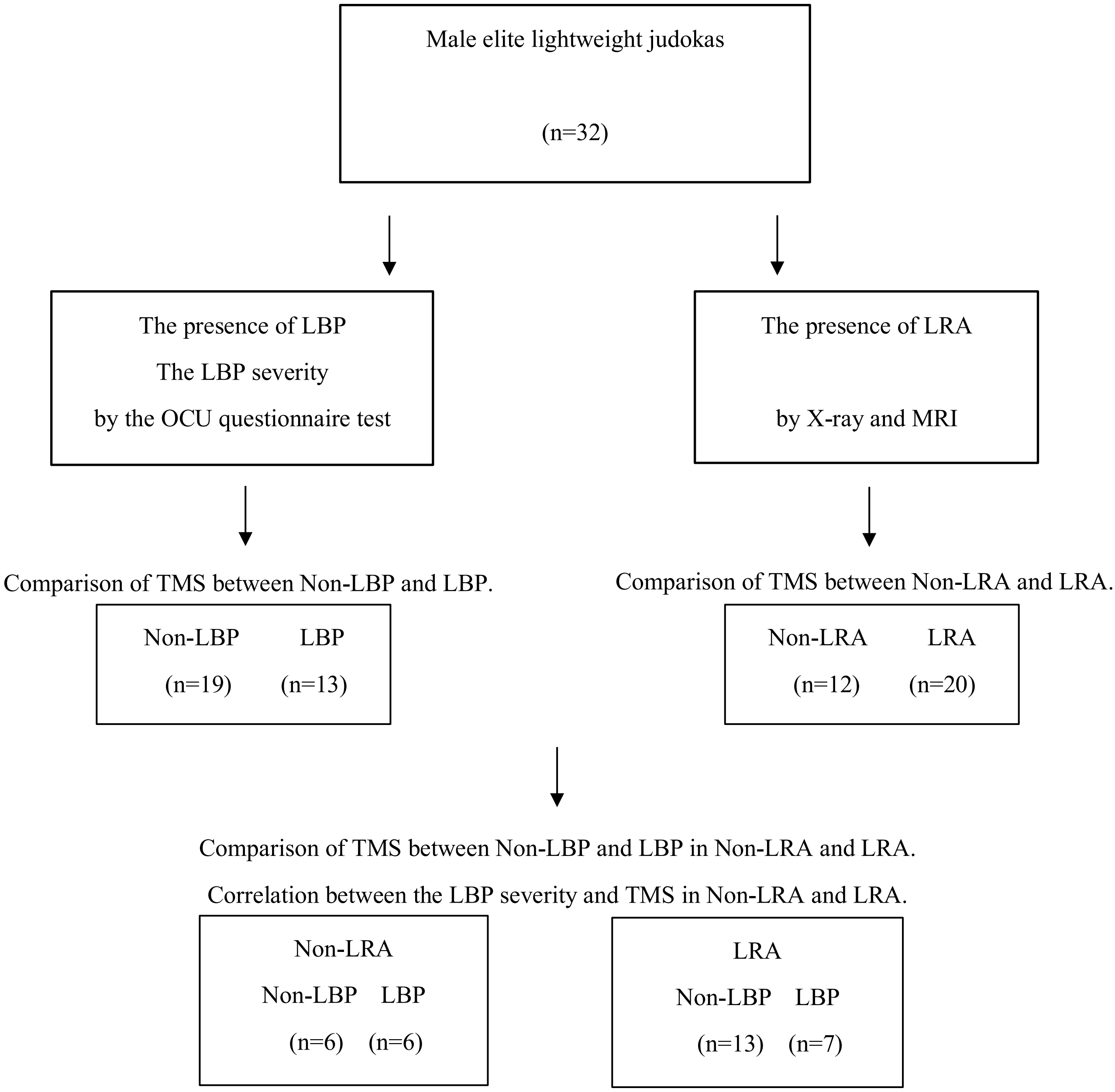

Figure 7-1. Classification of participants and experimental designs.

7-4. Results

Prevalence and Functional disability of LBP

The prevalence of LBP was 40.6% (13/32) , and that of non-LBP was 59.4% (19/32) (Table 7-2). The mean ± SD LBP severity (score on the OCU test) of those with LBP was 2.0 ± 1.2 (range, 1–5).

Prevalence of LRA and their details

The prevalence of LRA was 62.5% (20/32) , and that of non-LRA was 37.5% (12/32) (Table 7-2). Spondylolysis and lumbar intervertebral disc degeneration are frequently observed. The prevalence was 40.6% (13/32) and 31.3% (10/32), respectively. Other LRA included balloon disc 12.5% (4/32), limbus vertebrae 6.3% (2/32), spurring 3.1% (1/32), and disc space narrowing 3.1% (1/32).

Prevalence and Functional disability of LBP with and without LRA

In judokas with LRA, the prevalence of LBP was 35.0% (7/20) , and that of non-LBP was 65.0% (13/22) (Table 7-3). In the judokas without LRA, the prevalence of LBP was 50.0% (6/12) , and that of non-LBP was 50.0% (6/12) (Table 7-3).

The LBP severity (score on the OCU test, mean ± SD) was mean ± SD functional disability level (score on the OCU test) of those with LRA and without LRA were 2.1 ± 1.5 (range, 1–5) and 1.8 ± 1.0 (range, 1–3), respectively. There was no statistical difference between the LRA and non-LRA groups in the OCU test scores.

Comparison of TMS

There was no significant difference in TMS between judokas with and without LBP (Table 7-4) and between judokas with and without LRA (Table 7-5).

There were significant differences in judokas, not with LRA (Table 7-6), but without LRA (Table 7). Judokas without LRA had significantly lower TMS than those without LBP ($p<0.05$, the extensor 60°/s, 90°/s, and 120 °/s, flexor 60°/s, dominant rotator 60°/s, and 90 °/s, non-dominant rotator 90 °/s, and dominant/non-dominant rotator ratio 90 °/s).

Correlation between the severity of LBP and TMS

There was no significant correlation between the mean ± SD functional disability level (score on the OCU test) and TMS in all judokas and judokas with LRA (Table 7-8).

In judokas without LRA, there were significant negative correlations between the mean ± SD functional disability level (score on the OCU test) and TMS ($p<0.05$) in the extensor (90°/s; $r=-0.63$), dominant rotator (90°/s; $r=-0.648$) and dominant/non-dominant rotator ratio (90°/s; $r=-0.621$). (Table 10) Dominant/non-dominant rotator ratios were 1.17 to 1.03 in judokas without LRA.

Table 7-2. The prevalence of LBP and LRA in the lightweight judokas.

	Lightweight Judokas (n=32)
non LBP	59.4% (n=19)
LBP	40.6% (n=13)
non LRA	37.5% (n=12)
LRA	62.5% (n=20)

LBP, low back pain.

LRA, lumbar radiological abnormality.

Lightweight, under 60kg and 66kg judokas.

Table 7-3. The prevalence of LBP with and without LRA in the lightweight judokas.

	Judokas without LRA (n=12)	Judokas with LRA (n=20)
non LBP	50.0% (n=6)	65.0% (n=13)
LBP	50.0% (n=6)	35.0% (n=7)

LBP, low back pain.

LRA, lumbar radiological abnormality.

Lightweight, under 60kg and 66kg judokas.

Table 7-4. Comparison of peak torques of trunk muscles between subjects with and without LBP.

Variables	Non-LBP (n=19)	LBP (n=13)
Extensor (N・m)		
60°/s	463.8±90.0	409.4±66.1
90°/s	450.2±69.7	404.7±49.3
120°/s	430.6±81.1	389.0±53.8
Flexor (N・m)		
60°/s	223.4±54.6	205.5±46.7
90°/s	208.0±54.7	196.5±43.6
120°/s	188.4±55.0	183.9±31.2
Extensor/Flexor ratio		
60°/s	2.14±0.48	2.05±0.46
90°/s	2.28±0.63	2.12±0.38
120°/s	2.44±0.76	2.16±0.38
Dominant side rotator (N・m)		
60°/s	162.9±20.6	152.2±26.6
90°/s	159.5±20.2	146.5±24.7
120°/s	152.8±20.6	141.1±18.3
Non-dominant side rotator (N・m)		
60°/s	149.7±18.0	141.1±22.5
90°/s	147.6±18.3	135.7±23.7
120°/s	142.4±18.3	133.8±22.9
Dominant/Non-dominant rotator ratio		

60°/s	1.09±0.07	1.08±0.08
90°/s	1.08±0.05	1.07±0.05
120°/s	1.06±0.06	1.04±0.05

Data are presented as mean ± SD.

LBP, low back pain.

Table 7-5. Comparison of peak torques of trunk muscles between subjects with and without LRA.

Variables	Non-LRA (n=12)	LRA (n=20)
Extensor (N・m)		
60°/s	429.3±92.2	449.2±80.9
90°/s	420.3±65.5	438.6±66.0
120°/s	419.4±67.8	410.3±78.0
Flexor (N・m)		
60°/s	218.8±46.2	214.5±55.5
90°/s	199.4±52.2	205.7±50.0
120°/s	189.1±51.4	185.1±44.1
Extensor/Flexor ratio		
60°/s	1.98±0.25	2.19±0.55
90°/s	2.20±0.53	2.23±0.56
120°/s	2.38±0.78	2.30±0.56
Dominant side rotator (N・m)		
60°/s	159.3±19.4	158.1±26.0
90°/s	158.0±17.9	151.9±25.2
120°/s	149.4±21.8	147.3±23.6
Non-dominant side rotator (N・m)		
60°/s	148.9±17.6	144.6±21.6
90°/s	145.5±18.1	141.1±23.0
120°/s	140.4±22.1	138.0±19.9

Dominant/Non-dominant rotator ratio		
60°/s	1.08±0.08	1.09±0.07
90°/s	1.08±0.06	1.07±0.05
120°/s	1.05±0.05	1.06±0.06

Data are presented as mean ± SD.

LRA, lumbar radiological abnormality.

Table 7-6. Comparison of peak torques of trunk muscles between subjects with and without LBP in judokas having LRA.

Variables	Non-LBP (n=13)	LBP (n=7)
Extensor (N・m)		
60°/s	455.2±89.7	438.0±66.6
90°/s	443.6±78.4	429.3±36.6
120°/s	418.3±86.3	395.4±62.6
Flexor (N・m)		
60°/s	212.6±55.4	218.0±60.0
90°/s	202.9±50.5	210.8±52.7
120°/s	183.6±48.9	187.9±37.1
Extensor/Flexor ratio		
60°/s	2.22±0.54	2.11±0.60
90°/s	2.28±0.62	2.13±0.44
120°/s	2.37±0.61	2.16±0.46
Dominant side rotator (N・m)		
60°/s	158.8±20.5	156.8±36.1
90°/s	154.5±20.6	147.1±33.6
120°/s	149.4±18.1	143.4±32.8
Non-dominant side rotator (N・m)		
60°/s	145.6±17.0	142.6±29.9
90°/s	143.5±17.6	136.7±32.1

120°/s	139.1±11.6	136.0±31.2
Dominant/Non-dominant rotator ratio		
60°/s	1.08±0.07	1.10±0.08
90°/s	1.06±0.05	1.09±0.04
120°/s	1.06±0.07	1.04±0.05

Data are presented as mean ± SD.

LBP, low back pain.

LRA, lumbar radiological abnormality.

Table 7-7. Comparison of peak torques of trunk muscles between subjects with and without LBP in judokas not having LRA.

Variables	Non-LBP (n=6)	LBP (n=6)
Extensor (N・m)		
60°/s	482.5±96.0	376.1±51.8*
90°/s	464.6±48.4	376.0±48.9*
120°/s	457.3±67.7	381.5±45.9*
Flexor (N・m)		
60°/s	246.7±49.3	191.0±20.3*
90°/s	219.0±66.8	179.9±24.7
120°/s	198.8±70.3	179.3±25.5
Extensor/Flexor ratio		
60°/s	1.97±0.27	1.98±0.26
90°/s	2.28±0.71	2.12±0.33
120°/s	2.58±1.06	2.17±0.29
Dominant side rotator (N・m)		
60°/s	171.8±19.5	146.8±8.7*
90°/s	170.3±15.5	145.7±10.2*
120°/s	149.6±28.1	131.3±8.9
Non-dominant side rotator (N・m)		
60°/s	158.4±18.2	139.4±11.5
90°/s	156.4±18.0	134.5±10.4*

120°/s	149.6±28.1	131.3±8.9
Dominant/Non-dominant rotator ratio		
60°/s	1.10±0.06	1.05±0.08
90°/s	1.12±0.04	1.05±0.05*
120°/s	1.07±0.05	1.03±0.05

Data are presented as mean ± SD.

LBP, low back pain.

LRA, lumbar radiological abnormality.

*: The Non-LBP vs. the LBP is statistically different by unpaired Student's t-test ($p<0.05$).

Table 7-8. Correlation between the LBP severity and peak torques of trunk muscles in subjects with and without LRA.

	Judokas without LRA (n=12)		Judokas with LRA (n=20)	
Variables	r	p	r	p
Extensor				
60°/s	-0.449	0.143	0.043	0.856
90°/s	-0.630*	0.028	0.006	0.979
120°/s	-0.535	0.073	-0.184	0.437
Flexor				
60°/s	-0.543	0.068	0.134	0.575
90°/s	-0.185	0.565	0.226	0.339
120°/s	0.019	0.954	0.180	0.449
Extensor/Flexor ratio				
60°/s	0.285	0.369	-0.208	0.379
90°/s	-0.072	0.824	-0.200	0.398
120°/s	-0.055	0.865	-0.177	0.456
Dominant side rotator				
60°/s	-0.471	0.122	0.057	0.810
90°/s	-0.648*	0.023	-0.023	0.923
120°/s	-0.275	0.387	-0.004	0.985
Non-dominant side rotator				
60°/s	-0.268	0.400	0.010	0.968
90°/s	-0.392	0.207	-0.019	0.938
120°/s	-0.132	0.683	0.037	0.876
Dominant/Non-dominant rotator ratio				
60°/s	-0.389	0.211	0.172	0.470
90°/s	-0.621*	0.031	0.289	0.216
120°/s	-0.286	0.367	-0.101	0.671

LBP, low back pain.

LRA, lumbar radiological abnormality.

*: Statistical negative correlation between the Osaka City University test score and trunk muscle strength ($p<0.05$).

7-5. Discussions

Chapter 5 found that almost all LBPs accompanied LRA in middle and heavyweight judokas (100% and 88.9%, respectively) (95). However, no more than 50% of LBP in lightweight judokas is accompanied by LRA (95). Thus, this chapter used lumbar radiological examination to detect LRA and remove the influence of LRA on LBP to investigate the relationship between LBP and TMS in judokas. Moreover, this chapter limited the participants to lightweight judokas who could not reveal any LBP factors such as LRA and TMS in Chapter 5 and 6 (79, 95). Furthermore, this chapter analyzed the relationship between the severity of LBP and TMS for deeper examination. Although these factors and experimental procedures may be essential to analyze trunk conditions related to judokas' LBP, no study has examined the relationship between LBP, LRA, and TMS in judokas.

This chapter observed many relationships between LBP and TMS when limiting participants to lightweight judokas without LRA. Nevertheless, there was no relationship between judokas without LRA. Regarding those without accompanying LRA, lightweight judokas with LBP had weaker TMS than those without LBP. Significant differences were observed in all directions of TMS as follows: extensor, flexor, dominant rotator, and non-dominant rotator. Moreover, judokas with more severe LBP without LRA exhibited weaker TMS, especially for extensors and dominant rotators. Furthermore, the dominant/non-dominant rotator ratio was the only ratio that showed a significantly lower value with LBP severity. Although many studies on LBP and TMS, some have positive results, while others are negative. Despite these previous controversial studies (70, 96), this chapter detected the relationship between LBP and TMS due to detailed participant classification limited to lightweight judokas, and using the lumbar radiological examination. These results are generally consistent with those of my colleagues Iwai et al. regarding wrestlers (33).

The prevalence of LBP and LRA was 40.6% and 62.5%, respectively. In judokas with and without LRA, the prevalence of LBP was 35.0% and 50.0%, respectively. These values are close to those reported in Chapter 5 (95). Therefore, half of the lightweight judokas' LBP did not accompany LRA. However, it has been reported that most middle and heavyweight judokas with LBP had LRA in Chapter 5 (95). Judokas are loaded to the lumbar region from their body weight and their opponent's body weight. Thus, the load on the lumbar region in lightweight judokas should be lower than that in middleweight and heavyweight judokas. Moreover, Chapter 2 (79) showed that TMS per unit body weight of lighter-weight judokas was higher than that of heavier-weight judokas. These might be associated with a lower prevalence of LRA in lightweight judokas' than heavier weight judokas. The range 1–5 of LBP severity (score on the OCU test) obtained in this chapter ranges from slight LBP with only one painful ADL to LBP with 1/4th of all the ADLs painful. These values indicate the LBP severity at which judokas can continue to practice judo.

Additionally, differences in judo movement can influence the occurrence of LRA. In judo competitions, there are many movements, such as grasping opponents' judo-gi, which means a competitive jacket and swerving the opponent's posture. In an offensive situation, judokas use throwing techniques. Moreover, in defensive situations, they react against opponents' movements and rapidly escape or defend against opponents' offenses. Further, weight-category-dependent characteristics of activities certainly exist (3, 4). Lightweight judokas usually move more and faster than heavier-weight judokas (4). Moreover, their movements are multidirectional and sometimes highly flexible. These characteristics of lightweight judokas mean that they try to turn aside the opponent's force and body weight unless they face it head-on. Therefore, the lumbar region, especially for hard tissues such as vertebrae and intervertebral discs, would be harder to take a load off; hence, the prevalence of LRA is lower than that of heavier weight categories. Conversely, the load to the soft tissue, including the trunk muscles, can become stronger. Thus, the relationship between TMS and LBP was more significant than that of heavier weight categories.

Moreover, the prevalence of lumbar disc intervertebral degeneration and spondylolysis differed between lightweight judokas in this chapter and middle and heavy weight judokas in Chapter 5. In Chapter 5, the prevalence of lumbar intervertebral disc degeneration was overwhelmingly high, and spondylolysis was the next most prevalent LRA in middle and heavy weight judokas (95). Contrarily, in this chapter pertaining to lightweight judokas, lumbar intervertebral disc degeneration (31.3%) was the second most prevalent LRA following spondylolysis (40.6%). Thus, such differences in the order of prevalence of lumbar intervertebral disc degeneration and spondylolysis depending on the weight category certainly exist. This might be associated with the difference in stress on the lumbar region depending on the weight categories. These results suggest that the LRA of lightweight judokas does not depend on the axial load on the lumbar region, which may damage the lumbar vertebral discs. Still, their highly flexible movements that damage the pars interarticularis of the vertebral arch would cause spondylolysis (106). This suggests that lightweight judokas' movements differ from heavier weight judokas, precisely to move the whole body flexibly and rapidly, as mentioned above. Thus, this movement specificity is affected by the individual prevalence of LRA and the relationship between TMS and LBP.

Lightweight judokas with LBP without LRA had lower TMS in all movement directions, although this was not observed at all moment speeds. On the other hand, those with LRA did not show the same tendency. Trunk movement plays an essential role in almost all judo situations. The situation to throw the opponent with dynamic trunk movement is easy to understand, although the importance is not different even in other situations without dynamic trunk movement. Judokas must try to keep grasping the favorite parts of an opponent's judo-gi before judokas attempt to use their throwing techniques. It is essential to create a prevailing situation for each judoka. Even in this situation, trunk movement is critical (107). The trunk seems to be static in these situations, but the trunk statically outputs a strong force. Moreover, as mentioned above, lighter-weight judokas move their trunks multi-directionally and more flexibly than do heavier-weight judokas. Consequently, lightweight judokas especially had a lower prevalence of LRA than did heavier-weight judokas, and the associations between all directions of TMS and LBP became evident. It appears that the presence of LRA makes the detection of the relationship between TMS and LBP difficult.

As a further new finding, this chapter confirmed that lightweight judokas suffering from more severe LBP had lower TMS, especially for the extensor and rotator only in the case without LRA. No studies on judokas have pointed out the relationship between the severity of LBP and TMS. My colleagues Iwai et al. investigated extensor and flexor TMS, except for rotators of wrestlers (33). This previous report confirmed that wrestlers with severe LBP had weak extensors. Moreover, Chapter 4 reported that rotator TMS is more crucial for judokas than for wrestlers (22). Taken together, these findings are similar to the results of this chapter. I believe that the trunk extensor and rotator will be particularly important for judo movements. This is because judokas move their trunk extensionally and rotationally on many occasions. Thus, the relationship between low extension and rotation strength and LBP is becoming more robust in lightweight judokas without LRA. Judokas with LRA might have factors other than TMS that are related to LBP severity.

Asymmetry is considered a factor in sports injuries (100, 108). The asymmetry in TMS is significantly higher on the dominant side than on the non-dominant side, depending on the sport (109). This may be attributed to asymmetrical differences in movement patterns in sports. The asymmetry of the trunk muscles certainly exists in combat sports, including judo (108). However, its association with LBP remains unclear. This chapter examined trunk rotational strength, which has an important role, especially in judokas, to determine the laterality of the lumbar region. Only in the judokas without LRA, judokas having LBP showed a significantly lower dominant/non-dominant rotator ratio than that of judokas not having LBP. Moreover, LBP severity in lightweight judokas without LRA was significantly correlated with dominant rotator strength and dominant/non-dominant rotator ratio. In lightweight judokas without LRA, the weakness of dominant rotator strength will have a strong association with LBP severity. However, the dominant/non-dominant rotator ratio was close to 1.0, with more severe LBP. These results suggest that lightweight judokas with more severe LBP had relatively asymmetrical but symmetrical trunk rotators because of their dominant rotator weakness. Therefore, I considered that trunk rotational asymmetry was not associated with LBP severity, especially for lightweight judokas without LRA. Instead, the problem may have been the weakness of the dominant rotator. For lightweight judokas without LRA, trunk rotational asymmetry depending on strong dominant-rotator strength would not be associated with LBP and would be appropriate to compete in high-level matches. However, this tendency decreased more in judokas with severe LBP. This chapter investigated LBP by limiting participants to lightweight judokas and using LRA, revealing that the TMS characteristics of lightweight judokas, whose load to the lumbar region causing LBP are smaller than those of heavier weight categories.

This chapter attempted to divide judokas' LBP into LRA groups and limit participant to lightweight judokas. Consequently, not only were novel findings of LBP for elite judokas obtained, but this might have been a limitation in that the sample size of each group was small. It is necessary to accumulate participants to strengthen the reliability of the data. Moreover, this chapter and Chapter 6 cannot demonstrate whether the strengthening of TMS helps improve and prevent LBP because these findings are obtained cross-sectionally. Additionally, it may be essential to consider the day when LRA occurred. If LRA occurred recently, its effect may be more robust and cause LBP more directly. However, some evidence suggests that weak TMS has a definite possibility of causing LBP in lightweight judokas without LRA.

7-6. Conclusions

LRA would greatly impact the LBP of almost all judokas, although the relationship between low TMS and LBP will be more robust in lightweight judokas only in the absence of LRA. Moreover, judokas with a more severe LBP had lower TMS, especially for the extensors and dominant rotator. This tendency may be based on lightweight judokas' athletic specificity, as they move rapidly and multi-directionally with enormous flexibility.

Chapter 8. General discussion

8-1. Summary

This doctoral dissertation aimed to enhance the athletic performance of judokas by investigating the following:

1. The characteristics of trunk muscles and their relationship to athletic performance in elite judokas depending on weight categories (Chapters 2–4)

2. The relationship between low back injuries; namely LBP and LRA, and TMS in elite judokas depending on weight categories (Chapters 5–7)

Chapters 2–4 analyzed TMS and its relationship to the athletic performance of judokas as a functional aspect of the trunk region. Chapter 2 investigated the TMS of elite judokas. This doctoral dissertation mainly measured trunk rotator strength and analyzed TMS depending on the weight category. The results showed that the absolute TMS in all directions was stronger in the heavier weight category than in the lighter weight category. The relative TMS (normalized to body weight) of judokas decreased in the heavyweight category, except for rotations, suggesting that the rotator is more vital to judokas.

Chapter 3 analyzed the relationship between TMS and athletic performance in elite judokas.

This chapter observed stronger extensor, extensor per body weight, and extensor/flexor ratio in the middleweight category. In addition, both sides of the rotator were stronger in the heavyweight category. However, there were no significant differences in the lightweight category. Therefore, TMS was associated with athletic performance in elite judokas, except for lightweight judokas. Trunk extension and rotation were essential for middleweight and heavyweight judokas, respectively.

Chapter 4 compared trunk muscle CSA and TMS between elite judokas and wrestlers to determine the detailed characteristics specific to the trunk muscles in judokas. The CSAs of the QL and OB were larger in the judokas than those in the wrestlers. In contrast, the CSAs of the RA were smaller in the judokas than those in the wrestlers. In addition, this chapter confirmed significantly weaker extensor and flexor strengths in the judokas than those in the wrestlers. Thus, the sport-specific characteristics of the judokas' trunk muscles differed from wrestlers, who have athletic similarities. Thus, judokas should focus on strengthening the trunk rotation and lateral flexion motions.

Chapters 5–7 analyzed LRA, TMS, and their relationships to LBP in judokas as a medical aspect of the trunk region. Chapter 5 investigated the prevalence of nsLBP and LRA in elite judokas and analyzed its relationships according to weight categories. The prevalence of nsLBP was 30%–40%, with no difference between the weight categories. In contrast, the LRA prevalence was over 90% in the middle and heavyweight categories compared to 65.5% in the lightweight category. The prevalence of LRA in patients with nsLBP (79.3%) was similar to that in those without nsLBP (83.0%), suggesting a lack of direct association between nsLBP and LRA. However, the prevalence of LRA in judokas with nsLBP in the lightweight, middleweight, and heavyweight categories was 50.0%, 100%, and 88.9%, respectively, with differences between the lightweight and heavier categories.

Chapter 6 analyzed the relationship between weight-category-dependent TMS and LBP in elite judokas. Judokas with LBP showed significantly weaker extensors and bilateral rotators compared to judokas without LBP only in TMS (normalized by body weight) in the heavier weight category. The TMS of heavyweight judokas with LBP was characterized by lower trunk extensor and rotator strength. The relatively high load on the lumbar region caused by heavier body weight was likely due to its relationship with LBP and low TMS, especially for the rotator muscles. Both sides of the rotators were associated with both athletic performance and LBP.

Chapter 7 examined the impact of TMS on LBP occurrence in lightweight elite judokas based on the LRA because the LRA impact on LBP differed in lightweight judokas compared to the heavier weight categories. This chapter revealed the associations between LBP and TMS in lightweight judokas only in the absence of LRA. Lightweight judokas with LBP without LRA had weaker extensor, flexor, and bilateral rotator strength. Moreover, judokas with more severe LBP showed lower TMS, especially the extensor, dominant-rotator, and dominant/non-dominant rotator ratios. The same tendencies were not observed for lightweight judokas with LRA. Therefore, weak TMS affected LBP occurrence in lightweight judokas without LRA.

8-2. Practical implications

Since this was a cross-sectional study, it was impossible to clarify causal relationships. However, the findings from this study may be used to enhance athletic performance and prevent and improve low back injuries.

The results of Chapters 2–4, which examined the relationship between athletic performance and trunk muscles, indicated that all judoka athletes should increase their rotational muscle strength. Moreover, judokas in the middleweight and heavyweight categories should strengthen their high-speed extension and low-speed rotation, respectively. As the results did could not identify a relationship between TMS and athletic performance, lightweight judokas may need to strengthen factors other than TMS.

Trunk rotators also generate lateral trunk flexion. Although this study did not evaluate lateral flexion, the CSA of the quadratus lumborum muscle, a lateral flexor, was larger in judokas than in wrestlers. Many lateral flexion movements are required for grappling and throwing techniques, such as the sasae-tsurikomi-ashi. Judokas may also need to strengthen lateral trunk flexion and rotations.

The results of Chapters 5–7, which examined the relationship between low back injuries and trunk muscles, the association of trunk extensor and rotator strength with LBP in the heavyweight category. Although it is not clear whether trunk extensors and rotators are effective in preventing or improving LBP, they should be strengthened to prevent reduced athletic performance. Similarly, lightweight judokas without anatomical changes in the lumbar spine should strengthen all directions of TMS, particularly that related to extension and rotation. However, this study did not observe a relationship between the direction of trunk movement and LBP in the middleweight category; thus, this subject requires further research.

8-3. Limitations

The cross-sectional design of this study prevented the identification of causal relationships. However, it would be difficult to prove the causal relationships in a longitudinal study owing to the different patterns of winning and losing in judo, including patterns that are not affected by TMS. Therefore, although the cross-sectional design is a limitation, it allowed assessment of judoka trunk muscles and athletic performance. A future longitudinal study on the relationship between low back injuries and trunk muscles may also provide meaningful findings.

The quality of the participants; that is, their athletic performance level, was another limiting factor. The participants in this study were university judo club members who had been competing for about 10 years and belonged to the university judo club, which has top-ranked judokas in national championships in university division 1. Japanese university-level judokas possess a high athletic performance level, including world championships and Olympic Games medalists. Thus, the participants were experienced and demonstrated the typical physical characteristics of judokas. However, not all were at extremely high levels. The results may have been more accurate in judokas at higher athletic levels.

The number of participants was also a limitation. As the participants were classified by weight category, athletic performance level, and low back injuries, the sample size of each group inevitably decreased. Chapter 7, which used the weight category system, LBP, and LRA to classify the participants, most clearly illustrates this limitation. Therefore, future studies should include a higher number of participants.

This study classified participants by weight categories because athletic and injury characteristics differ according to the physical characteristics of each judoka. Therefore, although this study reported new findings, it did not fully consider the issues of physical characteristics, such as body composition, height, and BMI. However, as judo matches and daily practice are performed by weight category, this classification has some significance.

Furthermore, classification by weight may reflect a categorization based on the characteristics of the judo movements. However, although there is some relationship between weight categories and the characteristics of judo movements, some judokas in the same weight category have entirely different characteristics. Therefore, classification of judoka based on the movement characteristics, such as the techniques they are good at and how they win, warrants investigation. However, such classification is difficult to define objectively, and weight categories seem adequate to include these characteristics; thus, I believe this study has significance.

The method of TMS measurement, which was the primary measurement in this study, can also be a limiting factor. Even when measured using an isokinetic dynamometer, it is difficult to avoid familiarization with the measurement, which affects the results.

8-4. Future perspectives

Other factors may be useful in characterizing LBP in judokas. The present study of elite judokas evaluated the characteristics of trunk muscles according to differences in athletic performance, identified the characteristics of LBP, and assessed the relationship between LBP and LRA and TMS according to weight categories. The findings of this dissertation identified the association of the load on the trunk region due to body weight, differences in TMS per body weight, and movement characteristics depending on weight categories. However, as discussed in the Limitations section, this dissertation did not directly examine the movement of judokas. Therefore, assessing the differences in movement by classifying judokas according to these characteristics and analyzing the effects on trunk muscles and LBP may provide new insights.

The globalization of judo has resulted in the introduction of techniques from foreign ethnic martial arts to judo competitions, especially in close combat. Close combat is crucial for international judo competition and requires strong TMS. Therefore, a deeper understanding of the trunk characteristics of modern judokas, which must cope with various close combat techniques, requires study of both Japanese and foreign judokas. In close combat, the judoka's trunk remains close to that of the opponent, followed by lifting and throwing an opponent backward, which requires trunk extension and rotation. Judokas bend the trunk and rotate it to forward the opponent. Thus, close combat requires strong rotational TMS. Georgian judokas have thick trunk regions that are decisive in close combat. Moreover, judokas who do not perform these techniques frequently but have a strong defense against throwing techniques also possess a thick trunk region. A thin trunk region can cause mechanical fragility in the trunk. Thus, a thick trunk region plays a role in close combat, as it helps defend against an opponent's attack. It would be interesting to study overseas judokas with thick trunk regions that Japanese judokas rarely develop.

Further, investigations based on regular judo practice may also be essential. Performance in regular judo practice reflects performance in judo matches, and low back injuries, including LBP, occur even during regular judo practice. Thus, regular judo practice is crucial for judokas' athletic performance and the occurrence of low back injuries. Unlike matches, regular practice requires sustained effort. Thus, the muscular endurance of the trunk muscles is a vital parameter.

Especially for the lightweight category, the results of this doctoral dissertation could not clarify the relationship between LBP and TMS without combining LRA. As discussed in Chapter 7, this may be related to the body size and movement characteristics of this weight category. The LRA prevalence in the lightweight category may be lower than that of other heavier categories, with different LRA breakdown. Specifically, the prevalence of spondylolysis was higher than that of lumbar intervertebral disc degeneration. These differences may occur due to differences in both the magnitude and type of load on the lumbar region. Thus, comparisons other than muscle strength may be essential, such as flexibility and reaction time. Further studies are needed to understand other factors contributing to the characteristics of LBP in judokas.

Chapter 9. Conclusions

This doctoral dissertation aimed to enhance judokas' athletic performance by understanding TMS and low back injuries in elite judokas. The findings resulted in the following suggestions:

1. Trunk rotation strength is essential for judokas in all weight categories. High-speed trunk extension and low-speed rotation are particularly essential for the middleweight and heavyweight categories, respectively.
2. Although weight category does not affect the prevalence of LBP, LRA frequently occurs above the middleweight category. Almost all LBP accompanies LRA, except for the lightweight category.
3. Weak trunk rotation strength is associated with LBP in the heavyweight category, while weak TMS in all directions is associated with LBP only in the lightweight category without LRA, with trunk rotation and extension strength particularly evident.

This doctoral dissertation concluded that trunk muscles are related to athletic performance and low back injuries, including LBP, in elite judokas, depending on weight category. These findings suggested that rotational TMS is critical.

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