ORIGINAL ARTICLE

Isokinetic assessment of knee joint muscles in shotokan karate kata athletes

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A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
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Abstract

Background and Study Aim: Due to the observed phenomenon of knee joint pain in kata athletes, isokinetic assessment of hamstrings and quadriceps of shotokan karate kata athletes was performed and the results were compared to non-karate controls. The aim of the study was to verify whether under the influence of prolonged karate training there is an imbalance between the flexors and extensors of the knee joint and between the right and left lower limbs.

Material and Methods: The participants were 15 kata athletes (aged 25.9 ±6.9) with a minimum of 12 years of training experience and 15 physically active students (aged 22.6 ±3.8). Biodex System 3 PRO, measuring shaft at 60°·s^{-1} and 180°·s^{-1} was used in the study.

Results: Comparison of mean value of the H:Q ratio for the right knee at 60°·s^{-1} and left at 180°·s^{-1} showed that the values obtained by karate athletes were higher ($p \leq 0.05$). There were no significant differences in bilateral movement of the knees between the karate and control groups. Mean values of the H:Q ratio and BD did not show any irregularities. It was demonstrated that quadriceps BD increased along with the training experience of kata athletes.

Conclusions: The results of the study showed correct proportions between knee joint flexors and extensors and no bilateral deficit was found. It should be assumed that pain in lower limb joints, especially knee joints in karate athletes does not result from flexing and extending movements, but rather from the ground reaction forces during dynamic transitions. It is necessary to measure the forces generated during the transitions in zenkutsu dachi, kokutsu dachi and kiba dachi.

Key words: bilateral deficit • biomechanics • quadriceps • hamstrings • H:Q ratio • martial art

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Martial arts – *plural noun* any of various systems of combat and self-defence, e.g. judo or karate, developed especially in Japan and Korea and now usually practised as a sport [28].

Kata – *noun* a sequence of movements in some martial arts such as karate, used either for training or to demonstrate technique [28].

Kumite – is a semi-contact karate competitive concurrence, where two athletes perform various kicking, punching and blocking techniques towards each other with maximum control in order to gain points and win the match. Destruction is fictive.

Technique– *noun* a way of performing an action [28].

Dan (dan'i) – a term used to denote one's technical level or grade [29].

Kyū – the series of grades that precede ***dan*** ranks. ***Ikkyū*** is the grade immediately below ***shodan*** [29].

Training session – *noun* a period of time during which an athlete trains, either alone, with a trainer or with their team [28].

Performance – *noun* the level at which a player or athlete is carrying out their activity, either in relation to others or in relation to personal goals or standards [28].

INTRODUCTION

Karate shotokan (*shōtōkan*) is a martial art created in Japan with kumite and kata as the two main competitive sports disciplines. Kata is the presentation of a series of movements and techniques in an established order against imaginary opponents. Kumite is dynamic, structured and involves fighting an opponent with the use of various movements including defensive and offensive techniques [1, 2].

In the kata category, from the biomechanical point of view, victory to a large extent depends on how each movement and technical element is performed [3]. Perfect punches and blocks as part of basic techniques (*kihon*) [4] constitute an indispensable element of kata training sessions. Athletes participating in kata competitions at the highest level are characterized by high muscle explosive strength, balance and flexibility, which plays a key role in this discipline [5-7]. The ability to defend against any attack in all conditions depends mainly on maintaining the correct posture. The posture in karate depends primarily on the position of the lower limbs. A strong and stable posture is a prerequisite for the implementation of strong, fast, accurate and well-made techniques [8]. The stances in shotokan karate kata are unnatural, low and elongated, which significantly overloads knee joints [9, 10]. Therefore, it should be assumed that the results of survey-based studies carried out earlier by the authors of this paper [10] and the analysis of data available in the literature [11] show that lower limb joints, particularly knee joints, are the most common location of pain experienced by kata athletes. Performing kata positions and kicks during training sessions and competitions were enumerated among the circumstances in which pain occurred. Among kumite athletes, the most frequent injuries include upper limb fingers, followed by knee joints. The dominant causes of injuries are trauma, caused by training over-extension, inappropriate warm up and injury by training partner [12].

Due to high frequency of knee joint trauma in kata athletes, isokinetic tests of knee joint flexors and extensors were performed to verify whether excessive bilateral deficit and/or undesirable HQ ratio is one of the causes of injuries. Assessment of these indicators may be very useful in preventing future injury.

As a result of repeating the same movement patterns throughout a number of years, a negative adaptation of the body to the sport may occur, which often manifests itself as contralateral and ipsilateral strength and flexibility imbalances [13-15]. The indicators pointing to the occurrence of contralateral and ipsilateral imbalances are the following: the hamstrings-to-quadriceps peak torque ratio (H:Q) and bilateral deficit (BD). H:Q is regarded as an important indicator of the strength both in sports and rehabilitation [16-20]. A decrease in flexor muscle strength due to movements which overload knee extensors may lead to muscle imbalance between hamstrings and quadriceps, which constitutes an important risk factor in knee joint injury [17, 20]. Maintaining balance between hamstrings and quadriceps is essential for the general stabilization of the knee joint [21].

The aim of the study was to verify whether under the influence of prolonged karate training there is an imbalance between the flexors and extensors of the knee joint and between the right and left lower limbs.

The answer to this question (i.e. the empirical data obtained), implies an issue: whether karate kata athletes are more prone to knee joint injuries due to excessive bilateral deficits and/or inadequate imbalance between hamstrings and quadriceps.

MATERIAL AND METHODS

Participants

The subjects were male shotokan karate kata athletes aged 25.9 ±6.9 with a minimum of 12 years of training experience. The average training experience ratio calculated on the basis of age was 65 ±9% (Table 1). The levels of advancement ranged from 3 kyu to 4 dan. Each of the participants took an active part in kata competitions. In order to make sure that the results are objective, the athletes came from different sports clubs.

Table 1. Descriptive subject characteristics (mean and standard deviation).

Variable	Kata athletes (n = 15)	Control group (n = 15)
Age (y)	25.9 ±6.9	22.6 ±3.8
Height (cm)	179.3 ±5.9	179.7 ±7.2
Weight (kg)	78.1 ±6.1	76.9 ±10.8
BMI (kg/m^2)	24.3 ±2.2	23.7 ±2.3
Karate training experience (y)	16.6 ±4.1	0

The control group consisted of students of the University of Physical Education and Poznan University of Medical Sciences with an average age of 22.6 ±3.8 who were physically active but did not practise karate. Both the athletes and the students did not report any lower limb injuries in the last 12 months preceding the study and voluntarily agreed to participate in the study.

The laboratory tests were approved by the Bioethics Committee at Poznan University of Medical Sciences. Before the study was commenced, each participant was acquainted with the characteristics of the tests and the associated risks, and voluntarily agreed to participate in the study and acknowledged that the results would be made public.

Strength measurements

Isokinetic tests of concentric hamstrings and quadriceps strength at an angular velocity of 180°·s^{-1} and 60°·s^{-1} were conducted using Biodex System 3 (Biodex Medical Systems, Inc., Shirley, NY, USA). The test was conducted in the morning in the biomechanics laboratory at Poznan University of Physical Education. The isokinetic test was preceded by a 10 minute warm-up on stationary bicycle and stretching. The test was preceded by thorough instructions and an attempt to perform a particular movement correctly. During the test, the right and then left knee joints were flexed and extended with maximum force. In the first stage, 5 movements at 180°·s^{-1} were performed, followed by 3 movements at 60°·s^{-1}.

Hamstrings and quadriceps average peak torque (PT) together with the peak torque to body mass (PT·m^{-1}) were used for the analysis. Time to peak torque, which is a parameter that indicates how long it took to reach the peak torque, was also analysed.

The aim of this study was to analyse hamstrings and quadriceps peak torque bilateral deficit (BD). It was calculated according to the following formula:

$$BD = (X_1 - X_2) * \frac{100\%}{X_1}$$

In this equation $X_1 > X_2$ represents the values of the left and right lower limb peak torque. The hamstrings (H) to quadriceps (Q) peak torque ratio was also verified. It was calculated according to the following formula:

$$H{:}\,Q = \frac{H}{Q} * 100\%$$

Statistical analysis

All statistical analyses were performed with the use of the Statistica 13.1 software package (Statsoft Inc., Tulsa, Oklahoma, USA). The parameters obtained in the isokinetic evaluation of quadriceps and hamstrings, somatic indices and experience were expressed as mean and standard deviations.

Parametric Student's t-distribution test and non-parametric Wilcoxon signed-rank test and Pearson correlation and Spearman's rank correlation test were carried out. The Shapiro-Wilk test was conducted to check the compliance of the distribution of the tested parameters with the normal distribution. The non-parametric Mann-Whitney U test was used for variables that did not meet the normal distribution condition.

Critical significance level was assumed to be $p \leq 0.05$.

RESULTS

Spearman's rank correlation test showed that quadriceps BD increased along with an increase in the training experience ratio at an angular velocity of 60°·s^{-1} ($r = 0.527$; $p = 0.043$).

Moreover, it was found that 93% of the athletes declared that the right lower limb was dominant, however, there were no statistically significant differences for the mean peak torque between the right and left side, both between hamstrings and quadriceps (Table 2).

Comparison of mean values for the right knee H:Q ratio for the angular velocity of 60°·s^{-1} showed that the results obtained by karate athletes were statistically significantly higher ($p = 0.039$) than in the control group. Also the mean values for the left knee H:Q ratio for the angular velocity of 180°·s^{-1} were statistically significantly higher in karate athletes ($p = 0.023$).

Analysing the mean values of maximum muscle torque in relation to mass during knee joint extension at an angular velocity of 60°·s^{-1}, we observed a tendency towards significantly higher PT·m^{-1} values obtained by the control group in comparison to karate athletes for the right lower limb ($p = 0.059$) and for the left lower limb ($p = 0.062$).

Table 2. Karate athletes and control group values (mean and standard deviation) at two angular velocities.

Indicator	Lower limb	Kata karate athletes (n = 15)		Control group (n = 15)	
		60°·s^{-1}	180°·s^{-1}	60°·s^{-1}	180°·s^{-1}
Avg. PT Q (N · m)	R	214.16 ±37.90	163 ±20.27	229.65 ±34.92	169.19 ±27.53
	L	222.52 ±32.38	173.39 ±38.3	233,6 ±41,57	173.33 ±30.84
Avg. PT·m^{-1} Q (N · m · kg^{-1})	R	2.75 ±0.42	2.19 ±0.36	3.00 ±0.26	2.22 ±0.14
	L	2.86 ±0.31	2.23 ±0.45	3.04 ±0.29	2.28 ±0.15
Avg. PT H (N · m)	R	125.07 ±30.96	97.01 ±23.75	120.49 ±26.71	93.63 ±15.06
	L	121.63 ±22.57	99.07 ± 19.19	120.26 ±0.24	91.83 ±19.24
Avg. PT·m^{-1} H (N ·m ·kg^{-1})	R	1.61 ±0.32	1.24 ±0.23	1.56 ±0.19	1.22 ±0.10
	L	1.56 ±0.23	1.30 ±0.29	1.56 ±0.19	1.19 ±0.14
H:Q (%)	R	58.63 ±9.13*	58.95 ±8.94	52.23 ±6.9*	55.66 ±6.15
	L	54.75 ±6.9	59.38 ±5.94*	51.59 ±5.99	53.28 ±7.77*
Q BD (%)		7.95 ±5.91	8.36 ±12.02	5.01 ±4.24	5.24 ±2.63
H BD (%)		8.66 ±5.91	10.64 ±7.36	6.49 ±6.17	7.7 ±5
Quadriceps time to PT (ms)	R	424 ±86	205 ±55	451.33 ±111	207 ±38
	L	430 ±90	209 ±50	447 ±109	190 ±46
Hamstrings time to PT (ms)	R	394 ±132	282 ±126	457 ±176	340 ±129
	L	428 ±165	315 ±122	437 ±150	326 ±121

* p≤0.05 (significantly different from the same-side control)

DISCUSSION

The determined hamstrings and quadriceps peak torque bilateral deficit (BD) in the studied athletes at the angular speed of 60°·s^{-1} was below 10% (Biodex system standard), i.e. hamstrings 8.66 ±5.91% and quadriceps 7.95 ±5.91%. At the same time, an increase in BD was observed along with an increase in the training experience ratio. At this point it should be emphasized that the occurrence of considerable differences between the left and right lower limb muscle torque may contribute to an increased risk of injuries [17,22].

The H:Q ratio of the knee flexor peak torque to the knee extensor peak torque under isokinetic conditions should reach values about 60%. Data in the literature also indicate that the typical H:Q strength ratio of a healthy knee ranges from 50% to 80% [20, 23, 24]. The mean H:Q results in the tested athletes at the angular speed of 60°·s^{-1} were as follows: right limb 58.63 ±9.13%, left limb 54.75 ±6.9%. Additionally, it was shown that training experience does not have a statistically significant effect on the decrease of the H:Q ratio at 60°·s^{-1}. This may be indicative of the proper training involving both knee flexors and extensors. At the same time it is worth noting that decreased strength of hamstrings in relation to quadriceps could lead to an increased risk of knee joint injuries [17, 25, 26]. Analysis of the H:Q ratio in the studied karate athletes did not reveal any abnormalities.

However, comparing the values of maximum muscle torque determined in this study in relation to mass in the group of kata athletes with results of similar studies which were previously described in the literature and were carried out on karate athletes representing Serbia and the USA, it should be stated that PT*m^{-1} values for quadriceps are similar. At the angular velocity of 60°·s^{-1} Poles obtained the following results for the right lower limb: 2.75 ±0.42Nm·kg^{-1} and for the left lower limb: 2.86 ±0.31 Nm·kg^{-1}. Elite male karate athletes from Serbia at the same angular velocity obtained 2.72 ±0.44 Nm·kg^{-1} for the right lower limb and 2.76 ±0.46 Nm·kg^{-1} for the left lower limb [2], whereas athletes from the USA obtained 2.8 ±0.3Nm·kg^{-1} for the right lower limb and 2.8 ±0.2Nm·kg^{-1} for the left lower limb [15].

The mean PT·m^{-1} values for hamstrings in the group of athletes were highest in karate athletes from Serbia (right: 1.86 ±0.29Nm·kg^{-1}, left: 1.83

±0.44Nm·kg^{-1}) [2], USA (right: 1.8 ±0.3Nm·kg^{-1}, left: 1.7 ±0.3Nm·kg^{-1}) [15]. Noticeably lower results were obtained by Poles (right: 1.61 ±0.32Nm·kg^{-1}, left: 1.56 ±0.23Nm·kg^{-1}). These results are directly translated into the values of the H:Q ratio, which in karate athletes from Serbia were as follows: right 68.89 ±6.81, left 66.56 ±12.14 [2] and in karate athletes from the USA: right 62.8 ± 8.5, left 60.2 ± 8.6 [15]. Despite noticeable differences, all results of the H:Q ratio in the above mentioned groups of athletes were correct in terms of standard described in the literature.

Both Lisowska et al. in this research and Kotrljanovic et al. [2] included long-term top-level karate athletes, but there were only kumite athletes among Serbs. Probst et al. [15] studied 5 men and 4 women with less training experience and lower level of advancement, i.e. from green to black belt.

Comparing the results of relative muscle torque in other martial arts, one can observe clear differences. For the angular velocity of 180°·s^{-1} kata athletes obtained the following values of PT·m^{-1} during knee extension: right 2.19 ±0.36Nm·kg^{-1}; left 2.23 ±0.45Nm·kg^{-1}, which were very similar to taekwondo athletes (right 2.21 ±0.39Nm·kg^{-1} left 2.22 ±0.42Nm·kg^{-1}). However, boxers obtained lower values (right 1.75 ±0.43Nm·kg^{-1}, left 1.8±0.34Nm·kg^{-1}) [27]. The values of maximum knee flexion torque in relation to mass in karate athletes were lowest, i.e. right 1.24 ±0.23Nm·kg^{-1}, left 1.3±0.29Nm·kg^{-1}, in taekwondo athletes the results were as follows: right 1.7 ±0.27Nm·kg^{-1}, left 1.64 ±0.22Nm·kg^{-1}) and in boxers: right 1.42 ±0.4Nm·kg^{-1}, left 1.37 ±0.3Nm·kg^{-1}.

It should be noted that both at the speed of 60°·s^{-1} and 180°·s^{-1} the results for knee flexors in the studied kata athletes were lower compared to other studies involving karate or taekwondo athletes and boxers. The most likely cause are the characteristic positions practised by kata athletes, i.e. *zenkutsu dachi*, *kiba dachi* and *kokutsu dachi* engaging mainly quadriceps muscles. However, the specificity of this sport discipline does not require athletes to achieve above-average PTQ values for lower limb muscles. At this point it should be emphasized that in the studied group of athletes the tendency to achieve lower PT·m^{-1} Q values for quadriceps in both limbs at the speed of 60°·s^{-1} was observed as compared to the control group, which consisted of physically active men.

According to the World Karate Federation (WKF) championship rules for 2019, the kata evaluation system during sports competition accounts in 70% for technical performance and 30% for athletic presentation of the sequence. Therefore, the teaching process is based primarily on correct techniques followed by the performance of individual elements of kata in the shortest time possible. Dynamic transitions between stances, followed by stopping in a stable position, are possible due to very fast alternating tightening and relaxing of the muscles involved. The indicator that allows to verify how fast hamstrings and quadriceps reach their maximum torque is time to peak torque.

The studied Polish athletes achieved a shorter time to peak torque for the angular velocity of 60°·s^{-1} than the athletes from the USA [15]. In Polish kata athletes quadriceps time to peak torque was as follows: right 424 ±86ms, left 430 ±90ms. In Americans quadriceps time to peak torque was the following: right 554 ±75ms, left 556 ±76ms. The difference in hamstrings time to peak torque was slightly smaller, i.e. in Poles: right 394 ±132ms, left 428 ±165ms, in Americans: right 483 ±100ms, left 443 ±90ms. Probably the difference in this indicator was due to the specificity of the study involving American athletes, as the presented mean values of the measured indicators were obtained jointly for women and men [15].

CONCLUSIONS

The study provides information about the knee joint muscle torque under isokinetic conditions in kata athletes. The measurements confirmed the absence of H:Q ratio imbalance and correct mean BD values. Due to the increase of BD along with the increase of training experience, it is extremely important to periodically examine the athletes in order to verify the occurrence of imbalances and reduce them.

The results obtained were certainly helpful in the training process for the athletes themselves and their coaches. Repeating the measurements will allow to observe whether the applied training produced the desired effect of increasing muscle strength and shortening the time to peak torque, or reducing the disproportions that occurred in some athletes. Strengthening hamstrings, reducing BD and maintaining H:Q balance play a key role in preventing knee joint injuries. Thanks to

the reproducibility of the conducted tests, the results can be compared with other groups of athletes from around the world.

Despite the fact that the experimental group was not very numerous, the results indicate that kata athletes are characterized by the correct functional condition of knee joint flexors and extensors. The reason for the frequently reported knee joint pain must therefore be different. This is probably due to the very high ground reaction forces generated when performing dynamic transitions in the shotokan karate stances. Further research is needed to verify the values and directions of the forces in kata positions. It is assumed that in the dynamic transitions in the *kiba dachi* stance involve the highest values of ground reaction forces, lateral to the knee joint, thereby generating a high muscle torque and twisting the knee joint, which may constitute the main cause of pain in the knee joint.

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