ORIGINAL ARTICLE

The distribution of subcutaneous fat and fat pattern among male athletes of different combat sports

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

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Received: 07 February 2022; **Accepted:** 17 March 2022; **Published online:** 28 March 2022

AoBID: 14973

Abstract

Background and Study Aim: The distribution of fat can be of great importance to an athlete's body function, because individual adipose tissue deposits differ in metabolic and endocrine activity. The aim of the study was the answer to the question: whether the fat patterns of combat sports athletes differ among disciplines.

Material and Methods: Anthropometric measurements and body composition assessment of 390 combat sports athletes (boxing, Brazilian jiu-jitsu/BJJ, judo, karate, kick-boxing taekwondo, wrestling) were conducted. The body fat characteristics were determined based on skinfolds measurements, bioelectrical impedance analysis and also subcutaneous fat indices.

Results: The distribution of subcutaneous adipose tissue is similar in karate, taekwondo, judo and BJJ athletes, while the pattern of subcutaneous fat in boxers, kick-boxers and wrestlers differs slightly. Men practicing particular sports differ in limb to trunk subcutaneous fat proportion, as well as in total body fat. Kick-boxers have the highest proportion of subcutaneous fat, while judo and BJJ athletes have the lowest one. BJJ athletes are characterized by the greatest difference in subcutaneous fat distribution – limb fat is half that of the trunk. The distribution is more balanced in karate, kick-boxing and taekwondo athletes. In terms of total body fat content the wrestlers dominate, whereas judo and BJJ athletes had the lowest one.

Conclusions: Athletes representing various combat sports are characterized by different fat patterns. This became particularly apparent when the analysis simultaneously considered the thickness of the skinfolds in different parts of the body, the relative size of subcutaneous fat, and the percentage of total fat, as well as the distribution of subcutaneous fat on the limbs and torso.

Key words: adipose tissue • body build • body composition • body fat distribution • martial arts • skinfolds maps

Conflict of interest: Authors have declared that no competing interest exists

Ethical approval: The research was approved by the Senate's Research Bioethics Commission of the University School of Physical Education in Wrocław, Poland

Provenance & peer review: Not commissioned; externally peer-reviewed

Source of support: Internal grant of the University School of Physical Education in Wrocław, Poland (grant No. PN/BK/2020/08)

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Fat distribution – the location of fat on the body; in this article distribution concerns subcutaneous fat.

Fat pattern – the pattern of fat distribution defined on the basis of the skinfolds thickness in various locations (skinfolds maps) and the indices of subcutaneous fat.

Skinfolds maps – the radar plots that include the average thickness of particular skinfolds in athletes of each combat sport.

Subcutaneous fat indices – the indices assessing the proportion of subcutaneous fat in relation to body weight (SBFI) and height (SFI), as well as the distribution of subcutaneous fat in the extremities in relations to trunk (SFDI).

Total body fat – the percentage of fat component of the body mass as assessed by BIA method.

INTRODUCTION

The importance of body fat content, and the associated proportion of lean body mass, for physical performance and achievements in combat sports has been studied by numerous authors [1-9]. Low body fat level has been shown to positively affect athlete [10, 11, 9], however, success in combat sports does not depend on single isolated factors, but is the result of a combination of physiological, motor, mental and somatic features of competitor [12, 9], and also athletes characterized by greater adiposity achieve success [5].

Monitoring the changes in body composition, both during the competition period and during the remaining phases of the training cycle, has become one of the basic elements in the athlete's preparation [13-16]. On the one hand, it provides the coach and the nutritionist with information on the effectiveness of the training or nutrition program being conducted, and on the other hand, it allows for an effective control of the biological condition of the athlete exposed to frequent changes in weight and body composition [17]. Maintaining optimal fat levels in an athlete's body can help him boost performance during the competition period. Excessive and sudden reduction of body fat often leads to the development of health disorders [18, 15]. Stewart [19] points out that the concept of optimal body fat is understood differently in the health category and in the sport category, which may generate a conflict between an athlete's need to maintain good biological condition and striving to achieve success in sport. Both coaches and managers put a lot of pressure on athletes based on their fat level. It is necessary to always be mindful that pursuing maximum athletic performance should not result in increased health risk in athletes [20, 15].

With this in mind, a group of experts under the auspices of the International Olympic Committee Medical Commission have singled out weight category sports, including combat sports, as those in which special attention should be paid in the development of athlete weight regulations [13, 20]. Despite the lack of a single sport-universal method for measuring athletes' body composition and uniform criteria for assessing their body fat structure, the International Olympic Committee recommends using clear, health-risk minimizing and research-based principles for maintaining athletes' biological fitness, including their body weight and body fat level, even outside of Olympic competition [20].

Recent studies indicate that compared to other methods of estimating body fat, the best method in athletes is direct anthropometric measurement of skinfold thickness [16].

Because of that, it is necessary to regularly monitor the body fat of combat sports participants and to define normal, not health-threatening, reference values for both skinfold thickness and total fat content. In addition to body fat mass itself, the distribution of body fat between its various deposits and locations can be of great importance to an athlete's body function. Individual adipose tissue deposits differ in structure, function, gene expression, metabolic and endocrine activity, and affect internal organ function differently [21]. Although subcutaneous adipose tissue is less metabolically active than visceral deposits, changes in the amount of adipose tissue (changes in the thickness of the skinfolds) can result in altered conditions for athletes. There are large amounts of leptin secreted in subcutaneous tissue, enhancing lipolysis and energy production [22]. Hence, energy production may be greater in athletes characterized by a thicker subcutaneous fat layer. In contrast, a strong reduction in subcutaneous fat can lead to impaired leptin production and a body bias toward energy conservation, even when visceral fat deposition is available. In such a situation, the body gives up energy-intensive processes, which are primarily reproduction, thermogenesis, and body growth [22]. It is also unable to perform intense physical activity effectively.

Because of structural and physiological differences between fat deposits, they respond unequally to athletic training. A hierarchy in the consumption of individual fat deposits has been observed in trained men [23]. First, there is a reduction in fat of the abdominal region, then the upper extremities, and finally the lower extremities. This type of fat distribution, characteristic of athletes, with a tendency to a strong reduction of visceral fat with relatively constant adiposity of the extremities, especially the lower extremities, is called "fit fat" distribution [23, 24]. The type of training may modify this process to some extent, which is expressed in specific fat patterns of athletes of different disciplines. Our own research has shown that the fat phenotype is related to the specificity of the sport practiced and varies between competitors of different team sports games [25].

Training in combat sports provides a choice of fighting styles that vary in techniques and dynamics. Judo, Brazilian jiu-jitsu (BJJ) and wrestling are some of grappling sports, whereas boxing, karate, kick-boxing and taekwondo are striking sports. Kendo and fencing involve using weapons. There are also different general rules and regulations in each discipline, different scoring systems. Some styles are distinguished by an emphasis on ground fighting, others are dominated by stand-up and close combat, some are dominated by punches and strikes and others by kicks. Some disciplines allow using a more dangerous self-defence technique, while others have more restrictions [26, 8].

Taking this into account, the aim of the study was the answer to the question: whether the fat patterns of combat sports athletes differ among disciplines.

MATERIAL AND METHODS

Participants

Anthropometric measurements and body composition assessments of combat sports athletes were conducted. The study included a total of 390 men training different sports (listed alphabetically): boxing (n = 24), BJJ (n = 76), judo (n = 98), karate (n = 81), kick-boxing (n = 31), taekwondo (n = 67) and wrestling (n = 13). They were between the ages of 21 and 30 (U23 and senior age categories), and represented an intermediate sport level (academic/national competition level).

The study was carried out in the Scientific Research Laboratory of the Faculty of Sport and Physical Education (PN-EN ISO 9001:2009 certification) at the University School of Physical Education in Wrocław, Poland. All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Senate's Research Bioethics Commission of the University School of Physical Education in Wrocław, Poland.

Study design

Basic premises and assumptions

In combat sports, athletes are divided into weight categories, but these categories vary between disciplines, making comparative analyses difficult. An athlete's body mass, and consequently the weight category in which they fight, differentiates the massiveness of the structure [27] as well as the fat content and the pattern of subcutaneous adiposity [28]. Taking this into account, only measurements of athletes weighing 65-90 kg, representing middle and semi-heavy weight categories in their disciplines, were included in this study. Inclusion criteria in the analysis was also conditional on practicing the sport for at least 3 years, as well as the absence of injuries that impede the measurements.

The body fat characteristics were determined based on: direct anthropometric measurement of the skinfolds thickness at various body sites; fat indices that determine the relationship of subcutaneous fat to body weight and height, and the distribution of subcutaneous fat on the extremities and trunk; the total fat content of body weight, as measured by the bioelectrical impedance method. The available literature suggests that this approach to assessing athlete fat is valid and beneficial for controlling the training process and athlete wellbeing [29, 19, 16].

Measurements

Measurements were performed according to International Standards for Anthropometric Assessment (ISAK) [30] by professional anthropologists. All anthropometric and body composition measurements were done during the morning. The length and width measurements were taken with the use of certified GPM Anthropological Instruments (Siber Hegner Machinery Ltd., Zürich, Switzerland). The body mass was measured with the use of an electronic scale (Fawag, Lublin, Poland). Skinfold thickness was measured at the subscapular, abdominal, suprailiac, triceps, biceps and calf locations with a use of Tanner/Whitehouse skinfold calliper (Holtain LTD, Crosswell, Crymych, Pembs, UK).

The pattern of subcutaneous adiposity was visualized using skinfolds maps, which are radar plots that include the average thickness of skinfolds in athletes of each combat sport [29]. Three fat indices were also calculated: *subcutaneous fat index* [31], *subcutaneous fat distribution index* [32, 33], *skinfold-based fat index* [34]. *Subcutaneous fat index* (SFI) assesses subcutaneous fat in relation to body height. This index includes measurements of six skinfolds. The higher the index values, the more subcutaneous fat the subject has in relation to his body height [31]. The *skinfold-based fat index* (SBFI), which expresses the relationship between the sum of trunk and limb skinfolds and body weight, takes on higher values in subjects with greater subcutaneous fat in relation to their body weight [34]. *Subcutaneous fat distribution index* (SFDI) provides information on the distribution of subcutaneous fat in the extremities and trunk. In adult men and women, the mean values of the index do not exceed 100, indicating that subcutaneous fat content predominates on the trunk [32, 33]. The smaller the index values, the greater the difference between trunk and limb fat layer.

We also calculated BMI (Body Mass Index) informing about the massiveness of the body, as well as WHR (Waist *to Hip Ratio*), and WHtR *(Waist to Height Ratio*) – describing the adiposity of the trunk. The leg to trunk proportion was also assessed with use of Manouvrier's Skelic Index (ratio of leg length to sitting height).

Body composition was examined by bioelectrical impedance analysis (BIA). Resistance and reactance were measured according to the manufacturer's recommended procedure, in the supine position, using a BIA-101 Anniversary Sport Edition analyser (Akern, Italy). Body fat percentage (FM%), muscle mass percentage (MM%), as well as total body water (TBW%) and intracellular water percentage (ICW%) were estimated using Akern Bodygram 1.3.1 software.

Statistical analysis

Over the course of the analyses, the consistency of the variable distribution with the normal distribution was verified (using Levene's test). Parametric tests (ANOVA and Scheffe's post-hoc test) and non-parametric tests (Kruskal-Wallis ANOVA, multiple comparisons test of mean ranks) were used to assess the significance of differences in dimensions, body proportions and content of individual tissue components between disciplines. Statistical analyses were performed using Statsoft Statistica 13.3. Graphs were produced in Microsoft Office Pro Plus 2019 Excel.

RESULTS

Anthropometric characteristics of combat sports athletes

Combat sports athletes representing each discipline were characterized by average body height and did not differ significantly in this respect. Body mass and the overall massiveness of the body, expressed both by the BMI (Table 1), as well as by the width of the skeletal framework and bone epiphyses, and the development of muscle perimeters (Table 2), are the features that more clearly differentiate the athletes representing individual combat sports. Taekwondo and karate athletes appeared lighter and more slender, while judo and BJJ athletes were heavier and more massive. The physique of boxing, kickboxing and wrestling competitors was characterized by mean body mass and mass index values (Table 1).

BJJ athletes dominated in terms of shoulder width and hip width. Taekwondo and wrestling competitors were characterized by having the narrowest shoulders, while the narrowest hips were noted in kick-boxers (Table 2). Differences in limb bone massiveness were small between men representing different disciplines, with the narrowest elbows and knees characterizing karatekas, and the widest elbows and knees characterizing

Table 1. Overall body size and selected anthropometric indices of combat sports athletes.

Variable	Mean, SD							p-value
	Boxing	BJJ	judo	karate	kick-boxing	taekwondo	wrestling	
B-v [cm]	178.7 ±5.0	177.6 ±5.4	177.3 ±5.6	177.6 ±5.7	176.3 ±5.4	178.8 ±5.6	177.9 ±6.5	0.554
Body mass [kg]	75.5 ±7.4	77.6 ±5.1	77.4 ±6.4	74.1 ±4.7	75.3 ±5.2	73.2 ±5.6	76.6 ±7.7	**0.000**
BMI [kg/m^2]	23.6 ±1.5	24.6 ±1.6	24.6 ±1.8	23.5 ±1.6	24.2 ±1.5	22.9 ±1.7	24.2 ± 1.4	**0.000**
Manouvrier's Skelic Index	91.0 ±3.4	90.9 ±3.8	89.3 ±4.4	90.1 ±4.5	90.7 ±3.2	90.1 ±4.1	89.6 ±5.2	0.311
WHR	0.83 ±0.05	0.83 ±0.04	0.83 ±0.03	0.82 ±0.04	0.81 ±0.04	0.81 ±0.03	0.81 ±0.02	**0.014**
WHtR	44.6 ±2.8	45.5 ±2.6	45.4 ±2.7	44.5 ±2.9	45.1 ±3.1	43.5 ±2.6	44.9 ±1.6	**0.002**

B-v body height; **BMI** body mass index; **WHR** waist to hip ratio; **WHtR** waist to height ratio.

Table 2. Selected anthropometric features and body components of combat sports athletes.

Variable	Mean, SD							p-value
	Boxing	BJJ	judo	Karate	kick-boxing	Taekwondo	wrestling	
a-daIII [cm]	78.3 ±2.9	78.3 ±2.9	77.7 ±3.0	77.4 ±3.2	76.5 ±2.5	77.7 ±3.2	77.6 ±3.0	0.308
B-tro [cm]	94.0 ±3.9	95.1 ±3.3	92.6 ±3.9	94.0 ±4.2	92.1 ±2.7	94.1 ±3.9	93.8 ±4.6	**0.005**
a-a [cm]	41.6 ±1.5	42.2 ±1.5	41.4 ±2.1	40.6 ±1.8	41.4 ±1.7	40.8 ±1.8	41.1 ±2.0	**0.000**
ic-ic [cm]	28.0 ±1.7	28.7 ±1.3	28.0 ±1.4	28.0 ±1.2	27.3 ±1.1	27.8 ±1.4	28.2 ±2.4	**0.004**
cl-cm [cm]	6.9 ±0.4	7.1 ±0.3	7.2 ± 0.4	6.9 ±0.4	7.1 ±0.5	7.0 ±0.4	7.1 ±0.4	**0.000**
epl-epm [cm]	9.9 ±0.4	10.0 ±0.4	10.0 ±0.5	9.7 ±0.5	9.8 ±0.5	9.9 ±0.4	9.9 ±0.5	**0.023**
Arm circumference rest [cm]	31.5 ±2.6	32.7 ±2.0	32.2 ±2.3	30.4 ±2.0	32.4 ±1.8	29.8 ±2.1	31.5 ±2.0	**0.000**
Arm circumference tensed [cm]	35.1 ±2.4	35.9 ±2.2	35.8 ±2.3	33.9 ±2.0	35.8 ±2.3	33.5 ±2.2	35.0 ±2.4	**0.000**
Calf circumference [cm]	37.4 ±2.6	37.4 ±1.9	38.2 ±1.8	37.3 ±1.6	37.7 ±2.2	37.2 ±2.1	36.6 ±2.2	**0.006**
Chest circumference (xi) [cm]	87.7 ±6.0	89.3 ±3.3	89.8 ±4.6	88.2 ±4.4	88.8 ±5.3	86.7 ±4.3	89.6 ±4.0	**0.008**
Lean body mass [%]	82.0 ±4.6	83.1 ±4.2	83.2 ±4.8	82.3 ±4.2	81.6 ±3.4	80.5 ±4.2	78.7 ±3.0	**0.001**
Muscle mass [%]	60.3 ±5.0	58.5 ±4.9	58.7 ±9.0	58.3 ±8.5	60.2 ±9.1	55.0 ±7.6	54.9 ±12.3	**0.044**
Total body water [%]	60.0 ±3.3	60.8 ±3.1	60.9 ±3.5	60.3 ±3.1	59.7 ±2.5	58.9 ±3.1	57.6 ±2.1	**0.001**
Intracellular water [% of TBW]	61.0 ±2.4	58.7 ±2.3	59.9 ±3.8	61.0 ±3.7	61.0 ±3.4	60.1 ±3.4	60.6 ±5.4	**0.010**

a-daIII length of upper extremity; **B-tro** length of lower extremity; **a-a** shoulder width; **ic-ic** hip width; **cl-cm** elbow width; **epl-epm** knee width.

judoists and BJJ competitors. Taekwondo athletes had poor chest development compared to the other groups. Men practicing judo, wrestling, and BJJ had the most massive chests. By assessing the variation in limb musculature, it can be concluded that taekwondo and karate athletes have the slimmest arms, both at rest and under tension, whereas kick-boxing, judo, and BJJ athletes have the most massive arms. In terms of shin circumference, judo and kick-boxing athletes dominate, while wrestlers have the slimmest shins (Table 2).

Anthropometric indices assessing the proportions of waist circumference to hip and to body height took the highest values in judo and BJJ athletes, further confirming their greater massiveness, especially in the torso area. The narrowest waist in relation to hip and to body height was observed in taekwondo athletes (Table 1).

Male combat sports participants had similar Manouvrier index values, meaning that they did not differ in terms of trunk-extremity proportions (Table 1). Nevertheless, in direct comparisons of lower limb lengths, we found that judoists and kick-boxers had the shortest lower extremities, while jiu-jitsu athletes had the longest ones. Athletes did not differ significantly in terms of upper limb length (Table 2).

Body composition analysis demonstrated that kick-boxers and boxers had the highest percentage of muscle mass, and approximately 1.5% less muscle mass was exhibited by men practicing judo, Brazilian jiu-jitsu, and karate. The lowest percentage of muscle content among combat sports competitors is characteristic of male taekwondo and wrestling athletes. The differences in the percentage of intracellular water content between combat sports athletes are not large; all are very well hydrated. The highest percentage content of intracellular water was observed in boxers, kick-boxers and karatekas (Table 2).

Comparison of fat patterns between combat sports athletes

Comparisons of fat patterns between sports disciplines were made based on skinfolds maps, taking into account the thickness of the skinfolds, as well as on the basis of subcutaneous fat indices (SFI, SBFI, SFDI), and total fat content in body mass.

The shape of the radar graphs showing the development of subcutaneous adiposity is almost identical in taekwondo, karate, judo and BJJ athletes (Figure 1). In contrast, the skinfolds maps of boxing, kick-boxing and wrestling athletes differ slightly in shape. Boxers and kick-boxers have strongly developed subcutaneous fat on the abdomen compared to the other groups of athletes. Kick-boxers also have heavily developed fat layer on the triceps, whereas wrestlers show that on their biceps (Figure 2).

In direct comparisons of skinfold thickness, it can be seen that wrestlers dominate with the thickness of the biceps skinfold, while their other skinfolds take on average values compared to all combat sports athletes. The thinnest skinfolds on the limbs are characterized by BJJ athletes, but the differences compared to other groups of athletes are not large. Kick-boxers showed the thickest skinfolds on the upper arm (triceps) and lower leg among other groups. Male combat sports athletes differed significantly mainly in subcutaneous limb fat layers, as well as in total body fat content. The thickness of the skinfolds on the trunk varied greatly between individuals, yet no significant intergroup differences were observed for the skinfold on the abdomen and above the iliac crest. BJJ and kick-boxing athletes are somewhat dominant in terms of subcutaneous fat layer thickness under the inferior angle of the scapula (subscapular skinfold; Table 3).

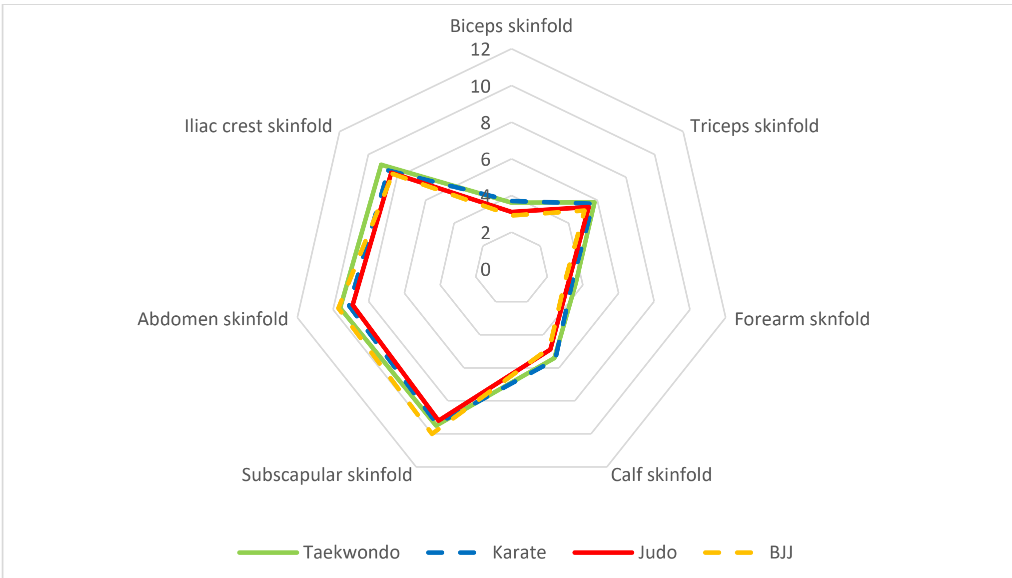

Figure 1. Skinfolds map of combat sports athletes: taekwondo, karate, judo, and Brazilian jiu-jitsu. Scale given in mm.

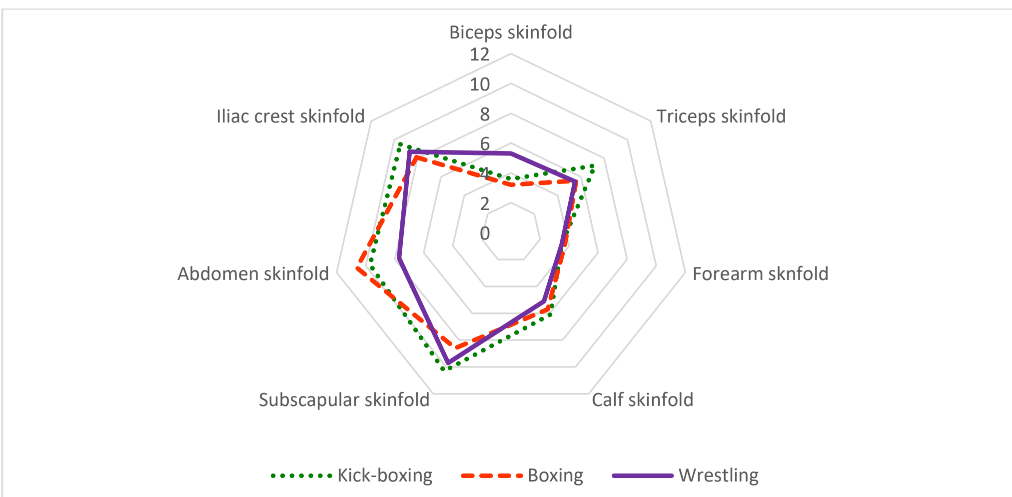

Figure 2. Skinfolds map of combat sports athletes: boxing, kick-boxing, wrestling. Scale given in mm.

Table 3. Skinfolds thickness and total fat content in combat sports athletes.

Variable	Me [Q1; Q3]							p-value
	boxing	BJJ	judo	karate	kick-boxing	taekwondo	wrestling	
Biceps skinfold [mm]	3.2 [2.8; 3.4]	2.8 [2.4; 3.4]	3.0 [2.6; 3.2]	3.0 [2.8; 4.4]	3.6 [3.2; 4.0]	3.0 [3.0; 3.8]	5.2 [4.4; 6.2]	**0.002**
Triceps skinfold [mm]	5.0 [4.2; 5.6]	4.4 [3.8; 5.3]	4.8 [4.0; 6.0]	5.2 [4.4; 6.2]	6.0 [5.4; 8.3]	5.4 [4.2; 6.8]	4.5 [4.0; 7.0]	**0.007**
Forearm skinfold [mm]	3.4 [3.0; 4.4]	3.0 [2.7; 3.4]	3.0 [2.8; 3.4]	3.3 [2.9; 3.6]	3.2 [3.0; 4.0]	3.4 [3.0; 4.0]	3.5 [3.0; 4.0]	**0.003**
Calf skinfold [mm]	5.2 [3.9; 6.1]	4.4 [3.6; 5.8]	4.4 [4.0; 5.2]	5.2 [4.0; 7.0]	6.1 [4.8; 6.8]	5.0 [4.0; 6.4]	5.1 [4.0; 6.0]	0.065
Subscapular skinfold [mm]	8.4 [7.6; 9.6]	10.0 [9.0; 11.0]	8.8 [7.8; 10.6]	8.8 [7.6; 10.5]	10.0 [9.0; 11.1]	9.0 [8.0; 11.2]	9.5 [8.0; 10.9]	**0.030**
Abdominal skinfold [mm]	10.2 [6.0; 14.0]	9.1 [7.2; 11.6]	8.0 [6.2; 10.0]	8.0 [6.6; 10.2]	9.5 [6.5; 11.1]	8.1 [6.2; 13.2]	8.4 [6.5; 9.2]	0.549
Iliac crest skinfold [mm]	7.8 [5.0; 9.8]	7.8 [6.5; 9.3]	7.2 [5.6; 9.8]	7.6 [6.0; 11.0]	7.9 [6.8; 10.8]	8.0 [6.0; 10.6]	9.1 [6.4; 9.5]	0.726
	Mean, SD							
Fat mass [%]	18.0 ±4.6	16.9 ±4.2	16.8 ±4.8	17.7 ±4.2	18.4 ±3.4	19.0 ±3.8	21.3 ±3.0	**0.004**

Wrestlers dominate when it comes to the total body fat content (approximately 21% FM). Judo and BJJ athletes demonstrate the lowest total fat content (less than 17% FM).

Based on the values of fat indices, it can be concluded that the type of combat sport practiced may be associated with relative subcutaneous fat content. The analysed groups of athletes differ in their subcutaneous fat content in relation to their body weight (SBFI). In this regard, kick-boxing athletes have the highest proportion of subcutaneous fat, while judo and BJJ athletes have the lowest one. No differences were observed in the mean values of the SFI index, which describes subcutaneous fat content in relation to body height (Table 4).

Combat sports athletes differ significantly in the distribution of subcutaneous fat on the extremities and trunk (SFDI). In BJJ athletes, there is the greatest difference in fat layers of the extremities and trunk – skinfolds of the limbs are half that of the trunk (only 51% of trunk fat structure). On the other hand, kick-boxing and taekwondo athletes show more balanced fat distribution, with limb fat layer accounting for 63-64% of torso subcutaneous fat (Table 4).

Table 4. Indices of subcutaneous fat in combat sports athletes.

Variable	Me [Q1; Q3]							p-value
	boxing	BJJ	judo	karate	kick-boxing	taekwondo	wrestling	
SFI	23.7 [16.7; 29.8]	21.5 [19.5; 26.1]	20.4 [18.1; 25.9]	22.6 [18.1; 27.8]	23.3 [21.1; 29.2]	21.8 [18.8; 28.1]	22.8 [20.1; 23.7]	0.599
SBFI	36.4 [28.8; 48.0]	35.7 [32.6; 43.1]	35.5 [29.6; 39.3]	36.7 [31.7; 46.9]	39.9 [34.3; 49.7]	38.0 [32.5; 49.2]	38.5 [30.4; 41.5]	**0.050**
SFDI	61.2 [50.0; 82.7]	51.2 [42.1; 67.0]	59.1 [51.3; 66.7]	62.8 [50.7; 73.1]	64.5 [47.8; 81.7]	63.5 [49.2; 72.2]	59.9 [46.5; 62.6]	**0.040**

SFI subcutaneous fat index; **SBFI** skinfold-based fat index; **SFDI** subcutaneous fat distribution index.

To better illustrate the differences in fat pattern between combat sports athletes, the distribution of subcutaneous adipose tissue on the limbs and trunk (SFDI) was shown against the relative size of subcutaneous fat and total fat content (Figures 3 to 5).

Brazilian Jiu-jitsu athletes and wrestlers differ the most from other men in terms of fat pattern. BJJ athletes have underdeveloped total fat and subcutaneous fat, as well as the least developed subcutaneous fat on the extremities relative to the torso. In contrast, wrestlers are characterized by a higher total and subcutaneous fat content, with an average subcutaneous fat distribution compared to other groups. Men practicing kick-boxing are characterized by an average development of total body fat, but they have a rather strong development of subcutaneous fat, especially on the limbs, in relation to the trunk (Figures 3 and 4). In terms of total fat and subcutaneous fat, judo and BJJ, as well as boxing and karate athletes are similar, but differ in the way subcutaneous fat is distributed on the limbs and trunk (Figure 4).

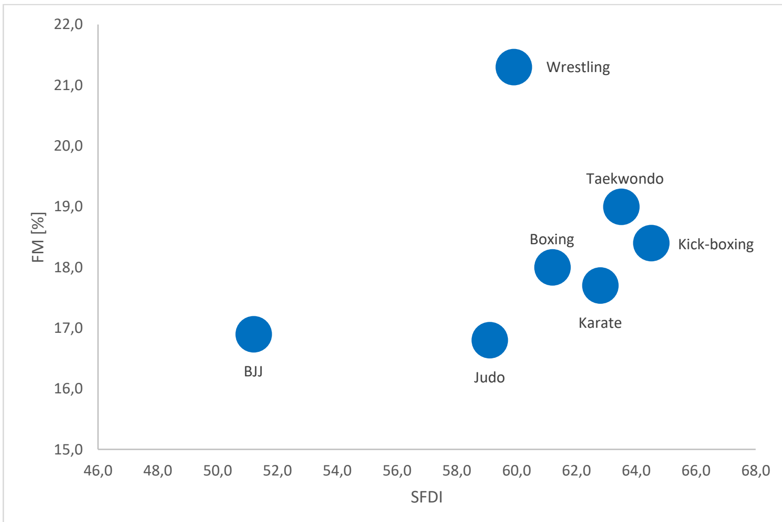

Figure 3. Subcutaneous fat distribution index in relation to total body fat in groups of combat sports athletes.

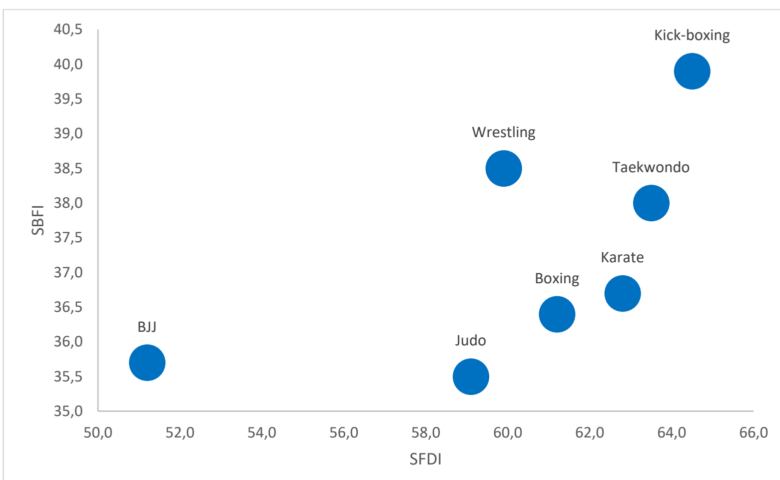

Figure 4. Subcutaneous fat distribution index in relation to skinfold-based fat index in groups of combat sports athletes.

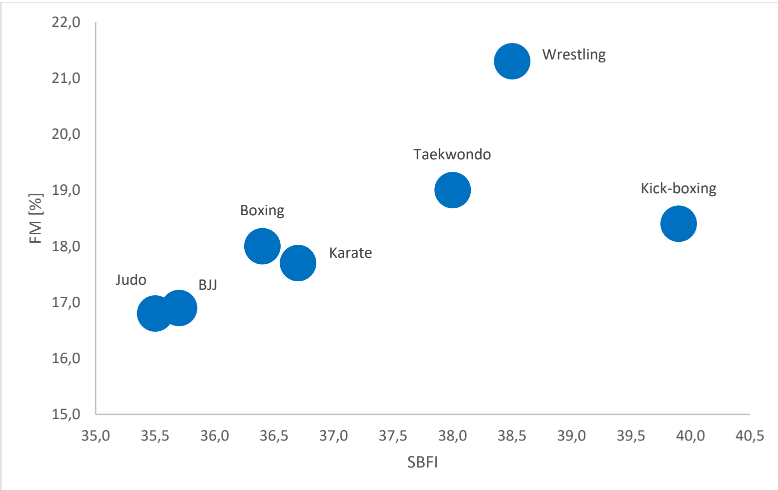

Figure 5. Skinfold-based fat index in relation to total fat content in groups of combat sports athletes.

Analysis of subcutaneous fat proportion (SBFI) in relation to total fat content in groups of combat sports athletes indicates that total fat increases along with the subcutaneous fat layer thickness. Only kick-boxing athletes have an average total fat content at the highest subcutaneous fat pattern.

DISCUSSION

The studied combat sport athletes (practicing judo, Brazilian jiu-jitsu, karate, taekwondo, boxing, kick-boxing, and wrestling) were characterized by an average body height, comparable to the average body height of Polish males, as well as domestic and foreign combat sport athletes [35-39, 8]. In the study by Mala et al. [40], the average body height of kick boxers, judo, and taekwondo athletes exceeded 180 cm. Groups of athletes characterized by slightly lower body height have also been described [28, 17, 40, 8], possibly driven by population variation, as well as weight categories and sport level.

In terms of body massiveness (BMI), wrestling, judo, and BJJ athletes dominated. A more massive physique is related to the fighting rules and techniques used in the foregoing disciplines. In grappling sports, competitors attempt to manipulate the opponent's body mass throwing them to the ground, pinning or forcing the opponent [41, 8]. The greater massiveness of the body is beneficial in this case. In this respect, the body build of wrestlers is similar to that described by Reale et al. [8]. However, in the study by Mala et al. [40], wrestlers were shorter, lighter and moderately slender. Wrestlers and judoists have also been described as more massive than our analyses suggest [36, 28]. However, it should be noted that the highest weight categories were also included in the cited studies. Studies by Shariat et al. [39] and Mala et al. [40] also show that judo athletes are the most massive group of combat sports athletes (the aforementioned authors did not analyse BJJ). However, previous studies indicate that this is particularly true for heavy categories [36, 42], which were not included in our study. A study by Øvretveit [43] indicates that BJJ athletes demonstrate a slightly more massive physique than described in the work presented here. The variation in massiveness of the BJJ athletes' physique was described in a review article by Andreato et al. [44], and it is related e.g. to the sport level, weight categories and preferred fighting techniques [46]. In our study, taekwondo and karate athletes were characterized by a more slender body build compared to judo and BJJ athletes, as well as wrestlers. Boxers were equally slender in terms of BMI, but slightly taller and heavier than karate and taekwondo athletes. These disciplines belong to striking sports, in which athletes utilize movement and distance, attempting to punch and kick with their hands or legs [26, 38, 8]. The aforementioned authors also describe boxers and taekwondo athletes as slender, or even slimmer and lighter than in the presented paper. In the case of taekwondo, it is related to established weight categories. The heavy category starts at 78 kg in this discipline, while the heavy category in other sports is represented by athletes weighing over 90 kg. The minimal contact is required to score here, therefore massiveness of body is not an advantageous trait [8].

Body build of karatekas, similar to that of the present study, was also indicated by previous studies [46, 37, 47, 40]. On the other hand, karate athletes studied by Sterkowicz-Przybycień [48] turned out to be slightly more massive, with comparable body height (the author took into account all weight categories in her analyses). It seems that the slimmer physique of karate athletes is related to the fighting rules. Karate fight is characterized by changeable effort intensity, i.e. periods of maximum exercise alternated with periods of lower intensity or with short intervals. Karate athletes move around in various directions on a square mat and attack their opponents with both upper and lower extremities in different moments of the match [48]. The aforementioned author pointed out the variation in body build among karate athletes depending on their preferred fighting technique. The karate participants who preferred hand techniques were characterized by higher development of mesomorphy component than those who are specialists in punches and kicks [48]. The slimmer body build of taekwondo and karate practitioners is also evident in waist to height proportions (WHtR). Similar to boxing competitors, they have less fat around the waist relative to their body height than judo and BJJ fighters. This is beneficial to them because, as noted by Shariat et al. [39], fighting in karate and taekwondo require moving their bodies in the utmost possible speed in the existing space. Greater fat of the waist region in judoists than in karatekas and taekwondo athletes was also demonstrated by Kankanala et al. [49]. Referring to the kick-boxers studied – in comparison to other combat sports, they were characterized by an average massiveness, similar to that of wrestlers, however they appeared slightly shorter and lighter than wrestlers. In a comparative study conducted by Mala et al. [40] kick-boxers were characterized by greater height and body mass than wrestlers and karate competitors, with average massiveness.

The analysis of other anthropometric characteristics showed that the competitors of various combat sports do not differ in terms of the absolute length of their upper limbs, while they differ in the length of their lower limbs and in the massiveness of their skeleton and musculature of extremities. The longest lower limbs were observed in men training BJJ, while the shortest were observed in those training kick-boxing and judo. Similar trends have been observed in previous studies [32]. Lower limb length has also been observed in wrestlers [50]. BJJ athletes are also characterized by a more massive skeleton, as expressed by wider shoulders and hips (wide body frame) and wide knees. Earlier studies were not always able to show such differentiation, and judo athletes were characterized by similar skeletal massiveness as men training BJJ [32, 50] and also – karate athletes [39].

Among the studied athletes, those training taekwondo and karate have the slimmest skeleton in terms of shoulder width, hip width, and bone epiphyses. Kick-boxers have average shoulder width and narrow hips compared to other groups. The studied judokas are characterized by average shoulder and hip width. They also feature a fairly massive limb skeleton. Previous studies have shown that the skeleton of the torso and limbs is sometimes even more massive in judo athletes than observed in the presented study, especially in high weight categories [36]. In addition to karate competitors, a slender limb skeleton is typical for boxers (narrow elbows) and kick boxers (narrow knees). In terms of thoracic development, men practicing taekwondo were found to be the most slender among martial arts competitors. Men practicing judo, wrestling and jiu-jitsu were characterized by the most massive thorax, confirming previous observations [50]. The variation in skeletal massiveness between athletes of different combat sports reflects differences in the techniques used. In grappling-based disciplines (BJJ, judo, and wrestling), athletes must manipulate their opponent's body weight by throwing them to the ground and holding them down, while at the same time they must be resistant to their opponent's body weight attacks. A massive skeleton encased in well-developed musculature is beneficial in this case.

This is supported by the results presented here. In terms of limb musculature, judo, BJJ, as well as kick-boxing athletes dominated among the combat sports athletes. In contrast, taekwondo and karate athletes have the slimmest arm at both rest and tension, and wrestlers have the slimmest shin, which confirmed previous observations [32, 50]. Contrary to those, combat sports athletes studied by Shariat et al. [39] were characterized by better developed lower leg musculature than Polish athletes, and among them, it was karate athletes who were characterized by the best developed arm musculature. In striking sports (karate, taekwondo, boxing), athletes use movement and distance, the fight requires them to rapidly accelerate as well as decelerate body segments, at the same time they try to inflict blows with their arms or legs with as much explosive limb force as possible, hence adequate limb musculature is beneficial [5, 8]. It is also worth mentioning that the advantage of upper limb musculature in karate athletes compared to male taekwondo athletes can be explained by using more upper limb techniques in karate [5]. However, Tabben et al. [37] showed that karate athletes had higher lower-limbs' power than taekwondo and judo athletes. The high level of mesomorphy described in judo athletes, caused exactly by large limb muscle circumferences and resulting in greater body mass, is beneficial and even necessary, because it increases the advantage under conditions of acute physical confrontation during exercise and competition [39]. Furthermore, it results in a higher level of maximal strength than in taekwondo and karate athletes [37].

Both the massiveness of the physique, as well as the effectiveness in executing appropriate body movements when fighting depend not only on the muscle mass and skeletal massiveness, but also on the content and distribution of body fat. The specificity of different combat sports is reflected, e.g., in the different fat patterns of athletes, while analysis of single isolated body fat characteristic may not reveal intergroup differences. In this study, we analyse fat patterns by simultaneously considering multiple features of subcutaneous and total fat.

Comparison of the individual skinfold thickness does not always facilitate demonstrating intergroup variation, mainly due to the large variation in this trait within specific groups [5]. On the other hand, simultaneous comparison of the skinfold thickness in several body segments makes it possible to describe the pattern of subcutaneous adipose tissue distribution specific to individual disciplines or groups of disciplines. Our results indicate that in terms of the skinfold thickness on the abdomen, above the iliac crest and on the lower leg, the analysed athlete groups did not differ significantly. However, skinfolds on the biceps and triceps and on the scapula showed significant intergroup variation. The thickness of the adipose layer is lower than that observed in the general population [51, 52], as well as in some foreign athletes [49, 39].

High physical activity levels have been shown to specifically shape the distribution of subcutaneous fat. Under the influence of high physical activity, fat is reduced in the abdominal region first, then in the upper limbs, and finally in the lower limbs [23, 24].

The type of training can modify this pattern to some extent. It is worth noting that the studied boxers and kick-boxers are characterized by the most developed subcutaneous fat on the abdomen among all the athletes, which can be justified by the shock-absorbing role of the fat padding when striking the torso. Wrestlers dominate in terms of the subcutaneous adipose tissue development in the supracrestal region. Thinner skinfolds in the abdominal region are characteristic of karate, judo and taekwondo athletes, and in the supracrestal region of judoists and karatekas. The skinfold at the inferior angle of the scapula was found to be thickest in kick-boxing and BJJ athletes, and the thinnest in boxers, judoists and karatekas. In direct comparisons of skinfolds thickness, it can also be observed that wrestlers dominate not only in terms of supracrestal adiposity, but also in terms of biceps skinfold, while their other skinfolds have average values compared to all combat sports competitors. The thinnest skinfolds on the limbs are characterized by the studied BJJ athletes, but the intergroup differences are not large. Kickboxers showed the thickest skinfolds under the scapula, on the arm and on the lower leg among other groups of men. BJJ athletes dominated over judo athletes in terms of torso fat layer, with similar limb fat layer as observed in previous studies [32]. These intergroup differences in the distribution of subcutaneous adipose tissue presented somewhat differently in Iranian athletes, among whom judo athletes had higher fat content than karate and taekwondo athletes [39]. Kankanala et al. [49] obtained higher values of skinfolds thickness on the upper extremity in karate athletes compared to judo and taekwondo groups. Shariat et al. [39] pointed out that not only high levels of mesomorphy may be beneficial for judo athletes, but also increased endomorphy (resulting from the subscapular, the iliac crest and the triceps skinfolds), because the fat padding plays a role in absorbing and dissipating forces during throws and punches. It is worth noting that this only refers to subcutaneous fat, not internal fat.

Our analysis of the subcutaneous fat patterns visualised by skinfolds maps showed that the shape of radar graphs depicting the distribution of subcutaneous adipose tissue are similar in karate, taekwondo, judo and jiu-jitsu athletes, while in boxers, kick-boxers and wrestlers they differ slightly. Additionally, based on the analysis of subcutaneous fat indices (SFI, SBFI), it can be concluded that the type of combat sport practiced differentiates the relative subcutaneous fat content (in relation to body weight). In this regard, kick-boxers have the highest proportion of subcutaneous fat, while judo and BJJ athletes have the lowest one.

The athletes differ significantly in the distribution of subcutaneous fat on the limbs and trunk (SFDI), which was overlooked by previous researchers. In BJJ athletes, there is the greatest difference between extremities and trunk in fat accumulation – limbs subcutaneous fat is half that of the trunk. On the other hand, the adipose tissue distribution is more balanced in karate, kick-boxing and taekwondo athletes – with limb fat accounting for 63-64% of torso fat. This is a clear indication of the differentiation of fat patterns in individual combat sports caused by specific training and fighting rules.

Men practicing particular combat sports differ significantly in subcutaneous fat distribution, as well as total body fat content. Wrestlers dominate in terms of total body fat content (approximately 21%). Among combat sports athletes analysed by Reale et al. [8], wrestlers were also the group showing the highest fat content. Judo and Brazilian jiu-jitsu athletes have the lowest total fat content in our study (at less than 17%). A similar or slightly lower fat level in judokas was reported in some previous studies [53, 54]. Previously studied karatekas also had total fat percentage fairly similar to that shown in our study (approximately 18%) [48, 55, 56]. Shariat et al. [39] and also Reale et al. [8] argued that judokas had higher fat content than karate and taekwondo athletes, but in this case the fat level may have depended on the weight categories included in the study. Numerous authors also found that body fat increased from the lower to the heavier categories of competitors [29, 42, 57]. There have also been publications with lower estimates of total fat of combat sports athletes than in the presented paper, also with respect to the bioelectrical impedance method [58-60, 43]; it seems that the kind of BIA analyser and the regression equations used are relevant in this case [61].

Nevertheless, Bratić et al. [62] pointed out that a lower percentage of adipose tissue allows top judokas to have better metabolic adaptation to different technical and tactical requirements during the match. In addition, based on a review study, Ahmedov et al. [9] concluded that high percentage of body fat in judokas is a factor that complicates judo performance. This rule can apply to all combat sports athletes. Previous studies have also shown that the thickness of individual skinfolds analysed separately did not differ between the winning group versus the defeated group. At the same time, it was found that some elite karate athletes have low levels of body fat, similar to that of elite endurance runners, while others had higher percentages of body fat that did not prevent them from high-level performance [5].

Still, only relative and total fat content were studied, but not fat distribution. Having considered this fact, even greater attention is drawn to the fact that it is not enough to evaluate only the total fat content or the thickness of particular skinfolds to provide a complete assessment of an athlete's physical condition. Knowledge of the body fat patterns of athletes in different sports (based on subcutaneous and total fat content and distribution) is especially useful for coaches and nutritionists in assessing the biological well-being of athletes and evaluating the training or diet effects. The fat pattern may not directly account for the athlete's chance of success in the sport, but the coach's awareness of it will help them provide better directions during the athlete's training. It is worth being aware that a wide range of techniques allow competitors to successfully apply those that best suit their morphological predispositions [9].

In our opinion, an important element of the presented research results there are skinfolds maps, which are radar plots showing the patterns of subcutaneous fat distribution of subjects representing various combat sports. These maps can be used by coaches, sports nutritionists, and researchers in various disciplines to assess the status of subcutaneous fat development in individual cases, which can contribute to optimizing an athlete's training and nutrition program.

In this work, we adopted an alphabetical presentation of combat sports results, although we examined representatives of two out of three groups distinguished in *Theory of Combat Sports* [63] due to the permissible form of direct combat: strikes (boxing, karate, kick-boxing, taekwondo) and throws and grips restraining the competitor's movements (other combat sports athletes). We did not study representatives of combat sports athletes operating with weapons (e.g. fencing, kendo). However, we are not elaborating on this important issue due to editorial constraints. On the other hand, we emphasize that Jagiełło individually or with other researchers studied body composition using the original Perkal method of representatives of many popular combat sports belonging to all groups of the above-mentioned division [64], including the only Olympic sport based on weapons activities – fencing [65]. In the cognitive sense and in view of the promotion and prophylaxis of health preferring martial arts and combat sports, it would be important to review the phenomenon of body composition practicing this type of psychophysical activity based on the classification theory of combat sports [63] and using various of the recommended methods.

CONCLUSIONS

Based on the presented results, it can be concluded that athletes representing various combat sports were characterized by different fat patterns. This became particularly apparent when the analysis simultaneously considered the thickness of the skinfolds in different sites of the body, the relative size of subcutaneous fat, and the percentage of total fat, as well as the distribution of subcutaneous fat on the limbs and torso.

Taking into account all the previously described characteristics of subcutaneous fat, as well as the total fat content (tested with the BIA method), it can be concluded that BJJ athletes and wrestlers differ from other male athletes the most, in terms of the fat pattern. Jiu-jitsu athletes have underdeveloped overall fat and subcutaneous fat, with the least developed subcutaneous fat on the extremities relative to the torso. In contrast, wrestlers are characterized by higher total and subcutaneous fat content, with average subcutaneous fat distribution compared to other athletes. Men practicing kick-boxing are characterized by an average development of total fat, but they have a fairly strong development of subcutaneous fat, especially on the limbs, in relation to the trunk. The other disciplines differ primarily in how subcutaneous fat is distributed in the extremities and trunk.

The original application contribution of the present study are skinfolds maps representative for the competitors of combat sports. These maps, as reference materials (specific norms for athletes), can be used by coaches, sports nutritionists, sports anthropologists and scientists of various disciplines to assess the level of subcutaneous fat development in individual cases, which can contribute to optimizing training and personalizing the nutritional program of athletes.

LIMITATIONS

The studied groups of combat sport athletes are characterized by different sizes, which may have affected the statistical significance of the observed differences. This was partly dictated by the narrowing weight categories of the athletes included in the study. Another reason may be the varying popularity of these sports in our region, and thus the varying accessibility to athletes, especially during the COVID-19 pandemic. Study inclusion criteria were rigorously followed. Above all, care was taken to include men who actively practiced the claimed sports (for at least 3 years), had regular workouts 2-3 times a week and did not have prolonged breaks in training and did not follow special diets. The number of the study participants for some disciplines also limited the ability to assess fat pattern in weight categories, which seems to be a valid approach, setting further directions for the authors' research.

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Cite this article as: Stachoń A, Pietraszewska J, Burdukiewicz A et al. The distribution of subcutaneous fat and fat pattern among male athletes of different combat sports. Arch Budo 2022; 18: 87-101