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Anthropometry Profile and its Influence on Injury Pattern in America's Cup Racing Crew

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Abstract

Aim: The America's Cup challenge involves intense physical stress due to racing sailboats. Therefore different anthropometric parameters and their influence on injury pattern were investigated.

Methods: The setting was the 32nd America's Cup hosted in 2007 in Valencia, Spain. Register of anthropometric parameters was obtained from all members of one syndicate (starting 27 in 2004 and 34 in the last 2007 season). Measurements included body weight, height, body mass index (BMI), skinfold thickness, fat, muscle and limb body mass in kg and percentage. The anatomic location, type, number and mechanism of injuries were registered during competition by a medical team.

Results: Mean BMI of the crew (27.14 in 2004 and 27.23 in 2007). Crew members with overuse injuries were older ($p<0.01$), showed significantly lower skinfold thickness in 2007 season ($p<0.01$) and also significantly lower muscle mass percentage in 2007 ($p<0.05$). Athletes suffering more than one injury had lower weight in both 2004 and 2007 seasons ($p<0.05$ in 2007). Athletes with injuries at the upper extremity had the lowest weight ($p<0.05$), the lowest skinfold thickness in 2007 ($p<0.01$), the lowest muscles mass also in 2007 ($p<0.01$), and the lowest body fat weight ($p<0.05$).

Conclusions: Anthropometric profile of athletes involved in America's Cup yachting was dependent on the different onboard physical requirements and had close relationship to injury pattern.

Keywords: Epidemiology; Physiology; Performance; Sports medicine

Introduction

Anthropometric parameters and morphological characteristics have been believed to play a crucial role in determining the performance successful of athletes [1-10]. These parameters reflect the nutritional and fitness status of specific populations, are largely dependent on heredity, and are closely correlated with age, gender, ethnicity, eating habits, and exercise practice [11-14]. Proper evaluation of anthropometric and body composition parameters seem to be especially relevant in persons involved in sports requiring high physical demands, as they are good indicators of prospective performance in sports [2,15-17]. Most of these morphological parameters are commonly used for the evaluation and selection of athletes for diverse sport disciplines. More research has been focused on determining the optimal anthropometric characteristics for different sport modalities.

Recently, new physiological data on elite America's Cup sailors describing well their anthropometrical and physical profiles have been reported [18,19]. Body anthropometrical characteristics were significantly related to sailing performance. In fact, grinders were bigger and stronger than all other positions. Sailing teams can therefore select athletes with anthropometric dimensions more suited to perform the sailing manoeuvres to enhance their likelihood of competitive success [20]. Understanding of the anthropometric characteristics of sailors seems to be crucial in the development of specific resistance training programmes. The anthropometric characteristics of the sailors will vary depending on the physical skills required in the sailing position [18,20-22]. There are also some studies in the peer-reviewed literature addressing sailing injuries in America's Cup yachting crews [23-29]. In these reports, the overall incidence of injuries varies from 5.7 to 10 /1000 sailing hours. Data suggest that America's Cup crew-members are at a similar risk of injury as athletes in other team sports.

There are no studies related to anthropometric profile and injury occurrence in America's Cup sailing. Therefore, differences between anthropometric parameters of sailors participating in an America's Cup yachting syndicate according to their boat position were investigated. Correlations of the anthropometric parameters and their influence on injury pattern were also analysed.

Material and Methods

Subjects and period of evaluation

All members of an America's Cup yachting crew, consisting of sailors from six different countries and four different continents, took part in the study. Physical and anthropometric measurements were recorded from 27 sailors in 2004 and 34 in 2007. Only a total of 21 sailors completed the entire 4-year season of competition. Crew-members had previously been involved in other sailing competitions, such as Olympic Games, World Cups, Volvo Ocean Races, and previous America's Cup editions. After receiving a detailed explanation about the importance and significance of the measurements, all crew-members signed a consent form agreeing to carry out the study and allowing use of the results for scientific purposes. The study had Ethics Committee approval given by the University of Valencia.

Data collection was performed at the beginning of each sailing season from February 2004 to January 2007. This period between 2004

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and 2007 (41 competition days) comprised of the preparatory Acts of the 32nd America's Cup, which was celebrated in Valencia, Spain, including the 2007 Louis Vuitton Cup (15 competition days). The total competition time-period consisted of 56 days, equivalent to 300h sailing hours (sum of all individually documented races).

Each crew-member had a specific role within the boat that required different physical work. For purposes of the study, positions on the boat were divided into three categories depending on the physical work intensity involved:

- high physical-work intensity (mastman, grinders, and bowman);
- mild physical work intensity (pitman, trimmer, runner, mid-bowman),
- low physical work intensity (navigator, skipper, tactician, strategist).

A detailed description of the different requirements of each boat position has been given in a previous publications [26,27,29].

Anthropometric measures

Anthropometry was conducted in accordance with the prescribed methods of the International Society for the Advancement of Kinanthropometry (ISAK). The following anthropometric measures were registered: body weight, height, body mass index (BMI), skinfold thickness (triceps, biceps, sub scapular, suprailiac, abdominal, front thigh, and medial calf), and body girths (calf-maximum, mid-thigh, and forearm-maximum).

Nude body mass was measured with digital scales to the nearest 0.1 kg (Seca 769, Hamburg, Germany) and height was measured with a stadiometer to the nearest 0.005 m. Skinfold thickness was measured in duplicate at seven sites (triceps, biceps, sub scapular, suprailiac, calf, thigh, abdomen) using Harpenden skinfold callipers (Baty International, West Sussex, UK) according to standard techniques [2,7]. To ensure accuracy, skinfold measurement were performed by a specialist with experience in anthropometric studies in order to decrease methodological bias (technical error of measurement less than 1% for all measures). Body girths were measured using a Lufkin metal tape. Body composition profile was obtained from skinfold thickness data by using the equations described by Jackson and Pollock [2]. Percent body fat was calculated from the sum of seven skinfolds [2]. Lean body mass (LBM) was calculated using formula: LBM = [(Body Weight)(100 - Body Fat Percentage)]/100. To calculate fat mass we used formula: Fat Mass = (Body Weight)(Body Fat Percentage / 100). Analysis of the variations in anthropometric parameters was obtained from the 21 sailors who complete the 4-year season of competition.

Assessment of injury and data collection

The injury definition and the register methodology have been previously described by our research group [26,29]. Briefly, injuries were classified into traumatic and overuse, depending on the causative mechanism. For the purposes of this study, the injury anatomic location was divided into three categories: trunk, upper extremity, and lower extremity.

Statistical data analysis

Results were analyzed using standard descriptive statistics. The mean and standard deviation (SD) of each item were calculated for all the sailors and from each physical work group (high intensive, moderate intensive, low intensive) according to boat position. Statistical analysis also involved pair wise comparisons between the three groups through a one-way analysis of co-variance and two-tailed t-test. Correlations between variables were made through the Pearson coefficient correlation. P values less than 0.05 were regarded as significant.

Results

Table 1 summarizes the main descriptive anthropometric characteristics of the crew in the check-ups performed at the beginning of the first and last season of study (2004 and 2007). Mean values did not statistically differ except for muscle mass, which was significantly higher in the 2007 season. Although part of the participants have changed, body composition profile comparisons at the beginning of competition and three years later showed that there were no significant differences between weight, BMI, body fat mass and percentage, muscle percentage, and lean body mass (LBM). The most interesting data concerns the high fat components in this particular group of America's Cup athletes. BMI was within the range of overweight people according to age. The mean percentage of body fat was around 17% and did not correspond with that expected in elite sportsmen.

Variations of different anthropometric parameters along the 4-season period were analyzed in the 21 crew-members who completed the whole 32nd America's Cup (Table 2). The only significant change was detected in muscle mass that progressively increased from the 2004 to 2007 season (2.08 ± 3.60 kg increment, $p=0.015$). Changes in the sum of skinfold were apparently evident (mean increment 6.21 mm) but the wide distribution of results made these differences not statistically significant ($p=0.07$).

Anthropometry data were analyzed according to boat positions in the 2007 season (Table 3). Sailors participating in high physical work intensity (mastman, grinders, and bowman) represented the youngest (mean 27.2 years), the tallest (mean 1.84 m), and the heaviest (mean 97.9 kg) group of athletes. These sailors weighed an average of 15 kg more than sailors from the group requiring low intensity physical work, and had higher skinfold thickness. This group also showed the highest BMI values (29.07, $p<0.05$), greater muscle mass (55.99 kg, $p<0.01$), and increased lean body mass (83.06 kg, $p<0.01$). Body fat percentage was almost similar to the other groups of sailors undergoing less physical activity.

In contrast, sailors with low intensity physical work (navigator, skipper, tactician, strategist) represented the oldest group of athletes (mean 41.7 years) with the lowest mean values of weight (82.3 kg), height (1.75 m), BMI (25.82), skinfold thickness (66.65 mm), body fat mass (14.27 kg), muscle mass (44.18 kg), and limb body mass (68.2 kg). Anthropometric data of sailors performing in boat positions requiring moderate physical work intensity showed mean values within the middle range between those found in the high and low physical intensity groups of sailors. No significant difference in BMI was found between athletes performing in boat positions of moderate and low physical work intensity.

The relationships between the variations in anthropometry parameters and the type and number of injuries were evaluated in the 21 permanent members of the crew (Table 4). Some interesting changes were observed between the beginning of competition (2004) and the final 2007 season. Sailors with traumatic injuries showed a significant mean increase in the sum of skinfold thickness in the 2007 season as compared to sailors with overuse injuries ($p=0.04$). The same tendency was observed for total muscle mass. Athletes with increased muscle mass had more traumatic injuries than those with overuse injuries ($p=0.02$). Sailors with overuse injuries had less muscle and fat mass percentages. When anthropometric variables were considered

	First season (February 2004) N=27			Fourth season (January 2007) N=34		
Dimension	**Mean**	**SD**	**Range**	**Mean**	**SD**	**Range**
Age	29.5	8.17	18-53	32.5	8.15	21-56
Weight (kg)	89.49	13.67	59.5-120.7	89.75	13.35	64.4-118.8
Height (cm)	181	0.07	168-195	182	0.07	168-198
BMI (kg/m^2)	27.14	3.48	20.11-34.9	27.23	3.16	21.43-34.3
Skinfold thickness (mm)*	100.5	21.02	37-126	81.57	27.7	41.1-149.2
Tricep (mm)	10.3	3.7	4.6-20	8.58	2.65	4.70-18.00
Bíceps (mm)	6.7	4.0	2.6-17	4.21	2.43	2.20-14.10
Subscapular (mm)	17.6	6.4	8.8-32	15.46	6.79	8.50-35.00
Suprailiac (mm)	12.8	5.2	5.4-23.7	10.63	4.12	5.40-21.80
Calf (mm)	12.5	4.8	6.6-22.6	8.53	3.49	3.20-19.40
Thigh (mm)	16.5	5.5	7-30.9	13.52	5.07	6.00-32.00
Abdominal (mm)	24.1	7.3	9-37	20.64	7.00	8.80-38.00
Calf Girth (cm)	40.8	2.1	38.5-45	37.73	6.52	6.9-44
Mid-thigh Girth (cm)	60.2	4.4	49.5-67	58.24	4.87	48.7-68.1
Forearm Girth (cm)	31.3	2.1	28-36	29.84	2.69	24-35.1
Fat mass (kg)	18.76	3.19	13.19-25.73	16.22	5.36	5.8-32.4
Body fat percentage (%)	16.87	3.38	8.3-24.2	17.17	3.53	9.2-25.2
Muscle mass (kg)	49.17	7.1	34.2-62.9	50.99 **	8.27	34.2-64.9
Muscle percentage (%)	55.09	2.85	49.2-61.77	53.33	8.55	16.2-61.8
Lean body mass (kg)	70.72	14.64	45.55-103.63	76	10.27	57.6-98.2

*Sum of skinfold thickness
** $p<0.01$

Table 1: Body composition profile of the whole crew taken at the beginning of the seasons 2004-2007.

	2004	2007	Variations
	Mean (SD) n=21	**Mean (SD) n=21**	**Mean (SD)**
Weight (kg)	89.65(14.39)	89.62(13.29)	0.02 (4.02)
BMI (Kg/m2)	27.16(3.76)	27.16(3.42)	0.00 (1.20)
Sum Skinfold (mm)	75.73(22.77)	81.94(30.10)	6.21 (20.07)
Muscle mass (kg)	49.19(7.32)	51.27(8.15)*	2.08 (3.60)
% Muscle	55.06(3.18)	53.24(9.59)	-1.72 (9.83)
% Fat	16.74(3.65)	16.91(4.00)	0.17 (2.74)

*$p=0.015$

Table 2: Variations of different anthropometric parameters along the 4-season period in the 21 members of the crew who completed the whole 32th Americas Cup.

	High Intensity N=15		Moderate Intensity N=12		Low Intensity N=7	
Dimension	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Age	27.2 **	4.3	34.1 $	5.8	41.7 ††	8.1
Weight	97.9 *	13.3	85	5.7	82.3 †	9.1
Height (m)	1.84	0.07	1.79	0.08	1.75	0.08
BMI (kg/m^2)	29.07 *	2.94	25.91	1.82	25.82	2.43
Skinfold thickness (sum in mm)	94.98	31.43	74.92	13.32	66.65	15.91
Fat mass (kg)	17.98	5.74	15.51	3.49	14.27	4.09
Body fat percentage (%)	17.47	3.57	17.48	2.83	17.02	2.95
Muscle mass (kg)	55.99	7.63	49.28	3.62	44.18 ††	6.14
Muscle percentage (%)	51.95	11.04	56.2 $	2.95	49.77	5.63
Lean body mass (kg)	83.06 **	9.6	71.79	2.57	68.2 ††	7.1

* $p<0.05$, ** $p<0.01$: as compared to moderate intensity group
$ $p<0.05$, $$ $p<0.01$: as compared to low intensity group
† $p<0.05$, †† $p<0.01$: as compared to high intensity group

Table 3: Anthropometry and body composition according to boat positions (2007 season).

in relation to the number of injuries some statistically significant differences were found (Table 4).

Independently of the injury type, athletes suffering more than one injury had lower weight loss along seasons ($p=0.03$). Variations in BMI according to the number of injuries were also statistically significant ($p=0.03$).

Concerning location of injuries and anthropometric variables, athletes with injuries at the trunk exhibited weight gain as compared to athletes with injuries at the extremities that lost weight (Figure 1).

However differences were not significant. Athletes with injuries at lower extremity showed a great mean increase in total Skinfold thickness. The widespread of changes made differences also not

	Type of injury				P	Number of injuries				P
	Traumatic		Overuse			1		More than 1		
	Mean value(SD)	Mean variation (SD)	Mean value (SD)	Mean variation (SD)		Mean value(SD)	Mean variation (SD)	Mean value (SD)	Mean variation (SD)	
Age (years)	24.33 (3.05)	-	28.91 (4.10)	-		28.00 (4.24)	-	27.89 (4.56)	-	
Weight (kg)	93.31 (16.38)	-3.13 (2.92)	86.31 (10.56)	-0.15 (3.52)		83.94 (7.65)	-3.42 (4.12)	91.63 (8.87)	0.66 (2.25)	0.03
BMI (Kg/m2)	29.16 (3.56)	0.86 (0.78)	27.00 (2.95)	0.06 (1.14)		26.74 (3.29)	1.05 (1.30)	27.86 (3.08)	-0.21 (0.69)	0.03
Sum Skinfold (mm)	96.23 (22.99)	22.03 (10.90)	72.90 (19.65)	1.07 (14.87)	0.04	63.88 (17.26)	2.52 (16.02)	85.70 (20.84)	7.25 (17.26)	
Muscle mass (kg)	58.46 (5.84)	5.63 (2.83)	50.68 (8.18)	2.14 (1.93)	0.02	47.56 (10.71)	1.90 (3.11)	55.01 (5.50)	3.44 (2.11)	
% Muscle	57.30 (2.48)	1.66 (2.58)	52.63 (12.49)	-3.80 (12.65)		55.80 (4.11)	-1.16 (4.05)	52.43 (13.79)	-3.44 (14.15)	
% Fat	16.66 (2.63)	1.23 (0.85)	15.30 (2.99)	-0.45 (2.56)		14.36 (3.51)	0.42 (3.12)	16.61 (2.52)	-0.37 (2.02)	

Table 4: Variations in anthropometry parameters in relation to the type and number of injuries in the 21 permanent members of the crew.

significant. Total muscle mass increase in all three groups of injury location, and here differences were statistically significant.

Discussion

Anthropometrical profile of elite America's Cup sailors has been related to sailing performance and is dependent on the physical skills required in the sailing position [18-20,27,28]. A special characteristic of the America's Cup yachting is the athlete's weight management; so gains or changes in body mass of an individual must be balanced through the entire team. Sailors usually need to reach a pre-established ideal mass for racing within the overall weight limits imposed by the rules of the America's Cup class. In our study, mean weight for sailors in high, moderate and low intensity groups were similar to those reported by Neville [19] and Pearson [20]. Some studies found a negative correlation between weight and performance indicating that heavier athletes present lower anaerobic power in activities that involve changing positions [30]. In our study, athletes with less weight had more overuse injuries, and lower injury recurrence. The absence of weight loss during competition was found related with multiple injury occurrences.

Another important peculiarity of the America's Cup class is that the age of athletes has a very wide range within the same crew. In our study, sailor mean age was 32.5 years ranging from 21 to 56. In other team sports, it is unusual to find such a large difference in age among athletes. In elite rugby players, an age range from 19 to 31 years has been described [31], which is similar to that found in professional soccer players [6]. The wider age range of America's Cup yachting crews is related to the particular physical work requirements of the different boat positions and has an obvious influence on physical conditioning of older sailors. In our study, older sailors had a tendency to undergo more overuse injuries and low injury recurrence.

Skinfold thickness is often examined for the evaluation of nutritional state and physical changes associated with conditioning. In our analysis on variations of anthropometric parameters obtained from the 21 sailors who completed the 4-season period of competition, the sum of skinfold thickness (triceps, biceps, sub scapular, suprailiac, calf, thigh and abdominal) disclosed high values along the seasons, increasing slightly in 2007. The group of sailors requiring heavy physical work showed the highest mean values. These findings are consistent with those of Pearson [20] in their study of the Team New Zealand crew. These data suggest that the nutritional behaviour of athletes involved in intensive physical demands (grinders), was inappropriate or at least underestimated. The low values of skinfold thickness in other aerobic sports use to be maintained through training over many years [10,32]. This feature did not apply for America's Cup sailors; besides, these athletes are also engaged in heavy training periods during many years. An interesting finding in our study was that the increase in skinfold thickness during competition was related to the occurrence of traumatic injuries, and a tendency to have injuries localized in the lower extremity.

Body mass was greater over the last three America's Cups, indicating a substantial increase in lean body mass. In fact, a common strategy of the teams has been to reduce the body fat of the whole crew to maximize lean muscle mass of the positions with the greatest strength and power requirements [19,20]. In our study, mean body fat mass along the 4-season period (16.91+4) was lower than reported previously during the 30th Americas Cup (19+5%) [33]. On the other hand, mean body fat was higher than that reported previously during the 31st (15+4%) [20], and 32nd (13+4%) America's Cups [19]. According to some boat positions, body fat percentage ranged from 11+4% for bowmen and 13+4% for trimmers to 13+4% for grinders and 15+6% for afterguard crew-members [19]. In our study, the mean value of body fat percentage in grinders was significantly higher (17.98±5.74), which is above the range corresponding to good physical condition. Body fat increments were found in sailors suffering from traumatic injuries. The persistent high body fat mass values indicate that the monitoring of this parameter was not well oriented or at least underestimated within the team. Optimal body fat described for elite sportsmen was previously under the limit of 15%. For example, in soccer Rico-Sanz [6] stated that football players should have a body fat percentage of around 10%. The negative influence of body fat on motor performance observed in these athletes has been described in other sports modalities [3,6,7].

Maximising the proportion of functional muscle mass to fat mass, which has little functional benefit, is an important crew selection consideration [19]. We found a positive gain on muscle mass between seasons 2004-2007, being the difference statistically significant (p=0.015). From a physiological point of view, this is a positive change because muscular strength is proportional to muscle size [34]. Bigger muscle mass can be advantageous specifically in sailors in the high intensity group. Actually, power production grinders are selected for their large muscle mass [18,25]. Increments in muscle mass imply higher muscle mass cross-sectional area and, consequently, higher power and force output for those segments. The data observed in our study concerning muscle mass between groups of athletes confirm this hypothesis. When total muscle mass was related to injury type and location, some relevant data were found. A lower gain in total muscle mass seemed to predispose to overuse injuries located at the upper extremities. Anthropometric characteristics of the high intensity physical group were significantly different than those for sailors in any other position on the boat, with the grinding group being larger in almost all linear measures of body shape. This is probably due to

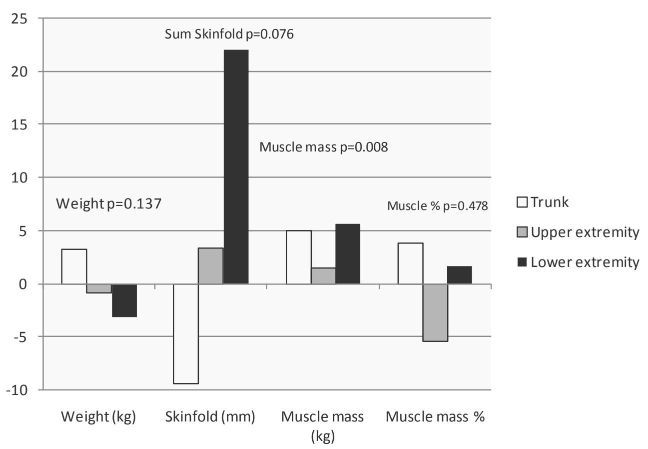

Figure 1: Weight, skinfold thickness, total muscle mass and muscle percentage according to injury location.

the nature of the tasks performed by each position during sailing [18,20,22,23,25-29]. The primary function of a grinder is to provide the power for the mechanical grinding winches that control the movement of the sail, hence why the grinders are sometimes referred to as the 'engine' of the boat [19,25,26]. In comparison, although most crew-members will be required to grind at some stage in a race, their primary responsibilities have either slightly less or at least different physical demands than those of the grinders. The sailors in moderate or low intensity groups showed very few differences in anthropometric characteristics between them.

Three important limitations of the study should be considered. One concerns the diverse characteristics of the team participants. America´s Cup crews are usually composed of a genetically diverse group of sailors representing different countries and races. This feature probably induced a dispersion of anthropometric parameters that could also affect injury occurrence. The other limiting aspect is related to the lack of nutritional monitoring of these athletes. Analyzing the results from a retrospective point of view we found that a deeper scrutiny and intervention on the nutritional behaviour would have been desirable. The discrepancy in some data may be the result of differences in athlete recruitment, preparation and management. For example, less well-resourced teams, where athletes are typically required to take on multiple roles because of the limited number of support staff. Consequently, their ability to prioritize on athletic performance could be compromised [19,27].

Conclusions

The anthropometric profile of athletes involved in America's Cup yachting is dependent on the different physical requirements of each boat position and has influence on injury pattern. Sailors grouped according to physical work intensity show similar anthropometrical profiles. Interesting relationships were found between anthropometric parameters and type, occurrence and location of injuries. Heavy weight, thicker skin folds and greater muscle masses were found to have preventive value against overuse injuries. Further research in this field is needed, especially regarding the influence of body composition on physical conditioning and injury epidemiology, prevention, and recovery.

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