Sport Sciences for Health (2020) 16:249–255
https://doi.org/10.1007/s11332-019-00598-2

ORIGINAL ARTICLE

Secular trends in adiposity and musculoskeletal dimensions of elite heavyweight boxers between 1889 and 2019

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Received: 27 May 2019 / Accepted: 14 October 2019 / Published online: 5 November 2019

Abstract

Purpose With improving nutrition and health, athletes have grown taller and heavier over the past century. Since there is no weight restriction in the heavyweight class, secular changes in anthropometric measurements of heavyweight boxers may mirror those of contemporary general populations.

Objectives We aimed to (1) examine secular trends in adiposity and musculoskeletal measurements in heavyweight boxers, (2) determine anthropometric differences between champions and unsuccessful challengers.

Methods Detailed demographics taken at time of contest (first official World Championship to current contest: 1889–2019) were collected from media archives.

Results All 237 boxers (83 champions, 154 challengers) contesting a recognised heavyweight World Championships were identified. They had mean (± SD) age = 28.9 ± 4.1 years, height = 187.3 ± 6.5 cm, reach = 195.2 ± 9.4 cm, weight = 97.5 ± 11.5 kg, BMI = 27.8 ± 2.4 kg/m^2 and waist = 87.9 ± 6.2 cm. Contest years explained 25.9% ($p < 0.001$) of the variance in BMI for champions and 30.9% ($p < 0.001$) for challengers, 9.1% ($p < 0.071$) in WC for champions and 19.9% ($p < 0.001$) for challengers. Contest years correlated with height ($r = 0.531$, $p < 0.001$), reach ($r = 0.341$, $p < 0.001$), weight ($r = 0.603$, $p < 0.001$) and BMI ($r = 0.370$, $p = 0.001$) among all documented boxers, and with waist only in challengers ($r = 0.349$, $p < 0.001$) but not in champions ($r = 0.078$, $p = 0.509$). Compared with challengers, champions had greater stature by + 3.4 cm ($p < 0.001$), reach + 3.6 cm ($p = 0.005$) and weight + 3.7 kg ($p = 0.017$), with similar BMI and waist. Champions had larger biceps and forearms but did not differ from challengers in other musculoskeletal dimensions.

Conclusions Over 130 years elite heavyweight boxers have increased in size (BMI) and reach but waists in champions have remained static. Being heavier, taller with longer and bigger arms, but with similar in BMI and waist, appear to be differentiating factors between champions and challengers.

Keywords Anthropometry · Musculoskeletal growth · Stature · BMI · Waist

Abbreviations

BMI Body mass index
WC Waist circumference

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Introduction

With improving nutrition and healthcare, general populations in developed countries have become progressively heavier and taller over the past century [1–3]. The trend in body mass index (BMI), often interpreted as body fatness, has risen dramatically [4]. In parallel, increases in weight and height have also been observed among Olympic athletes over a 48-year period between 1928 and 1976 [5].

Since the end of the nineteenth century, sports organisers have routinely documented detailed anthropometric measurements ('tale of the tape') of professional boxers at the time of major contests. Data from this group of athletes provide a unique opportunity for studying secular trends in anthropometry. Since there is no weight restriction in the heavyweight class, secular changes in anthropometric

Key points

With improving nutrition and health, athletes including heavyweight boxers (in parallel with general populations) have grown taller and heavier over the past century. Other anthropometric changes may also occur.

Contest years explained 25.9% ($p < 0.001$) of the variance in BMI for champions and 30.9% ($p < 0.001$) for challengers, 9.1% ($p < 0.071$) in WC for champions and 19.9% ($p < 0.001$) for challengers. The trends of BMI and WC moved upwards with contest years in challengers while BMI and WC plateaued or moved upwards less steeply in champions.

Contest years correlated with height, reach, weight and BMI among all documented boxers, and with waist only in challengers but not in champions.

Compared with challengers who never won a heavyweight boxing championship, champions had greater stature, reach and weight, with similar BMI and waist. Champions also had larger biceps and forearms but did not differ from challengers in other musculoskeletal dimensions.

Elite heavyweight boxers have increased in size as determined by BMI and reach but waist measurements in champions have remained static. Being heavier, taller with longer and bigger arms, but with similar in BMI and waist, appear to be differentiating factors between champions and challengers.

measurements of heavyweight boxers may mirror those of contemporary general populations. However, it is not established, (1) how secular trends have been changing for other body dimensions which reflect adiposity and musculoskeletal structures, or (2) whether these anthropometric measurements are different between champion boxers and challengers who have never won a title that may provide insights into physical and fitness attributes of champions that set them apart from unsuccessful challengers. To address these questions, we studied all male heavyweight boxers who have contested for official World championship titles.

Methods

Data procurement

Data were collected from published media, primarily newspapers [6, 7], and supplemented by information from sports magazines, official match programmes, books, encyclopedias [8, 9] and official websites [10] of all internationally recognised Heavyweight World boxing championships, from the first ever official contest (August 8th, 1889) to the latest (February 8th, 2019).

Demographic and anthropometric data

Demographic information of male boxers measured at the time of the championship contests was collected including age, champion/challenger status (champions of any of the recognised World boxing titles, principally World Boxing Council, World Boxing Association, World Boxing Organization and International Boxing Federation [11], and unsuccessful challengers who contested but never prevailed in any of the World title bouts), nationality (categorised to North America, Europe and others), and ethnicity (American white, African American, European white, and others including mixed race, Hispanic, Samoan and African) [12].

Anthropometric measurements of boxers have been meticulously documented and closely regulated by boxing governing bodies since the first official contest to ensure fair play. We grouped these measurements into four anatomical categories: (1) body lengths (height and reach), (2) body mass and indices of adiposity (weight, BMI and waist circumference, WC), (3) muscle dimensions (neck, normal and expanded chest, biceps, forearm, thigh and calf circumferences), and (4) skeletal dimensions (fist, wrist and ankle circumferences). Data on individuals were obtained from as many sources as possible to verify consistency. When there were discrepancies in reported values between sources, the average was used.

Definition of contest years

"Contest years" were defined as the period between the first ever official Heavyweight World Championship contest on 08-08-1889 (baseline) and the current contest on 08-02-2019 (year 130). Each contest year indicates specifically the date (precisely to the day-month-year) in which a championship bout took place which coincides with the time when the boxers had their anthropometry measured, e.g., if the contest took place in 1899, the contest year would be 10.

Statistical analysis

Partial correlations (adjusted for age, champion/challenger status, nationality and ethnicity) were performed separately for champions and for challengers to assess the associations between anthropometric measurements and contest years. Linear and polynomial regression models were used to evaluate the associations of contest years with BMI and with WC. Independent *t* tests were performed to assess for differences in anthropometric measurements between champion boxers and unsuccessful challengers. Analyses were conducted using SPSS v23.0 (IBM Corp., NY, USA). The null hypothesis was rejected when $p < 0.05$.

Results

All 239 boxers who contested for heavyweight championships of the World between 1889 and 2019 were identified. Two were excluded after being stripped of the titles having

being found positive for banned substances, leaving 237 for analysis.

There were 83 (35.0%) champions and 154 (65.0%) unsuccessful challengers, of whom 154 (65.0%) came from the USA and Canada, 40 (16.9%) from the UK, 18 (7.6%) from other European countries and 25 (10.5%) from other places. Among these boxers, 125 (52.7%) were white and 112 (47.3%) non-white. The none-white group comprised 93 (39.2%) blacks, 9 (3.8%) mixed race individuals and 10 (4.2%) others including Samoans, Hispanics and Latinos.

To ensure that anthropometric measurements at the same contest were reliably reported by different sources, we compared 25 sets of measurements reported by two different newspapers and found no substantial inconsistency in reported body weight, height and musculoskeletal dimensions, with only one describing a 2 cm difference in anthropometry between two sources.

Among all boxers studied, the mean (± SD) age was 28.9 ± 4.1 years, height 187.3 ± 6.5 cm, reach 195.2 ± 9.4 cm, weight 97.5 ± 11.5 kg, BMI 27.8 ± 2.4 kg/m^2 and WC 87.9 ± 6.2 cm. The remaining anthropometric measurements of musculoskeletal dimensions are shown in Table 1.

Linear regression analysis showed year since the first championship explained 21.5% ($p < 0.001$) for champions and 24.8% ($p < 0.001$) for challengers of the variance in BMI and 4.7% ($p = 0.059$) for champions and 13.9% ($p < 0.001$) for challengers of the variance of WC. Further exploration using curve estimation revealed cubic regression increased the explained variances in BMI for champions ($r^2 = 25.9\%$, $p < 0.001$) and challengers ($r^2 = 30.9\%$, $p < 0.001$) as well as explained variances in WC for champions ($r^2 = 9.1\%$, $p < 0.071$) and challengers ($r^2 = 19.9\%$, $p < 0.001$). Compared with challengers where the trends of both BMI and WC continued to move upwards, the champions' BMI had plateaued and WC moved upwards less steeply (Fig. 1a, b).

Partial correlations with adjustments for age, nationality and ethnicity and champion/challenger status (Table 2) show that among all boxers, contest years correlated positively with height ($r = 0.531$, $p < 0.001$), reach ($r = 0.341$, $p < 0.001$), weight ($r = 0.603$, $p < 0.001$), BMI ($r = 0.370$, $p < 0.001$) and WC ($r = 0.248$, $p = 0.001$). Contest years also correlated significantly with measurements of musculoskeletal dimensions including neck, chest, biceps, forearm, thigh and ankle circumferences (Table 2). Analysis within each group according to champions/challengers status showed that height, reach, weight, BMI, neck, unexpanded chest and biceps correlated significantly with contest years in both groups. While WC correlated significantly with contest years among challengers ($r = 0.349$, $p < 0.001$), this association was not observed in champion boxers ($r = 0.078$, $p = 0.509$) (Table 2). Contest years correlated significantly with expanded chest, forearm and thigh only in challengers but not with calf, wrist or fist size in either group.

Table 1 Characteristics of heavyweight boxers

	n	Mean	SD	95% CI
Age (years)	237	28.9	4.1	20.9–36.9
Body lengths				
Height (cm)	236	187.3	6.5	174.6–200.0
Reach (cm)	222	195.2	9.4	176.8–213.6
Body mass and indices of adiposity				
Weight (kg)	237	97.5	11.5	75.0–120.0
Body mass index (kg/m^2)	236	27.8	2.4	23.1–32.5
Waist circumference (cm)	184	87.9	6.2	75.7–100.1
Muscle size				
Neck circumference (cm)	178	44.5	2.4	39.8–49.2
Unexpanded chest circumference (cm)	183	109.1	6.7	96.0–122.2
Expanded chest circumference (cm)	181	116.0	7.1	102.1–129.9
Biceps (cm)	182	39.8	3.6	32.7–46.9
Forearm (cm)	165	33.3	3.0	27.4–39.2
Thigh circumference (cm)	178	61.3	5.9	49.7–72.9
Calf (cm)	180	40.3	3.8	32.9–47.7
Skeletal dimensions				
Wrist (cm)	161	20.2	1.9	16.5–23.9
Fist size (cm)	152	32.4	2.4	27.7–37.1
Ankle (cm)	142	25.5	2.6	20.4–30.6

Imperial units were converted to metric units where necessary

Compared with unsuccessful challengers, champion boxers were significantly taller by + 3.4 cm ($p < 0.001$), had longer reach by + 3.6 cm ($p = 0.005$) and heavier by + 3.7 kg ($p = 0.017$). The two groups of boxers had similar BMI and WC. Compared with challengers, champion boxers also had larger neck by + 0.8 cm ($p = 0.029$), biceps by + 1.2 cm ($p = 0.024$) and forearm by 1.3 cm ($p = 0.007$). There were no group differences in other musculoskeletal dimensions (Table 3).

Overall, 10.5% of boxers had BMI < 25 kg/m^2, 74.3% between 25 and 29.9 kg/m^2 and 14.8% had BMI ≥ 30 kg/m^2 (Fig. 2a). By contrast, over 88.0% had WC < 94 cm while only about 9.2% between 94 and 101.9 cm and less than 2.7% had WC ≥ 102 cm (Fig. 2b). The portions of champions or challengers in different categories of BMI ($\chi^2 = 0.3$, $p = 0.866$) or WC ($\chi^2 = 0.7$, $p = 0.706$).

Discussion

The present study finds clear evidence of increasing secular trends in most of the anthropometric measurements including weight, height, reach, and BMI other measurements reflecting musculoskeletal dimensions in elite heavyweight boxers at the peak of their career. Although champion boxers

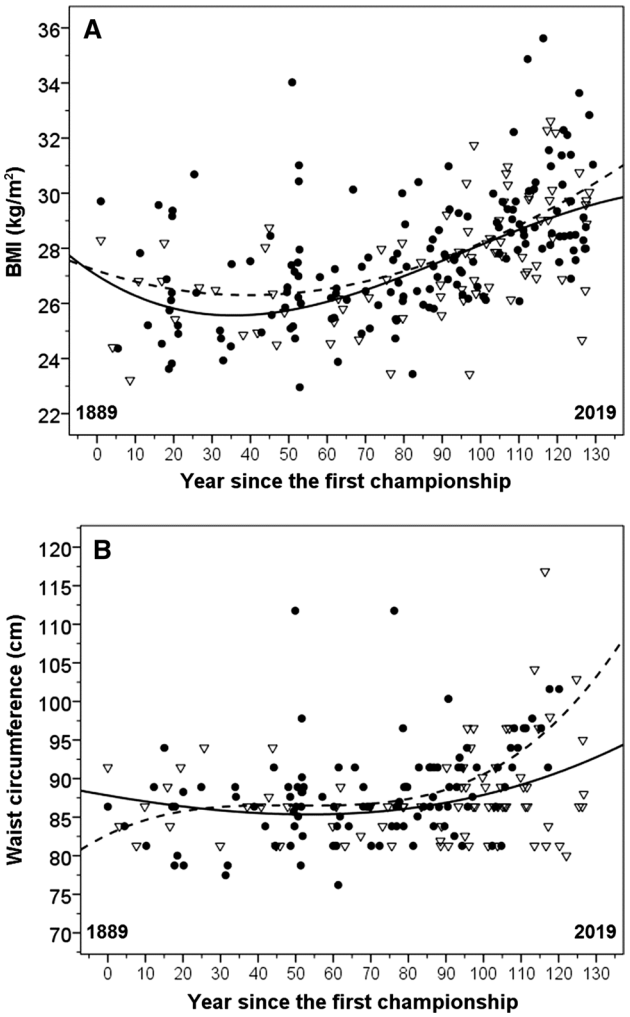

Fig. 1 Distribution of BMI (**a**) and WC (**b**) against year of championship contests for champions (open triangles and solid regression line) and challengers (solid circles and dashed regression line)

and challengers had similar musculoskeletal dimensions, the champions were heavier and taller and had longer reach as well as large arm measurements (biceps and forearm) while their WC was not different from that of the challengers.

There was a disassociation in changes between BMI and WC among champion boxers; whereas BMI was found to increase, WC remained unchanged with contest years. We have found that the majority of these boxers would be classified as overweight or even obese according to WHO classification of BMI [13] while most of them had WC below action level 1 (< 94 cm) [14]. These observations have important implications on the use of BMI in athletes as an indicator of adiposity [15, 16], which may misclassify a substantial proportion of these fit individuals among the general population as overweight or obese; sometimes BMI is used and recommended inappropriately in clinical settings [17, 18]. The use of equations to differentiate skeletal muscle and adipose tissue would be more useful for athletes [19]. Our findings are highly relevant to sports science on several levels. First, the data provide an insight into the continuing improvement in growth of elite power athletes and second, the discrepancy between champions and challengers has remained remarkably persistent. These differences are likely to be a combination of genetic and environmental interaction that differentiate these athletes apart, and could well be similar to other sports such as swimming (limb lengths) [20], rugby (body mass) [21, 22] or basketball (height) [23].

Secular trends in musculoskeletal dimensions

The observations of increasing weight and height over the past 130 years are in line with secular changes observed in sport [1] and general populations across developed countries [2, 3]. Our data also provide additional information on secular changes in other anthropometric measurements including neck, chest, biceps, forearm, thigh, calf and ankle circumferences which indicate that in this group of athletes, and likely in other sports performers, the musculoskeletal structures have increased progressively over the years.

Secular trends in BMI and WC

An important finding emerged from our analysis which revealed a disparity in secular changes in BMI and WC (often used as indices of adiposity). It is likely that the increasing BMI overtime reflects a continuing gain in musculoskeletal mass rather than adiposity. The drawback of the use of BMI as index of adiposity lies in its inability to distinguish between musculoskeletal and adipose components [19], i.e., a BMI of 28 or 30 kg/m^2 can be perfectly normal for a person participating in power sport such as a rugby player [21, 22] or heavyweight boxer. For any given BMI, the body composition (proportion of musculoskeletal tissue relatively to adipose tissue) of boxers in the twenty-first century is likely to differ from that of boxers in the early nineteenth century. It is therefore important to interpret published reports from national health surveys with caution with respect to the use of BMI to indicate prevalence and incidence of overweight and obesity without considering secular changes in body composition. Based on the trends observed in the present study, BMI and WC of the challengers are set to continue to rise while BMI of the champions has plateaued and the rise in WC is less sharp than that seen in the challengers. These increasing trends BMI in heavyweight boxers are similarly observed in national or state rugby union players from the UK, USA and Australia from 1905 to 1999 [21] and in English Premiere rugby players between 2002 and 2011 [22].

Table 2 Correlation analysis to assess the relationship between anthropometric measurements and contest years (years at which the contests took place)

	Partial correlations with adjustments for age, nationality and ethnicity					
	All boxers[a]		Champions		Unsuccessful challengers	
	r	*p*	*r*	*p*	*r*	*p*
Body lengths						
Height (cm)	0.531	< 0.001	0.379	0.001	0.589	< 0.001
Reach (cm)	0.341	< 0.001	0.300	0.007	0.373	< 0.001
Body mass and indices of adiposity						
Weight (kg)	0.603	< 0.001	0.437	< 0.001	0.666	< 0.001
Body mass index (kg/m^2)	0.370	< 0.001	0.290	0.009	0.381	< 0.001
Waist circumference (cm)	0.248	0.001	0.078	0.509	0.349	< 0.001
Muscle size						
Neck circumference (cm)	0.379	< 0.001	0.430	< 0.001	0.304	0.002
Unexpanded chest circumference (cm)	0.426	< 0.001	0.331	0.004	0.439	< 0.001
Expanded chest circumference (cm)	0.281	< 0.001	0.173	0.140	0.303	0.002
Biceps (cm)	0.510	< 0.001	0.409	< 0.001	0.549	< 0.001
Forearm (cm)	0.239	0.002	0.120	0.328	0.263	0.012
Thigh circumference (cm)	0.343	< 0.001	0.229	0.053	0.452	< 0.001
Calf (cm)	0.061	0.420	0.128	0.288	0.046	0.642
Skeletal dimensions						
Wrist (cm)	0.081	0.314	0.009	0.943	0.089	0.410
Fist size (cm)	0.015	0.854	− 0.087	0.482	0.172	0.129
Ankle (cm)	0.312	< 0.001	0.298	0.026	0.293	0.008

[a]Additional adjustment for champion/challenger status

Table 3 Independent *t* test to assess differences in anthropometry between champions and unsuccessful challengers

	Champions (referent group)		Unsuccessful challengers		Difference (champions minus challengers)		
	Mean	SD	Mean	SD	Mean	95% CI	p
Age (years)	28.6	3.8	29.1	4.2	− 0.5	− 1.6, 0.6	0.391
Body lengths							
Height (cm)	189.6	6.4	186.1	6.2	3.4	1.7, 5.1	< 0.001
Reach (cm)	197.4	9.1	193.8	9.4	3.6	1.1, 6.2	0.005
Body mass and indices of adiposity							
Weight (kg)	100.0	12.2	96.2	10.8	3.7	0.7, 6.8	0.017
Body mass index (kg/m^2)	27.8	2.5	27.8	2.3	0.0	− 0.6, 0.6	0.984
Waist circumference (cm)	87.8	6.2	88.0	6.2	− 0.2	− 2.1, 1.6	0.809
Muscle size							
Neck circumference (cm)	44.9	2.7	44.1	2.0	0.8	0.1, 1.5	0.029
Unexpanded chest circumference (cm)	109.8	7.0	108.6	6.5	1.2	− 0.8, 3.2	0.249
Expanded chest circumference (cm)	116.5	7.6	115.7	6.7	0.9	− 1.2, 3.0	0.416
Biceps (cm)	40.5	3.4	39.3	3.6	1.2	0.2, 2.3	0.024
Forearm (cm)	34.1	3.5	32.8	2.4	1.3	0.4, 2.2	0.007
Thigh circumference (cm)	62.0	6.7	60.8	5.3	1.3	− 0.5, 3.0	0.169
Calf (cm)	39.6	4.4	40.7	3.3	− 1.1	− 2.3, 0.0	0.052
Skeletal dimensions							
Wrist (cm)	20.2	1.9	20.0	2.0	0.2	− 0.4, 0.8	0.575
Fist size (cm)	32.5	2.2	32.2	2.4	0.3	− 0.4, 1.1	0.392
Ankle (cm)	25.2	2.9	25.8	2.5	− 0.5	− 1.4, 0.4	0.253

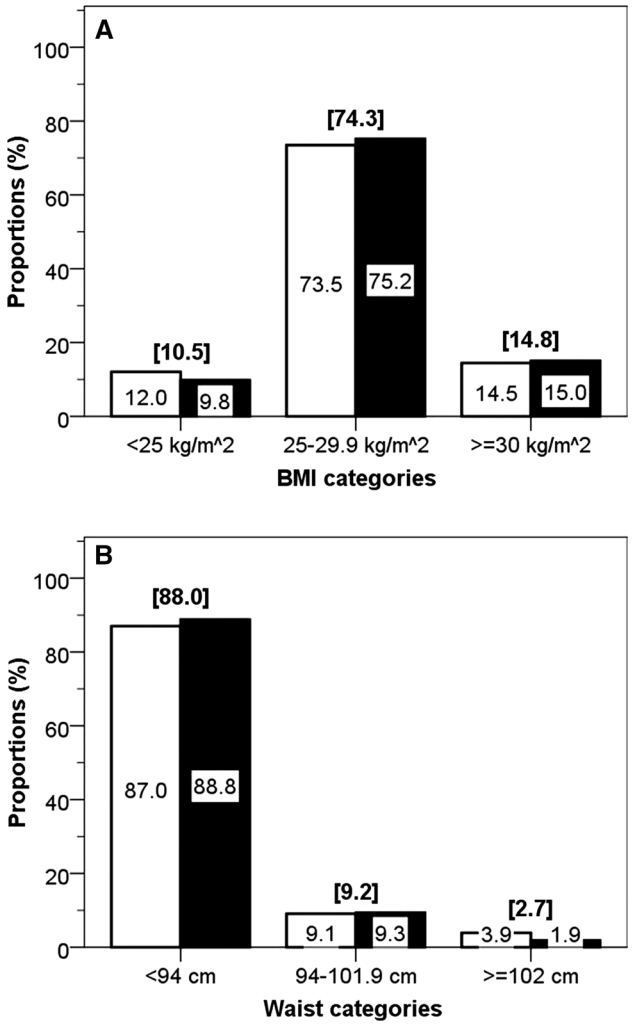

Fig. 2 Proportions of champions (open bars) and challengers (solid bars) in different categories of BMI (**a**) WC (**b**). Proportions for both champions and challengers are indicated in square brackets

Differences between champions and unsuccessful challengers

Heavyweight champions are considered to be one of the most elite group of athletes and the very best of boxers. We found a number of key measurements that distinguished champion boxers from unsuccessful challengers including their heavier weight, taller stature and longer reach as well as larger arm dimensions while their BMI and WC were similar to those of the challengers'. Although a bigger heavyweight contestant is generally more successful than a smaller heavyweight, we do recognise that the right balance of power and endurance, skills, and psychological factors all play vital roles for a boxer in prevailing over an opponent [24].

Strengths and limitations

The strengths of the present study lie in its unique data on both BMI and WC and detailed anthropometric measurements to enable analysis of secular trends in adiposity that dated back to the early twentieth century. The data appear very stable on repeated measurements during the time the boxers were at their prime indicating reliability of data collection and reporting. The age of boxers was similar throughout contest years and well matched between comparative subgroups. This type of data is the only record that is available publically for male boxers therefore our findings should only be inferred to this group of athletes. Anthropometric measurements are well regulated and standardised by international boxing boards but there might be inter-observer errors. Our measurements relied on historical records in the public domain but appear consistent between different media. Information on demographic data, weight and height were almost complete for every boxer while other measurements of musculoskeletal dimensions were not in a proportion of boxers but these subjects' characteristics including age, weight and height did not differ from the study sample. We could only verify information on nationality but not ethnicity. Although most champions were from the USA, we found no significant differences in anthropometry or body composition between athletes from other continents suggesting that nationality (and possible presumed ethnicity) may not play a major role in secular changes among these athletes.

In conclusion, all elite professional heavyweight boxers have increased in size over the last 130 years. Being heavier, taller with longer and bigger arms, but with similarity in BMI and waist, appear to be differentiating factors between champions and challengers.

Author contributions TSH and MEJL reviewed the topic related literature and performed the study concept and analysis design. TSH performed the study coordination and data collection and TGC contributed additional data. TSH analysed the data and wrote the first draft. TSH, TGC, PS and MEJL interpreted the data and revised the manuscript. All authors checked, interpreted results and approved the final version.

Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

Ethical approval This study does not require NHS Research Ethics Committee approval. This study was conducted in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Statement of human and animal rights This article does not contain any studies with animals performed by any of the authors.

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement No additional data are available.

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