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Triceps brachii muscle architecture, upper-body rate of force development, and bench press maximum strength of strong and weak trained participants

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ABSTRACT
Purpose. The study aim was: (a) to investigate the relationship between triceps brachii muscle architecture and upper-body isometric rate of force development (RFD), isometric peak force (IPF), and maximum strength (one-repetition maximum, 1-RM) in bench press and (b) to explore whether triceps brachii architecture might determine RFD, IPF, and 1-RM strength in stronger and weaker participants.
Methods. The study involved 21 males (age: 22.6 ± 4.7 years, weight: 76.6 ± 10.2 kg, height: 1.79 ± 0.07 m) with 3.4 ± 2.1 years of experience in resistance training. They were divided into a strong and weak group depending on their relative 1-RM strength in bench press. Measurements included triceps brachii muscle architecture, upper-body isometric RFD, IPF, and 1-RM strength in bench press.
Results. Moderate to large correlations were found for triceps brachii thickness and fascicle angle with upper-body RFD (r: 0.379–0.627), IPF (r: 0.582 and 0.564, respectively), and 1-RM strength in bench press (r: 0.530 and 0.412, respectively). Maximum strength in bench press was largely correlated with IPF ($r = 0.816$); moderate to very large correlations were observed with RFD (r: 0.499–0.725). The strong group presented significantly higher 1-RM relative strength, RFD, and IPF ($p < 0.05$) than the weak group, but no significant between-group difference was found for triceps brachii architecture ($p > 0.05$).
Conclusions. Triceps brachii architecture correlates with 1-RM strength, upper-body RFD, and IPF in trained participants. However, triceps brachii architecture may not distinguish upper-body strength and RFD between stronger and weaker male participants.
Key words: resistance training, muscle strength, muscle thickness, explosive performance

Introduction

Bench press is a multi-joint exercise regularly applied by athletes and strength and conditioning coaches to increase upper-body maximum strength, as well as muscle hypertrophy and stamina [1]. It is also a useful testing exercise/tool to measure upper-body maximum strength (one-repetition maximum, 1-RM) [2]. Bench press exercise involves the activation of the upper-body musculature system, mainly the pectoral muscles, the anterior deltoid, and the triceps brachii [3]. More specifically, triceps brachii is an important muscle for many athletic actions which include elbow extension, such as the shot put and the basketball shot [4, 5]. Regular resistance training may induce significant changes in the triceps brachii muscle architecture. Long-term training studies have shown that resistance training, including bench press, may increase triceps brachii muscle thickness and fascicle angle in untrained males, but no significant change occurred for fascicle length [6–8]. In line with these results, 1-RM strength in elbow extension exercise was significantly correlated with triceps brachii thickness (r: 0.706–0.831), fascicle angle ($r = 0.827$), and fascicle length

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(r = –0.723) in male participants [8]. Similarly, Wakahara et al. [9] reported that during concentric elbow extension, the triceps brachii muscle volume and fascicle angle were significantly correlated with joint power production (r = 0.600) and angular velocity (r = 0.563), respectively. However, whether the triceps brachii muscle architecture characteristics may correlate with 1-RM strength in bench press remains largely unknown.

One major factor that highly contributes to maximum strength and fast force production is the rate of force development (RFD) [10, 11]. RFD can be calculated by the force/time curve and evaluates the force that can be produced per a unit of time, usually in time frames of 0–250 ms. It depends on both neural and muscular factors [11, 12]. Muscle architecture characteristics have been linked with RFD. Studies showed strong correlations of vastus lateralis (VL) muscle thickness, fascicle angle, and fascicle length with RFD performance in power athletes [11–13]. Although a strong correlation exists between lower-body muscle architecture and RFD, the relationship between upper-body RFD and triceps brachii muscle architecture remains unexplored. The investigation of this relationship might provide important insights into the role of upper-body muscle architecture in fast force production, which will be very useful for strength and conditioning coaches to design more effective training programs for athletes in whom the upper-body muscles have a key significance for performance.

It has been well documented that muscle mass is an essential factor responsible for high force and power production [13, 14]. Individuals with greater muscle mass might perform higher in strength- and power-oriented tasks compared with individuals with lower muscle mass [15]. Thus, stronger athletes may possess greater muscle mass, produce greater amounts of maximum force, and obtain higher power outputs and RFD than weaker individuals [13, 16–18]. In line with these findings, a study in elite surfing athletes showed that stronger athletes exhibited greater VL thickness and median gastrocnemius thickness and fascicle angle as compared with weaker athletes [19]. Similarly, significant differences in the quadriceps cross-sectional area, fascicle length, and fascicle angle were found between long-term trained participants and their untrained counterparts [16]. However, scarce data exist regarding the comparison between stronger and weaker individuals in upper-body muscles. Ichinose et al. [20] indicated that male athletes in soccer and gymnastics presented greater triceps brachii muscle thickness than their female counterparts, while male gymnastics athletes had greater fascicle angle than female gymnastics athletes. It would be particularly interesting to investigate whether upper-body maximum strength and RFD among stronger and weaker individuals may be determined by triceps brachii muscle architecture characteristics.

Therefore, the purpose of the study was 2-fold: (a) to investigate the correlation between triceps brachii muscle architecture and 1-RM strength in bench press, upper-body RFD, and isometric peak force (IPF); and (b) to examine whether triceps brachii muscle architecture might determine 1-RM strength, RFD, and IPF in strong and weak male participants. The hypothesis was that triceps brachii muscle architecture characteristics would correlate with 1-RM strength, RFD, and IPF in trained participants, while stronger participants would exhibit higher muscle thickness, fascicle angle, and longer fascicle length compared with weaker male subjects.

Material and methods

Participants

A total of 21 male physical education and sports science students with a resistance training experience of 3.4 ± 2.1 years responded to a written message of the study posted in the announcement area of the School of Physical Education and Sport Science of the National and Kapodistrian University of Athens. The participants were further divided into a strong and a weak group in accordance with their 1-RM relative strength in bench press. The anthropometric characteristics of the subjects are presented in Table 1. The students were informed about the experimental procedures. The inclusion criteria were as follows: (a) absence of any cardiovascular, orthopaedic, and neuro-

Table 1. Anthropometric characteristics and 1-RM strength of the participants

Participants	Age (years)	Weight (kg)	Height (m)	1-RM strength in bench press (kg)
All (n = 21)	22.6 ± 4.7	76.6 ± 10.2	1.79 ± 0.07	95.4 ± 18.2
Strong (n = 10)	22.5 ± 2.8	72.4 ± 7.4	1.78 ± 0.07	97.50 ± 13.74
Weak (n = 11)	22.5 ± 6.2	79.6 ± 11.7	1.81 ± 0.07	88.05 ± 10.41

1-RM – one-repetition maximum

muscular issue; (b) systematic resistance training at least 2 times per week within the previous 6 months; and (c) absence of drug abuse or nutritional supplement intake.

Procedures

The current study aimed (a) to investigate the relationship between triceps brachii muscle architecture and 1-RM strength in bench press, upper-body RFD, and IPF; and (b) to observe whether triceps brachii muscle architecture might determine the 1-RM strength, RFD, and IPF among strong and weak participants. Male resistance-trained participants were recruited. All subjects were familiar with the bench press exercise and with 1-RM strength measurements. Evaluations were performed during a 4-day schedule. More specifically, on the first day, the individuals visited a laboratory for anthropometric measurements (weight and height) and a familiarization session with the upper-body RFD assessment. On the second day, the triceps brachii muscle architecture was evaluated. On the third day, the participants underwent the upper-body RFD measurement and, finally, during the fourth day, the 1-RM bench press test was performed. After the assessments, the subjects were further divided into a strong (n = 10) and a weak (n = 11) group, in accordance with the median value of the 1-RM strength in bench press expressed per body mass (median: 1.223 kg/weight) [19, 21, 22]. In order to answer the first research question, a correlation analysis was applied including all participants (n = 21), while for the second research question, a Student's t-test for independent samples statistical analysis was performed to examine differences between the stronger and weaker individuals.

Triceps brachii muscle architecture characteristics

For the triceps brachii long head architecture, B-mode panoramic ultrasound images were obtained with a 38-mm linear probe using the i-Scape software of the ultrasound device (10.0 MHz, Mindray Z5, China). The measurement began with the participants remaining in a standing position with their arms extended on the sides of the body. The distance between the posterior surface of the acromion and the lateral epicondyle of the humerus was marked and used as the total length of the upper arm [23]. Then, the subjects lay supine with their measuring arm extended on a laboratory bed at a position of 90° to their torso. In order to capture the largest continuous fascicle visualization, a dashed line was drawn from the insertion of the triceps long head up to the medial epicondyle of the humerus and the transducer was placed along this line with parallel orientation with muscle fascicles [8]. A continuous single view (extended field of view) was taken by moving the transducer along that dashed line. Two images were captured and analysed for muscle thickness, fascicle angle, and fascicle length by the image analysis software (Motic Images Plus 2.0, Hong Kong) and the mean was used for the statistical analysis.

Upper-body rate of force development

For the evaluation of upper-body RFD and IPF, the participants sat on a custom-made steel chair (assuming a seated bench press position) and placed their arms on a barbell which was positioned with struts on the force platform (Applied Measurements Ltd. Co., Reading, UK; WP800, A/D sampling frequency 1 kHz). The barbell was positioned in parallel to the floor and located at the middle of the distance between the top of the shoulders and the lower point of the breastbone, allowing an angle of 90° between the elbow and the armpits [24, 25]. A computer monitor was placed just above the force platform in front of the participants in order to provide real-time visual feedback of the force applied for each effort. During the familiarization sessions, the subjects trained with 6–8 short-time attempts (1-s duration) to apply their force as fast as possible. Then, on the third visit, RFD and IPF measurements were performed. Briefly, after a short warm-up on a treadmill, dynamic upper-body stretching and 2 sets of 6 fast unloaded push-ups, the participants performed 2 attempts with progressively increasing force and 2 fast attempts with approximately 80% of their maximum strength. Subsequently, 4 maximum efforts were performed with 3-s duration each, and 3 minutes of rest in between. During all efforts, the individuals were instructed to apply their maximum force as fast as possible and received strong vocal encouragement. From the 4 maximum efforts, the best and the worst were excluded from the analysis and the mean of the other 2 efforts was used for the statistical analysis [26]. Data from the force platform were recorded (Kyowa sensor interface PCD-320A) and the force-time curve was analysed for IPF, which was the greatest force generated, and the RFD in specific time windows of 0–30, 0–50, 0–80, 0–100, 0–150, 0–200, and 0–250 ms, relative to the onset of contraction, which was set at 2.5% of the difference between baseline and maximum force [15].

1-RM strength in bench press

Bench press 1-RM strength testing was conducted on a parallel bench [27]. Briefly, after a light run on a treadmill followed by dynamic upper-body stretching, the participants performed 2 sets of 6–8 fast push-up repetitions followed by 2 sets of 10 repetitions in the bench press with a constant load of 40 kg. Then, 3 sets of 8, 6, and 4 repetitions with approximately 50–60%, 70–75%, and 80–85%, respectively, of the predicted 1-RM were carried out. For the determination of maximum strength (1-RM), 4–5 sets of 1 repetition were performed with 2–3 minutes of rest between efforts. At all times, 2 of the researchers were present to monitor the technique of the exercise, assisting all participants during lifting and encouraging them to apply their maximum possible strength.

Statistical analysis

All variables are presented as means and standard deviations. Normality of data was assessed with the Shapiro-Wilk test and no violations in normality were observed. Correlations between variables were examined with *r*-Pearson coefficient. In addition, magnitude of effect for the correlations was based on the following scale: trivial (< 0.10), small (0.10–0.29), moderate (0.30–0.49), large (0.50–0.69), very large (0.70–0.89), and nearly perfect (≥ 0.9) [28]. Independent samples *t*-test analysis was used to compare the differences between the strong and weak groups. Cohen's *d* effect size was calculated, with the following criteria used to infer the magnitude of the difference: < 0.2 (trivial), 0.2–0.5 (small), 0.5–0.8 (moderate), and > 0.8 (large) [29]. The reliability of all measurements was determined with a 2-way random effect intraclass correlation coefficient, confidence intervals, and the coefficient of variation. Significance was set at $p \leq 0.05$.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the bioethics committee board of the School of Physical Education and Sport Science of the National and Kapodistrian University of Athens in Greece (project No.: 1024/8/11/2017).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

The intraclass correlation coefficients, confidence intervals, and the coefficients of variation of the performed measurements are provided in Table 2.

Table 2. Intraclass correlation coefficients, confidence intervals, and the coefficients of variation of the measurements

Variables	ICC	95% CI		CV%
		Upper bound	Lower bound	
Muscle thickness (cm)	0.984	0.995	0.951	14.8
Fascicle angle (°)	0.858	0.952	0.626	17.0
Fascicle length (cm)	0.794	0.928	0.483	11.5
RFD 30 ms (N/s)	0.838	0.938	0.610	17.6
RFD 50 ms (N/s)	0.845	0.941	0.622	15.6
RFD 80 ms (N/s)	0.815	0.928	0.567	17.3
RFD 100 ms (N/s)	0.787	0.917	0.514	17.9
RFD 150 ms (N/s)	0.652	0.859	0.261	17.5
RFD 200 ms (N/s)	0.582	0.827	0.143	18.4
RFD 250 ms (N/s)	0.744	0.899	0.427	18.0
IPF (N)	0.869	0.899	0.427	18.0
1-RM bench press (kg)	0.966	0.985	0.914	12.8

RFD – rate of force development, IPF – isometric peak force, 1-RM – one-repetition maximum, ICC – intraclass correlation coefficient, CI – confidence interval, CV% – coefficient of variation

All participants completed the measurements without any injury. Correlational analysis for all subjects revealed moderate to large correlations between triceps brachii muscle thickness and fascicle angle with absolute upper-body RFD and IPF (Table 3). Additionally, trivial to moderate correlations were found for triceps brachii muscle thickness and fascicle angle with relative upper-body RFD and IPF (Table 4). 1-RM absolute strength in bench press was correlated with triceps brachii muscle thickness (r = 0.530, large), with fascicle angle (r = 0.412, moderate), and with fascicle length (r = 0.165, small). Small correlations were observed between 1-RM relative strength in bench press and triceps brachii muscle thickness (r = 0.295), fascicle angle (r = 0.174), and fascicle length (r = 0.250). There were large to very large correlations between 1-RM relative strength in bench press and upper-body relative RFD (Table 4). A very large correlation was established between 1-RM strength in bench press and IPF both in absolute values and those relative to body mass (Figure 1).

The results concerning 1-RM strength, RFD, IPF, and muscle architecture for the strong and weak

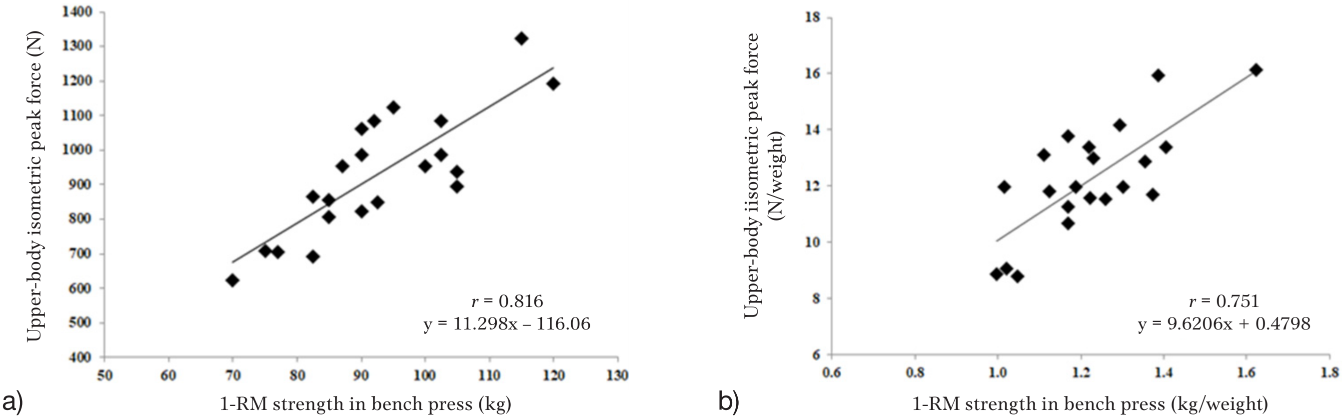

Figure 1. Correlation scatterplots for (a) 1-RM absolute strength in bench press and upper-body absolute isometric peak force ($p < 0.01$) and (b) 1-RM relative strength in bench press [force (kg) / weight (kg)] and upper-body relative isometric peak force [N / weight (kg)] ($p < 0.01$)

Table 3. Correlation coefficients between absolute values in 1-RM strength in bench press, triceps brachii muscle architecture, upper-body rate of force development, and isometric peak force (n = 21)

Variables	RFD 30 ms	RFD 50 ms	RFD 80 ms	RFD 100 ms	RFD 150 ms	RFD 200 ms	RFD 250 ms	IPF
1-RM bench press	0.499†*	0.642‡**	0.725#**	0.716#**	0.663‡**	0.616‡**	0.639‡**	0.816#**
TB thickness	0.372†	0.471†*	0.564‡**	0.591‡**	0.627‡**	0.615‡**	0.494†*	0.582‡**
TB angle	0.424†	0.515‡*	0.552‡**	0.548‡*	0.609‡**	0.625‡**	0.591‡**	0.564‡**
TB length	–0.033^{+}	0.028^{+}	0.135^{+}	0.167$^{\gamma}$	0.093$^{\gamma}$	0.024$^{\gamma}$	–0.071^{+}	0.051^{+}

1-RM – one-repetition maximum, RFD – rate of force development, IPF – isometric peak force, TB – triceps brachii
$^{+}$ trivial (< 0.10), $^{\gamma}$ small (0.10–0.29), † moderate (0.30–0.49), ‡ large (0.50–0.69), # very large (0.70–0.89),
§ nearly perfect (≥ 0.9), * $p < 0.05$, ** $p < 0.01$

Table 4. Correlation coefficients between 1-RM strength in bench press, triceps brachii muscle architecture, upper-body rate of force development, and isometric peak force relative to weight (n = 21)

Variables	RFDR 30 ms	RFDR 50 ms	RFDR 80 ms	RFDR 100 ms	RFDR 150 ms	RFDR 200 ms	RFDR 250 ms	IPFR
1-RM bench press relative	0.594‡**	0.727#**	0.781#**	0.770#**	0.646‡**	0.539‡*	0.513‡*	0.751#**
TB thickness	0.262$^{\gamma}$	0.315†	0.360†	0.368†	0.412†	0.431†	0.320†	0.466†*
TB angle	0.317†	0.362†	0.353†	0.333†	0.395†	0.440†*	0.428†	0.427†
TB length	–0.011^{+}	0.056^{+}	0.163$^{\gamma}$	0.190$^{\gamma}$	0.132$^{\gamma}$	0.068^{+}	–0.037^{+}	0.129$^{\gamma}$

1-RM – one-repetition maximum, RFDR – rate of force development relative to body mass, IPFR – isometric peak force relative to body mass, TB – triceps brachii
$^{+}$ trivial (< 0.10), $^{\gamma}$ small (0.10–0.29), † moderate (0.30–0.49), ‡ large (0.50–0.69), # very large (0.70–0.89),
§ nearly perfect (≥ 0.9), * $p < 0.05$, ** $p < 0.01$

groups are presented in Table 5. Absolute maximum strength in bench press was similar in both groups (percentage difference: 10.7%, p = 0.090), but higher for the stronger participants when expressed per body mass (percentage difference: 21.1%, p = 0.000). In addition, the stronger subjects presented significantly higher absolute RFD in time frames of 0–30 ms (percentage difference: 28.5%, p = 0.050) and 0–50 ms (percentage difference: 22.6%, p = 0.043) compared with the weaker individuals. When RFD was expressed in relation to body mass, then the stronger participants exhibited significantly higher relative RFD in time frames of 0–30 ms (percentage difference: 38.2%, p = 0.009), 0–50 ms (percentage difference: 32.6%, p = 0.004), 0–80 ms (percentage difference: 27.5%, p = 0.004), 0–100 ms (percentage difference: 26.0%, p = 0.004), 0–150 ms (percentage difference: 19.3%, p = 0.018), and 0–200 ms (percentage difference: 15.3%,

Table 5. Results of the analysis between strong and weak participants for anthropometric characteristics, 1-RM strength in bench press, rate of force development, and isometric peak force

Variables	Strong (n = 10)	Weak (n = 11)	p	Effect size	Interpretation of effect size
Anthropometric characteristics					
Weight (kg)	72.39 ± 7.29	79.61 ± 11.72	0.110	0.741	Moderate
Height (m)	1.78 ± 0.07	1.81 ± 0.07	0.246	0.522	Moderate
BMI (kg/m^2)	22.93 ± 1.19	24.18 ± 0.06	0.190	0.604	Moderate
1-RM strength					
Bench press (kg)	97.50 ± 13.74	88.05 ± 10.41	0.090	0.776	Moderate
Bench press (kg/weight)	1.345 ± 0.117	1.112 ± 0.079	0.000	2.344	Large
RFD absolute values					
30 ms (N/s)	8930.8 ± 2796.5	6948.1 ± 1382.9	0.050	0.899	Large
50 ms (N/s)	6948.1 ± 1382.9	8872.4 ± 2089.9	0.043	0.938	Large
80 ms (N/s)	8872.4 ± 2089.9	7233.1 ± 1320.4	0.063	0.864	Large
100 ms (N/s)	7233.1 ± 1320.4	7494.9 ± 1270.1	0.074	0.828	Large
150 ms (N/s)	7494.9 ± 1270.1	6391.3 ± 1284.1	0.269	0.498	Small
200 ms (N/s)	6391.3 ± 1284.1	6652.3 ± 999.3	0.528	0.281	Small
250 ms (N/s)	6652.3 ± 999.3	5749.8 ± 1172.5	0.765	0.132	Trivial
IPF (N)	962.7 ± 189.2	899.4 ± 167.7	0.427	0.354	Small
Ratio of bench press to IPF (kg/N)	0.1024 ± 0.009	0.0996 ± 0.012	0.541	0.274	Small
RFD relative to body mass					
30 ms (N/s/weight)	122.6 ± 32.1	88.7 ± 20.4	0.009	1.260	Large
50 ms (N/s/weight)	88.7 ± 20.4	122.1 ± 23.0	0.004	1.425	Large
80 ms (N/s/weight)	122.1 ± 23.0	92.1 ± 18.9	0.004	1.454	Large
100 ms (N/s/weight)	92.1 ± 18.9	103.4 ± 13.4	0.004	1.424	Large
150 ms (N/s/weight)	103.4 ± 13.4	81.1 ± 17.0	0.018	1.132	Large
200 ms (N/s/weight)	81.1 ± 17.0	91.9 ± 10.7	0.060	0.875	Large
250 ms (N/s/weight)	91.9 ± 10.7	73.0 ± 15.5	0.117	0.715	Moderate
IPF (N/weight)	73.0 ± 15.5	68.4 ± 9.2	0.023	1.079	Large
Triceps brachii muscle structure					
TB thickness (cm)	2.00 ± 0.32	1.92 ± 0.38	0.598	0.235	Small
TB angle (°)	15.20 ± 2.05	14.15 ± 2.82	0.345	0.427	Small
TB length (cm)	9.91 ± 1.22	9.65 ± 1.19	0.633	0.212	Small

1-RM – one-repetition maximum, BMI – body mass index, RFD – rate of force development, IPF – isometric peak force, TB – triceps brachii

p = 0.060) compared with the weaker subjects. Similarly, IPF relative to body mass was significantly higher for the stronger participants (percentage difference: 16.7%, p = 0.023) than among the weaker ones.

Comparisons between the strong and weak subjects for triceps brachii muscle architecture showed no significant differences between the groups for muscle thickness (percentage difference: 4.2%, p = 0.598), fascicle angle (percentage difference: 7.4%, p = 0.345), and fascicle length (percentage difference: 2.7%, p = 0.633), while only small effect sizes were obtained (Table 5).

Discussion

The purpose of the study was to investigate the correlation between triceps brachii muscle architecture and upper-body RFD, IPF, and 1-RM strength in bench press, as well as to examine whether triceps brachii muscle architecture might determine upper-body RFD, IPF, and 1-RM strength in bench press among stronger and weaker participants. The main findings of the study are as follows: (a) triceps brachii muscle architecture, especially muscle thickness and fascicle angle, were moderately correlated with RFD and IPF, while large to moderate correlations were found for muscle thickness and fascicle angle with 1-RM strength in bench press; (b) RFD and IPF were very largely correlated with 1-RM strength in bench press; and (c) triceps brachii muscle architecture may not determine 1-RM strength in bench press, RFD, or IPF in stronger and weaker participants. These results suggest that triceps brachii muscle thickness and fascicle angle were correlated with upper-body RFD, IPF, and 1-RM strength in bench press in trained subjects. However, triceps brachii muscle architecture may not determine 1-RM bench press strength, upper-body RFD, or IPF in stronger and weaker participants.

Bench press is a fundamental exercise for upper-body muscular system. Triceps brachii, along with pectoral and deltoid muscles, is mainly involved in the bench press movement [3]. Triceps brachii muscle architecture, especially muscle thickness and fascicle angle, was moderately to largely correlated with upper-body RFD in absolute and relative values, respectively, in all time frames. Although triceps brachii has a smaller contribution in bench press compared with pectoral and deltoid muscles [30], its role during the final application of force in various athletic movements is important [4, 5]. The current results indicate that triceps brachii muscle architecture largely contributes to the upper-body RFD in trained participants. In addition, studies examining lower-body muscles revealed significant correlations between VL muscle architecture and lower-body RFD [11, 12]. According to the authors' knowledge, this is the first study to investigate the correlation between upper-body muscle architecture and RFD performance. Consequently, these results should be interpreted with caution, and further research is needed to reach certain conclusions about the relationship of upper-body RFD with triceps brachii muscle architecture.

Similarly to RFD, IPF was moderately to largely correlated with triceps brachii muscle thickness and fascicle angle both in absolute values and in those relative to body mass. In line with these findings, moderate to large correlations were found for triceps brachii muscle thickness and fascicle angle with 1-RM absolute strength in bench press, while only small correlations were observed with 1-RM relative strength in bench press. Previous studies showed that VL muscle architecture (thickness, fascicle angle, and fascicle length) was significantly correlated with leg press IPF (r: 0.636–0.848) and 1-RM strength in leg press (r: 0.585–0.761) [11]. According to the results of the present study, triceps brachii muscle architecture may be a good predictor of upper-body muscle strength in trained individuals. Lastly, IPF was very largely correlated with 1-RM strength in bench press in both absolute values and those relative to body mass. Thus, seated upper-body IPF measurement may be a strong predictor of 1-RM strength in bench press in male trained subjects.

Stronger participants presented higher 1-RM relative strength, relative RFD, and relative IPF compared with weaker individuals. However, scarce data exist regarding the comparison of upper-body maximum strength and RFD between strong and weak subjects. A previous study showed significant differences between stronger and weaker collegiate athletes concerning lower-body muscle strength, isometric mid-thigh pull maximum RFD, and IPF [17]. Similar results were determined between stronger and weaker netball players for lower-body mid-thigh pull IPF, countermovement jump, and squat jump, as well as for sprint and change of direction speed [18]. In line with these findings, stronger surfing athletes may produce greater isometric mid-thigh pull force, as well as higher countermovement jump and squat jump compared with weaker surfers [19]. The results of the current study confirm that upper-body RFD and IPF may be significantly different between stronger and weaker trained individuals, comparably with the results of lower-body studies. RFD is affected by both neural and muscle factors, with maximum strength and muscle mass being vital elements to differentiate between stronger and weaker subjects [10, 14]. Nevertheless, the comparison between stronger and weaker participants regarding upper-body RFD and IPF needs further investigation.

An unexpected finding of the current study was that triceps brachii muscle architecture characteristics were similar between stronger and weaker participants (the effect size was only small). Although stronger subjects presented greater 1-RM relative strength in bench press and higher upper-body relative RFD and IPF than weaker individuals, no significant difference was found for triceps brachii muscle thickness, fascicle angle, or fascicle length. Results obtained among elite surfing athletes showed that stronger surfers exhibited greater VL muscle thickness, as well as lateral gastrocnemius thickness and fascicle angle compared with weaker ones [19]. Thus, triceps brachii muscle architecture may not be a significant parameter to distinguish upper-body muscle strength, RFD, or IPF between stronger and weaker subjects, although differences in muscle fibre type composition and neural factors may contribute to this finding. Another hypothesis refers to the effects of training experience [27] and long-term systematic resistance training on muscle architecture [12]. Different strength parameters (i.e. sets, repetitions, loads, etc.) combined with different training goals (i.e. hypertrophy, maximum strength, etc.) might induce alternative muscle adaptations, leading to another shaping form of the triceps brachii muscle architecture. Consequently, the initial hypothesis that triceps brachii muscle architecture may differentiate between stronger and weaker individuals is rejected. Therefore, it can be hypothesized that upper-body muscle strength and fast force production may depend more on pectoral and deltoid muscle architecture; however, such a premise needs further investigation.

To the best of our knowledge, this is the first study to examine the correlation between triceps brachii muscle architecture and upper-body strength, RFD, and IPF in trained participants. Thus, the current results should be interpreted with caution. A limitation of the current study is that muscle architecture characteristics were investigated only for the triceps brachii muscle and not for the pectoral and deltoid muscles, which might have provided a better insight into the nature of the link between upper-body strength and muscle architecture. Moreover, upper-body RFD and IPF were evaluated at a certain elbow angle (90°). In addition, this study is one of the few to examine upper-body RFD and IPF in a large number of participants. Still, more research is needed to investigate the differences in upper-body muscle architecture between stronger and weaker trained individuals.

Conclusions

The results of the current study suggest that triceps brachii muscle architecture was correlated with upper-body maximum strength in bench press, RFD, and IPF. In addition, stronger participants presented greater upper-body relative RFD and IPF compared with their weaker counterparts, but triceps brachii muscle architecture might not differentiate between stronger and weaker individuals in bench press, RFD, and IPF. The triceps brachii muscle plays a major role during the elbow extension and the final application of force in various athletic movements, such as basketball and shot put. Therefore, strength and conditioning coaches should design training programs including the bench press exercise to develop triceps brachii muscle architecture and upper-body fast force production. Moreover, the very large correlation between 1-RM strength in bench press and IPF implies that this might be a functional laboratory test to predict maximum strength in bench press. However, triceps brachii muscle architecture may not determine 1-RM strength or RFD among stronger and weaker subjects, which means that pectoral and deltoid muscle architecture may contribute to upper-body force production.

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Disclosure statement

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Conflict of interest

The authors state no conflict of interest.

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