Surface electromyographic analysis of the serratus anterior during bench press variations

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Abstract

Purpose: Bench press variations that elicit greater serratus anterior muscle activation may be preferable for improving scapula stability and avoiding injury in overhead throwing athletes. Here we compare serratus anterior activity during dumbbell and barbell bench press using surface electromyography (EMG).

Methods: Forty college and professional baseball pitchers (men, age 22.6 ± 2.5 years) performed four sets of bench press—light (43 kg) and heavy (61 kg) dumbbell and barbell—with five repetitions each. Each pitcher was instructed in proper technique and rested for 90 seconds between sets. Surface electrodes were used to record serratus anterior activity during isometric contraction (for normalization) and during each set.

Results: Dumbbell sets showed significantly greater serratus anterior activation than barbell sets at both weights (weight-normalized mean EMG amplitude, 44.7 versus 38.2; $p = .005$).

Conclusion: This suggests that dumbbell press is preferable to barbell press for building serratus anterior muscle strength.

Keywords

overhead throwing athlete, dumbbell, barbell, scapular stability, activation

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1. Introduction

Scapula stability and shoulder muscle strength are primary concerns for overhead throwing athletes such as baseball pitchers. Instability of the scapula and weakness of overhead stabilizing muscles can cause poor force generation during throwing and vulnerability to shoulder injury.¹ The serratus anterior is critical to upward scapula rotation and scapula stabilization during overhead movements, and the strength of this muscle can be the limiting factor in overall scapula movement.² Bench press exercises target the serratus anterior and are commonly used by pitchers to improve upper-body strength and stability. Variations of the bench press that elicit greater serratus anterior activation may be preferable for improving scapula stability, minimizing movement dysfunction, and avoiding injury.³

Surface electromyography (EMG) has been used to study the activation of large muscles in the upper extremity during bench press and related exercises.⁴⁻⁶ Surface EMG measures the electric potential across skeletal muscles in response to muscle stimulation. The medial deltoid shows greater activation during barbell bench press than during bench press using a Smith machine.⁴ The serratus anterior shows greater activation during the “push-up plus” and “dynamic hug” than during other low-resistance rehabilitation exercises,⁵ and greater activation during barbell press than during standard push-ups or wall push-ups.⁶ However, there has been no comparison of the effects of different bench press variations on serratus anterior activity.

In this study we measured serratus anterior activity during barbell and dumbbell bench press at two weights (43 and 61 kg, or 95 and 135 lb) using surface EMG (Figures 1 and 2). We hypothesized that dumbbell press—the more unstable of the two exercises—would elicit greater serratus anterior activity than barbell press regardless of weight.

Figure 1 Caption: An example of a subject performing barbell bench press with 135 pounds

Figure 2 Caption: An example of a subject performing dumbbell bench press with 67.5 pound dumbbells

2. Methods

2.1 Subjects

Forty healthy college and professional baseball pitchers (age, 22.6 ± 2.5 years; height, 185.4 ± 6.4 cm; body weight, 93.6 ± 7.8 kg) were recruited for the study. The following inclusion criteria were used: men, age 18-40 years, and able to bench press 61 kg using barbell and dumbbell techniques without pain or discomfort in the upper extremities (including forearm, elbow, shoulder, and neck) during or after exercises. Subjects were provided a verbal explanation of the study, and were given an Informed Consent form to review and sign. If pain or discomfort was experienced at any point during the trials, the participant ceased exercises and the subject's data was discarded. The study was approved by an independent institutional review board (Hummingbird IRB; IRB# 2018-17).

2.2 Procedures

The subjects were divided into four groups of 10 using a single-blind block randomization process; each group performed four sets of bench press exercises (described below) in a different order. Subjects performed no high-intensity exercise for 24 h before the EMG-monitored exercises. Bench press exercises were performed after a warm-up, which consisted of low-intensity foam rolling and upper-body mobility stretches.

Surface EMG data were collected as described previously.⁷ Raw EMG signals were collected at 1,000 Hz using a Somaxis Cricket EMG sensor and Chirp for Cricket app (Somaxis Inc., San Francisco, CA). Skin application sites were cleaned and sensors were applied vertically across a standardized site on the serratus anterior on both the left and right sides using kinesiology tape (RockTape, Inc., Campbell, CA), with 5-6 inches between sensors (Figures 3 and 4).

Figure 3 Caption: Application of the Somaxis EMG sensor to the right serratus anterior of the subject

Figure 4 Caption: Application of the Somaxis EMG sensor to the left serratus anterior of the subject

To normalize EMG signals by muscle strength, the maximum voluntary isometric contraction (MVIC) of the serratus anterior on both sides of each subject was measured before bench press exercises. Subjects were instructed to raise their right arm to 125° of shoulder abduction in the sagittal plane, as measured using a goniometer. (Manual resistance at this

shoulder abduction angle causes greater serratus anterior excitation than at other angles.⁸⁾ Subjects were then instructed to resist a downward applied to the humerus using a hand-held dynamometer (Lafayette Instrument Co., Lafayette, IN) until the goniometer read 5 lbs to obtain the MVIC EMG signal. Tests were roughly 3-4 seconds long and performed on first the right arm (Figures 5 and 6) then the left arm (Figures 7 and 8), with a ten second rest in between.

Figure 5 and 6 Captions: Measurement of the first MVIC position with the goniometer and first MVIC test done on the subject

Figure 7 and 8 Captions: Measurement of the second MVIC position with the goniometer and second MVIC test done on the subject

Subjects were instructed to engage the latissimus dorsi muscles throughout the bench press exercises, and to perform the sets at a moderate pace and intensity. Subjects performed four sets of bench press—light and heavy dumbbell and barbell—with five repetitions each and 90 seconds of rest between sets. The weights used in the four sets were the following:

1. Light dumbbells: two 21.5 kg (47.5 lb) dumbbells; total weight: 43.1 kg (95 lb)
2. Light barbells: two 11.3 kg (25 lb) plates on a 20.4 kg (45 lb) barbell; total weight: 43.1 kg (95 lb)
3. Heavy dumbbells: two 30.6 kg (67.5 lb) dumbbells; total weight: 61.2 kg (135 lb)
4. Heavy barbells: two 20.4 kg (45 lb) plates on a 20.4 kg (45 lb) barbell, total weight: 61.2 kg (135 lb)

These weights were chosen as moderate loads for the subjects: most subjects were able to bench press well above 61 kg. These types of loads were common in the majority of the sample athlete's strength programs. The order of the sets was varied between the four groups as shown in Table 1.

Table 1 Sequence of sets for each group

Group	Set 1	Set 2	Set 3	Set 4
1	Light barbell	Light dumbbell	Heavy barbell	Heavy dumbbell
2	Light dumbbell	Light barbell	Heavy dumbbell	Heavy barbell
3	Light barbell	Light dumbbell	Heavy dumbbell	Heavy barbell
4	Light dumbbell	Light barbell	Heavy barbell	Heavy dumbbell

2.3 Data Processing

Surface EMG data were processed as described previously.⁷ A tenth-order band-pass Butterworth filter with a lower cutoff frequency of 10 Hz and higher cutoff frequency of 450 Hz was used.⁹ The lower cutoff was used to remove electrical noise, wire sway, and biological artifacts; the higher cutoff was used to remove tissue noise at electrode sites.¹⁰ The output was rectified, then smoothed using a moving average with a window size of 200 to further separate signal from noise.¹¹ Serratus anterior MVIC EMG values were identified and used to normalize bench press EMG data for both sides of each subject to provide better comparisons between subjects.^{12,13}

2.4 Statistical Analysis

Statistical analysis was performed on filtered, smoothed, and normalized EMG data. The dataset of mean EMG amplitudes for each bench press set was assessed for normality by using a Shapiro Test on the residuals of the most-fitted ANOVA tests ($p < 0.01$), and by using quantile-quantile (Q-Q) plots. Based on these tests, it was unclear whether the mean EMG amplitude for each set was normally distributed. Thus, permutation tests were used to resample the mean EMG data, and permutation tests of symmetry and pairwise permutation tests were applied to comparisons for which the original test reported a significant difference. *P*-values for the pairwise permutation tests were adjusted using the Benjamini–Hochberg procedure to control for the false discovery rate due to multiple comparisons.¹⁴ In addition, bootstrap estimates using 1000 samples were performed to generate estimators and bias-corrected confidence intervals for both the general sample and for various comparisons.

3. Results

Mean and median serratus anterior EMG amplitudes for each group and set are listed in Table 2. The order of sets was varied between the four groups; set numbers in Table 2 correspond to those in Table 1.

Table 2 Serratus anterior surface EMG amplitudes

Group	Side	Set 1*		Set 2		Set 3		Set 4	
		Mean	Median	Mean	Median	Mean	Median	Mean	Median
1	L	41.7	39.7	44.9	42.2	55.6	55.5	66.9	63.0
	R	31.3	29.6	32.8	31.2	40.7	39.9	44.2	41.7
	Avg	36.5	34.6	38.8	36.7	48.2	47.7	55.6	52.4
2	L	29.1	26.7	42.8	30.2	42.9	42.3	43.8	42.4
	R	36.1	31.2	29.0	27.3	41.3	39.1	43.8	41.7
	Avg	32.6	28.9	35.9	28.7	42.1	40.7	43.8	42.0
3	L	36.9	34.2	34.6	32.4	43.9	41.1	55.2	51.5
	R	33.7	31.6	26.2	25.0	32.6	31.7	41.3	38.3
	Avg	35.3	32.9	30.4	28.7	38.2	36.4	48.3	44.9
4	L	40.7	38.5	31.7	29.8	53.3	52.6	46.1	46.0
	R	28.2	26.3	23.5	22.1	38.4	38.5	34.7	33.0
	Avg	34.5	32.4	27.6	26.0	45.0	45.5	40.4	39.5
Overall Avg		34.7	32.2	33.2	30.0	43.6	42.6	47.0	44.7

*Set numbers correspond to Table 1.

For all subjects, sets 1 and 2 used the lighter weight (43 kg) and sets 3 and 4 used the heavier weight (61 kg); as expected, higher EMG values were observed at the heavier weight (mean EMG amplitude, 47.340 versus 35.533; $p < .001$). Mean EMG amplitudes for light and heavy barbell and dumbbell bench presses are shown in Table 3. Dumbbell presses showed greater mean EMG amplitude than barbell presses at both weights (total weight-normalized mean EMG amplitude: 44.742 versus 38.179, $p = .005$; mean EMG amplitude at 43 kg: 39.449 versus 31.617, $p = .044$; mean EMG amplitude at 61 kg: 49.938 versus 44.742, $p = .025$).

Table 3 Mean EMG amplitude by bench press type and weight

Bench press type/weight	Mean
Light barbell	31.6
Light dumbbell	39.4
Heavy barbell	44.7
Heavy dumbbell	49.9
Light ^a	35.5
Heavy ^a	47.3
Barbell ^b	38.2
Dumbbell ^b	44.7

^aAverage of barbell and dumbbell

^bAverage of light and heavy

Since it was unclear whether the mean EMG amplitude distributions for our pooled samples were normally distributed, bootstrap estimates and confidence intervals were calculated to provide a more accurate estimate of the means of these values (Table 4), and a permutation test of symmetry was used to assess differences in mean EMG values between bench press variations and weights (Table 5).

Table 4 Bootstrapped mean EMG amplitudes and 95% confidence intervals (CI)

Bench press type/weight	Bootstrapped mean	95% CI
Light barbell	31.6	(27.3, 37.0)
Light dumbbell	39.5	(33.4, 50.7)
Heavy barbell	44.9	(38.6, 51.9)
Heavy dumbbell	50.1	(42.3, 62.0)
Light ^a	35.5	(31.8, 41.3)
Heavy ^a	47.2	(42.7, 55.4)
Barbell ^b	38.3	(34.3, 43.0)
Dumbbell ^b	44.7	(39.3, 52.0)

^aAverage of barbell and dumbbell

^bAverage of light and heavy

Table 5 Permutation test of symmetry

# of factors	Mean EMG amplitude	Factor	<i>P</i> -value
2	All	Exercise	0.005
2	All	Weight	< .001
4	All	Exercise & weight	< .001

Significant differences in mean EMG amplitude were observed between the following pairs: light barbell and light dumbbell, heavy barbell and heavy dumbbell, light and heavy (averages of barbell and dumbbell), and barbell and dumbbell (averages of light and heavy). Pairwise permutation tests were used to compare the mean EMG values; Table 6 shows the output of the test statistic corresponding to differences in mean EMG value and corresponding *p*-values. Table 7 shows bootstrapped estimates of differences between means, with bias-corrected 95% confidence intervals.

Table 6 Pairwise permutation tests: Test statistic (*P*-value)

	Heavy barbell	Light barbell	Heavy dumbbell
Light barbell	5.28 (< .001)		
Heavy dumbbell	-2.09 (.044)	-4.48 (< .001)	
Light dumbbell	1.80 (.072)	-2.40 (.025)	2.57 (.020)

Table 7 Bootstrapped estimates of differences between mean EMG values (bias-corrected 95% confidence intervals)

	Heavy barbell	Light barbell	Heavy dumbbell
Light barbell	0.877 (0.505, 1.17)		
Heavy dumbbell	-0.138 (-0.428, 0.143)	-0.633 (-0.806, -0.310)	
Light dumbbell	0.210 (-0.161, 0.518)	-0.255 (-0.479, 0.073)	0.414 (-0.124, 0.794)

4. Discussion

In this study we examined whether barbell and dumbbell bench press elicit different degrees of serratus anterior muscle activation. Dumbbell bench press sets elicited significantly greater serratus anterior activity than barbell press sets at both weights tested (43 and 61 kg). Because of the importance of the serratus anterior to scapula stability and mobility, these results suggest that dumbbell press may be preferable to barbell press for upper-body strength training by overhead throwing athletes.

One limitation of this study is the large amount of noise that was associated with the EMG signals.¹⁵ To minimize the effect of noise on data analysis, each subject followed the same rest period between sets, and was provided the same instructions regarding technique, including minimizing movement or muscle recruitment unrelated to the exercise. Following data collection, filtering, smoothing, normalizing, and amplitude extraction methods were used to separate signal from noise.¹⁶

The results indicate that the more unstable of the two bench press exercises—dumbbell press—resulted in greater serratus anterior muscle activation. These results are consistent with previous studies that used surface EMG analysis to measure serratus anterior activity during bench press. Caravan et al. found that the ratio of serratus anterior to upper trapezius activity was greater during push-ups than during the more stable barbell bench press.⁶ Similarly, Tucci et al. found that serratus anterior activity was greater during wall press than during barbell press.¹⁷ Other upper-body muscles also show greater activity during less stable bench press exercises based on surface EMG analysis. For example, the triceps, upper trapezius, and gluteus maximus exhibited greater activity during suspended push-ups than during more stable standard push-ups.¹⁸

Interestingly, pre-activation of the serratus anterior and other muscles (pectoralis major, deltoid anterior, and triceps brachii) by bench press can cause greater muscle activation during subsequent sets.²⁰ Baker et al. found that power output in explosive bench press throws was greater when preceded by a heavy bench press set.¹⁹ To avoid a systemic muscle pre-activation effect, we varied the order of the four sets, with the two two lights sets followed by the two heavy sets.

Future studies of serratus anterior activation during bench press should investigate the effect of muscle pre-activation, using a greater range of weights, and should control for differences in trunk inclination and hand spacing. Barnett et al. measured the activity of five shoulder muscles using surface EMG at four trunk inclinations and two hand spacings, and showed that both of these variables had a significant effect on muscle activity.²¹ Another important variable is whether muscle-specific instructions on technique are provided to subjects before exercises. Daniels et al. showed that triceps brachii activity varied significantly depending on whether instructions were provided.²² Subjects also use different movement patterns during

bench press exercises, and these differences are likely to cause differences in muscle activation.²³ Instructions that ensure more uniform movement patterns are desired.

5. Practical Applications

Overhead throwing athletes like baseball players are subject to high forces and torques during their sports-specific performance. General rehabilitation and injury-preventive exercises are highly sought after to reduce the impact of performance on arm and general physical health. The statistically robust finding that the dumbbell bench press variation elicits more serratus anterior muscle activation is of great value to anyone interested in designing exercise routines or programming for overhead athletes.

6. Conclusion

Dumbbell bench press elicited greater serratus anterior muscle activation than barbell bench press at both weights tested. These results provide insight for overhead throwing athletes into the selection of bench press exercise for serratus anterior strengthening and for general arm health.

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