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SCIENTIFIC ARTICLE

Distal clavicular osteolysis in adults: association with bench pressing intensity

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Abstract
Objectives To investigate the association between distal clavicular osteolysis (DCO) and bench pressing intensity.
Methods From a retrospective review of MRI shoulder reports of individuals between 20 and 40 years of age, 262 male patients with DCO and 227 age-matched male patients without DCO were selected. All patients had completed a bench pressing questionnaire. The patients' bench pressing frequency (times per week), duration (years of bench pressing), bench pressing weight (maximum bench pressing weight with one repetition = 1RM) and the ratio of bench pressing weight to body weight were compared between both groups using Chi-square and Mann–Whitney tests.
Results The results showed that 56 % (146/262) of patients with DCO were high-intensity bench pressers (1RM more than 1.5 times the body weight) compared to 6 % (14/227) in patients without DCO. High-intensity bench pressing was a risk factor for DCO (OR = 19; 95 %CI = 11–35; $p < 0.001$). Low-intensity bench pressing (1RM less than 1.5 times the body weight) was not a risk factor for DCO (OR = 0.6; 95 % CI = 0.4–0.8). High frequency (>1×/week) and duration (>5 years) of bench pressing were risk factors. In bench pressers who suffered from DCO, the mean 1RM was 283 lbs (±SD 57) compared to 209 lbs (±SD 60) in bench pressers not affected by DCO ($p < 0.001$, Mann–Whitney).
Conclusions High-intensity, but not low-intensity bench pressing is a risk factor for DCO.

Keywords Distal clavicular osteolysis · Magnetic resonance imaging · MRI · Bench pressing · Clavicular resection · Acromioclavicular joint · Osteoarthritis

Introduction

The popularity of weight and resistance training continues to grow with 50.2 million health club members in the USA in 2012 compared to 41.5 million in 2007 and with 21.4 million Americans using weight/resistance machines in 2014 [1]. As the number of participants in weight training continues to increase, so does the number of people at risk for injury [2]. In the past few decades, the incidence of weight training related injuries has increased by 35 %, with about one-fourth of those injuries attributed to improper training [3]. Moreover, 25–30 % of participants in resistance training reported an injury severe enough to seek medical attention [3, 4]. The majority of weight training injuries occur among males and involve the shoulder [2]. Specific injuries associated with bench pressing are posterior labral tears [5], pectoralis major tears [6], pectoralis minor tendinosis [7], subcoracoid bursitis [8], triceps tendinosis [9], and distal clavicular osteolysis (DCO) [10]. In a study by Cahill et al. [10], 45 of 46 patients with DCO had a history of bench pressing. Another study found that 28 % of elite weight lifters had DCO [11]. However, it is unknown which bench pressing parameters (bench pressing weight, frequency, duration) increase an athlete's risk of DCO and which thresholds can be used to avoid injury. These risk factors are investigated in our study. We hypothesize that

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high-intensity, but not low-intensity bench pressing is a risk factor for DCO.

Materials and methods

Subjects

Institutional review board approval was obtained. The requirement for informed consent was waived. The MRI reports of 7463 consecutive patients, between 20 and 40 years of age, who underwent shoulder MRI for shoulder pain between July 2006 and December 2012 were investigated. These 7463 consecutive MRI shoulder reports were searched for "distal clavicular osteolysis" yielding 451 patients. The 451 MRIs were reviewed by two musculoskeletal radiologists and all of the following four inclusion criteria had to be present for a diagnosis of DCO (definition is in part based on previous studies) [12, 13]. (1) Bone marrow edema at the distal clavicle without edema at the acromion; (2) Subchondral fracture or subchondral cystic change at the distal clavicle; (3) Superior shoulder pain and/or acromioclavicular (AC) joint tenderness; (4) No significant concurrent shoulder pathology including no labral tears, no rotator cuff tears and no AC joint osteoarthritis. AC joint osteoarthritis was defined as osteophytes (bone spurs) and bone marrow edema at both sides of the AC joint. Out of the 451 patients, 381 fulfilled the inclusion criteria for DCO and had no history of trauma. The prevalence of DCO was 5 % (381 of 7463 subjects). Thirty-four of the 381 (9 %) patients were female. From the remaining 7082 (7463 minus 381) patients, 381 age-matched control patients were randomly selected after excluding patients with AC joint osteoarthritis or history of shoulder trauma. The complete bench pressing history was available in 292 of the 381 DCO patients and in 309 of the 381 control subjects. Due to the relatively low number of female patients, only male patients were included in the bench pressing analysis. The final study group therefore consisted of 262 male patients with DCO and the control group of 227 male patients without DCO.

Bench pressing and clinical data

Bench pressing data was retrieved from a pre-MRI athletic questionnaire that every patient fills out at our institution prior to the shoulder MRI. A positive bench pressing history required bench pressing on a regular basis at least once per week over the last 12 months and with at least three sets per bench pressing workout session. Patients were asked their average bench pressing weight and average repetitions per set over the last 12 months. The standard reference for comparing bench pressing weight among bench pressers is the maximum bench pressing weight with one repetition (one rep max, 1RM) [14]. Aside from asking the patient her/his maximum bench pressing weight (1RM) in the questionnaire, it was also calculated from the patient's average bench pressing weight over the last 12 months and the corresponding maximum repetitions based on the following commonly used formula by Brzycki et al. [14]: 1RM (in lbs) = bench pressing weight /[1.0278-(0.0278 × number of repetitions)].

An online calculator [15] applying this formula was used to determine the one rep max for each patient. For example, if a patient noted in the questionnaire that she/he bench pressed 200 lbs with ten repetitions during workout sessions (over the last 12 months), then based on the formula above, the 1RM for this patient would be 267 lbs. Thereby, the 1RM was determined with both methods: The patient was directly asked for the 1 RM in the questionnaire and it was calculated with the above formula. Additionally, the maximum bench pressing weight (1RM) to body weight ratio was calculated (benchweight/bodyweight ratio). For example, if the above patient weighs 175 lbs, then the benchweight/bodyweight ratio is 1.53 (267 lbs/175 lbs). From here on in, bench pressing weight refers to the maximum bench pressing weight with one repetition (1RM). Furthermore, bench pressing frequency (times per week) and bench pressing duration (in years) were retrieved from the pre-MRI athletic questionnaire. Findings from the physical examination performed by five fellowship-trained orthopedic surgeons at the time of the initial MRI exam and on follow-up office visits were available from the electronic medical records. AC joint and/or distal clavicular pain/tenderness to palpation and/or a positive cross-body adduction test were considered the corresponding clinical findings of DCO. The type of treatment for DCO (conservative vs. surgical) and treatment outcome were recorded. Outcome of conservative treatment was considered positive when there was substantial improvement of symptoms to the degree that surgery was not required.

Magnetic resonance imaging

All shoulder MR imaging was performed on 1.5-Tesla MRI scanners (Optima and Signa, General Electric Medical Systems, Milwaukee, WI, USA) with dedicated shoulder coils and routine non-contrast shoulder protocols in three planes (axial, coronal, and sagittal) and with T1, T2 FS (fat-saturated), PD (proton-density) and STIR (short-tau inversion recovery) sequences. Please see Table 1 for MR imaging parameters. As described above under "Subjects", both bone marrow edema and subchondral fracture or subchondral cystic change had to be present at the distal clavicle for a diagnosis of DCO on MRI. Grading of DCO was dependent on the degree of bone marrow edema and periostitis at the distal clavicle. Grade I represents mild edema not spanning the entire anteroposterior (AP) dimension on axial imaging (Fig. 1a). In grade II, edema spans the clavicle entirely in the AP dimension (Fig. 1b). In grade III, periostitis along the distal clavicle is seen in addition to bone marrow edema (Fig. 1c).

Table 1 Parameters of MR imaging

Parameters	Coronal T1 SE, non FS	Coronal STIR	Axial PD □FSE, FS□	Sagittal T2 FSE, non FS
TR□ (in ms)	400–800	2000–6000	2000–3000	2000–6000
TE□ (in ms)	10–20	20–40	25–30	90–110
TI (in ms)		120		
Flip (in degrees)		90°		
FOV (in mm)	160 × 160	160 × 160	100 × 100	160 × 160
Matrix□	256 × 256	256 × 192	512 × 256	256 × 256
Thickness□ (in mm)	3	4	4	3
ETL□		8	8	8
NEX□	1	3	2	2
Gap (in mm)	0.5	0.5	0.5	0.5
BW□ (in MHz)	16	16	16	16

SE spin echo, *FS* fat-saturated, *STIR* short-tau inversion recovery, *PD* proton density, *FSE* fast spin echo, □*ms* milliseconds, *TR* time to repeat, *TE* time to echo, *TI* inversion time, *Flip* flip angle, *FOV* field of view, *mm* millimeters, *Thickness* slice thickness, *ETL* echo train length, *NEX* number of excitations, *Gap* gap between slices, *BW* bandwidth, *MHz* megahertz

Bone marrow edema was defined as hyperintense (bright) signal on both the STIR and T2 FS sequences and as hypointense signal on the T1-weighted images. The normal bone marrow signal at the adjacent acromion was used as a reference and the T2 signal at the distal clavicle had to be higher (brighter) than the signal at the distal acromion. Fracture was defined as a hypointense subchondral line on all sequences with associated bone marrow edema on the T2-weighted sequences. Two blinded, fellowship-trained musculoskeletal radiologists reviewed the MR images. In case of disagreement, a third musculoskeletal radiologist made a final decision.

Treatment

Initially, all patients diagnosed with DCO underwent conservative treatment with restriction of upper extremity activities for 4 weeks and then gradual return to a low-intensity rehabilitation program over the subsequent 8 weeks. After 12 weeks, patients slowly returned to bench pressing. In patients who did not respond to conservative treatment, surgery was performed by resecting 8–10 mm of the distal clavicle.

Statistics

Differences in age, bench pressing weight (1RM), benchweight/bodyweight ratio, bench pressing frequency (times per week) and bench pressing duration (in years) between the study and control group (Tables 2 and 3) were assessed with the Mann–Whitney *U* test. Chi-square (Tables 2 and 3) tests were performed for the other variables. Receiver operator curves (ROC) and Youden index analysis of the bench pressing parameters (benchweight/bodyweight ratio, frequency and duration) were used to determine the most accurate thresholds predicting DCO. A binary logistic regression analysis was performed with DCO as the dependent

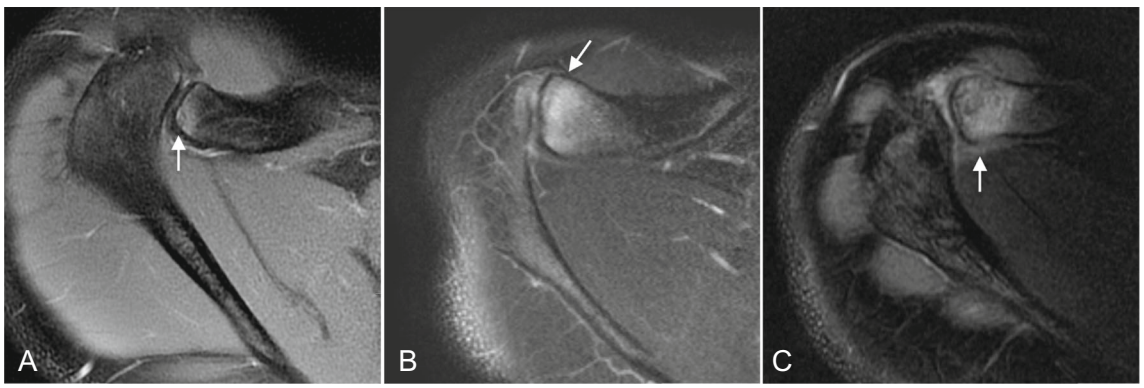

Fig. 1 Grading of distal clavicular osteolysis (DCO) in three adult bench pressers. **a** A 22-year-old weight lifter with a small subchondral fracture (*arrow*) and mild distal clavicular edema. The edema is not spanning the entire anterior-posterior (AP) dimension of the distal clavicle (grade I DCO). **b** A 26-year-old professional football player with a subchondral fracture (*arrow*) and moderate distal clavicular edema spanning the entire AP dimension of the distal clavicle (grade II DCO). **c** A 38-year-old cross-fit trainer who regularly bench presses three times a week with subchondral cystic change, severe edema, and periostitis (*arrow*) at the distal clavicle (grade III DCO)

Table 2 Patient bench pressing history

	DCO $n=262$	No DCO $n=227$	p
Bench pressing history	84 % (220/262)	47 % (107/227)	$p<0.001$; OR 5.9 (3.9–9)
High-intensity bench pressing[a] history	56 % (146/262)	6 % (14/227)	$p<0.001$; OR 19.2 (10.6–34.6)
Low-intensity bench pressing[a] history	28 % (74/262)	41 % (93/227)	$p<0.04$; OR 0.6 (0.4–0.8)
Bodyweight in lbs ± SD	190.1 lbs ± 33.8;	189.9 lbs ± 36.5;	$p=0.34$
Age; in years, mean ± SD; range	28.7 ± 5.2; 20.0–39.0	29.1 ± 5.4; 20.2–39.7	$p=0.64$

Differences between patients with distal clavicular osteolysis (DCO) and the control group (No DCO) were calculated with the Mann–Whitney U test for age and bodyweight and Chi-square tests for the other variables

[a] High-intensity bench pressing was defined as a maximum bench pressing weight with one repetition (one rep max, 1RM) of more than 1.5 times the patient's body weight. Low-intensity bench pressing was defined as a maximum bench pressing weight of less than 1.5 times the body weight

variable and with the three bench pressing parameters as the independent variables. Statistical software (SPSS Inc, version 21.0, Chicago, IL) was used for the analysis.

Results

History of bench pressing as a risk factor for DCO

Among male patients, a positive history of bench pressing increased the risk of developing DCO by 5.9 (odds ratio 5.9, 95 % confidence interval 3.9.-9; $p<0.001$; Table 2). However, a more detailed analysis by distinguishing high-intensity from low-intensity bench pressing patients shows that only those who bench pressed >1.5 times their body weight (56 %, 146/262 in the DCO group vs. 6 %, 14/227 in the control group; $p<0.001$, Chi-square) were at increased risk of developing DCO (OR = 19.2, 95 % CI = 10.6–34.6). The >1.5 threshold was determined by a ROC analysis. Low-intensity bench pressing (bench pressing weight <1.5 times the body weight) was not a risk factor for DCO (see Table 2). There was no significant difference in age and bodyweight between patients of the DCO and the control group (Table 2).

Bench pressing weight, frequency, and duration as risk factors for DCO

Table 3 analyzes all patients of the study who had a positive bench pressing history (bench pressers). Table 3 compares patients who bench pressed and developed DCO ($n=220$) with patients who bench pressed and did not develop DCO ($n=107$). Bench pressers who developed DCO had a significantly higher maximum bench pressing weight (283 lbs) compared to bench pressers not suffering from DCO (209 lbs; $p<0.001$; Mann–Whitney test). The average benchweight/bodyweight ratio was 1.5 in bench pressers with DCO

Table 3 Risk factors for DCO including bench pressing weight, frequency, and duration

	Bench pressers with DCO $n=220$	Bench pressers without DCO $n=107$	p; Odds ratio (95 % CI)
Bench pressing weight[a] in lbs (mean ± SD)	283 ± 57 lbs ($n=220$)	209 ± 60 lbs ($n=107$)	$p<0.001$
Benchweight[a]/bodyweight ratio (mean ± SD and > 1.5 in percent)	1.5 ± 0.2; 66 % (146/220)	1.1 ± 0.3; 13 % (14/107)	$p<0.001$; 13.1 (7.0–24.6)
Bench pressing frequency per week (mean ± SD and >1×/week in percent)	1.8 ± 0.7; 78 % (172/220)	1.4 ± 0.7; 30 % (32/107)	$p<0.001$; 8.4 (5.0–14.2)
Bench pressing duration in years (mean ± SD and >5 years in percent)	9.5 ± 4.3; 83 % (182/220)	5.6 ± 3.8; 45 % (48/107)	$p<0.001$; 8.5 (5.6–12.8)
Combined score (benchweight/bodyweight ratio > 1.5 plus frequency >1×/week plus >5 years; in percent)	48 % (126/220)	1 % (3/107)	$p<0.001$; 46.5 (14.3–151.0)

Differences between bench pressers with distal clavicular osteolysis (DCO) and bench pressers without DCO were calculated with the Mann–Whitney U test for bench pressing weight and benchweight/bodyweight ratio and with Chi-square tests for the other variables. Odds ratios (OR) and 95 % confidence intervals (CI) are listed for risk factors of DCO including high bench pressing weight (more than 1.5 the bodyweight), high bench pressing frequency (>×1/week) and long duration (>5 years)

[a] Maximum bench pressing weight with one repetition (one rep max, 1RM)

compared to 1.1 in bench pressers without DCO ($p<0.001$; Mann–Whitney). The odds ratio for developing DCO was 13.1 (Table 3) in patients who bench pressed more than 1.5 times their body weight (high-intensity bench pressing). Additionally, the mean bench pressing frequency was significantly higher in bench pressers with DCO (mean bench pressing frequency of 1.8 times per week; 78 % of patients bench pressed more than once per week) compared to bench pressers without DCO (mean bench pressing frequency of 1.4 times per week; only 30 % of patients bench pressed more than once per week; $p<0.001$). Bench pressers who developed DCO were bench pressing for more years (mean 9.5 years) compared to patients not suffering from DCO (5.6 years, $p<0.001$, Table 3). The odds ratio for DCO was 8.5 when bench pressing for more than 5 years (Table 3). The thresholds of the bench pressing parameters were determined by a ROC analysis. A binary logistic regression with DCO as the dependent variable and with the three bench pressing parameters (weight ratio, frequency, and duration) as independent variables showed that all three parameters are significant ($p<0.001$) and independent predictors of DCO. Therefore, a combined score of the three risk factors was feasible, which was considered positive if patients bench pressed more than 1.5 times their body weight (benchweight/bodyweight ratio >1.5), more than once per week (>1×/week) and for more than 5 years. The combination of those three bench pressing characteristics (a positive combined score) increased the risk of DCO in bench pressers by 46.5 (OR = 46.5, 14.3–151.0; $p<0.001$).

Treatment and outcome of DCO

All DCO patients were initially treated conservatively for 3 months; 76 % (199/262) of the DCO patients (with an available bench pressing history) had improvement of symptoms to a degree that they did not require surgery; 63 of the 262 patients (24 %) did not respond to conservative treatment and underwent distal clavicular resection. All 63 patients had improvement of symptoms after surgery and did not require revision surgery. All patients were followed for at least 11 months after surgery with a mean follow-up time of 14.2 months.

Interreader reliability

Interreader reliability was excellent (kappa >0.8) for all variables: The kappa values between both readers were 0.94 for applying the inclusion criteria to establish the DCO study group. There was also excellent correlation between the two different methods of determining the bench pressing weight, meaning the maximum bench pressing weight with one repetition (one rep max, 1RM): The calculated method based on the formula by Brzycki et al. [14] from the average bench pressing weight over the last 12 months and the maximum corresponding repetitions (both asked for in the questionnaire) correlated highly with the direct method by asking the patient in the questionnaire about her/his 1RM (Spearman 0.90, $p<0.001$). The calculated 1RM was used for the statistical analysis since it represents more accurately the bench pressing weight over a longer period of time (12 months).

Discussion

Previous studies have shown the association between a history of bench pressing and DCO [10, 11]. However, our study demonstrates that only intense bench pressing with a bench pressing weight more than 1.5 times the patient's body weight is a risk factor for DCO. We found that the risk of DCO increases with the bench pressing weight, frequency, and duration.

Despite the benefits, serious injuries have been associated with resistance training, especially shoulder injuries from bench pressing [2, 3, 5, 7–9, 16]. The susceptibility of the shoulder complex to bench pressing is at least in part explained by the considerable stress on the AC joints. Both the distal clavicle and the acromion are prone to stress-related injury from repetitive activities [12, 13, 17]. Bench pressing requires the traditionally non-weight bearing AC joint to assume the role of a weight-bearing joint during the course of repetitive lifting. The lowering phase of the bench pressing movement results in an unfavorable position in end-range external rotation when the elbow joints are positioned posterior to the trunk. This puts considerable stress and excessive traction on the distal clavicle while under heavy loads [18]. Repeated trauma with fracture of the subchondral bone is thought to cause DCO [11, 13]. The subchondral fracture with associated bone marrow edema or the subchondral cystic changes (in chronic cases) at the distal clavicle are well seen on MRI [13]. In our study, 84 % (220/262) of DCO patients were bench pressing. This percentage is slightly lower than found in a smaller study by Cahill et al., where 98 % (45/46) of patients with DCO were weightlifting [11]. The average age was 23.3 years in Cahill's report compared to 28.7 years in our investigation. Therefore, the slightly higher participation in weight training in the study by Cahill et al. might be explained by the younger patient population. This investigation by Cahill et al. in 1982 was the first to show the association between lifting weights and DCO. They examined 46 males, none of whom had a history of acute injury to the acromioclavicular joint; 45 of them participated in a weight training routine, at least three times a week.

Since then, there have been more than 100 reported cases of DCO in patients participating in weight training. Like in Cahill's report, none of our patients had a history of accidental trauma to the shoulder area. Our results indicate that high-intensity bench pressing more than 1.5 times the body weight is associated with DCO. Bench pressing frequency of more than once per week and bench pressing duration of more than 5 years further increases the risk of DCO. To the best of our knowledge, this is the first study describing a direct association between bench pressing intensity and risk of DCO. Adjusting the bench pressing weight and frequency below the thresholds provided in our study may decrease the risk of DCO in athletes. This might be important since many athletes benefit from the muscle strength gained by regular bench pressing.

During the patient selection process of this retrospective study, we found that 5 % of patients undergoing shoulder MRIs between the ages of 20 and 40 had a diagnosis of DCO. To our knowledge, no prior study has reported the prevalence of this overuse injury. Females comprised about 9 %, which is concordant with a prior report where 11 % (4/36) of patients with DCO were females [13]. However, due to the low number of female patients with a complete bench pressing history, only males were included in our final study population.

Our investigation shows that the majority of adult DCO patients (76 %, 199/262) improved after conservative strategies and did not require surgery. However, in 24 % (63/262) of patients, symptoms continued despite conservative measures. Prior studies have reported success with distal clavicular resection in DCO [10, 11, 19]. This is concordant with our study where none of the patients treated surgically needed a second (revision) surgery.

Limitations of our study are the retrospective study design and that the bench pressing performance was assessed with a questionnaire and not measured. Therefore, patients might have exaggerated their bench pressing weight. A prospective study comparing the risk of DCO between high-intensity and low-intensity bench pressers is warranted. Furthermore, the frequency of DCO and the bench pressing weight is likely higher in our patient population than at other institutions. Many of our patients are competitive athletes (including football players) referred from an outpatient sports medicine clinic. This might make it difficult to extrapolate our results to other patient populations.

In conclusion, high-intensity bench pressing (bench pressing weight more than 1.5 times the body weight) is a risk factor of DCO. High frequency (>1×/week) and long duration (>5 years) of bench pressing further increase the risk of DCO.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Institutional review board approval was obtained and the requirement for informed consent was waived.

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