Heliyon 10 (2024) e25401

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Damage for gain: The useful damage of the Pitcher's paradox

Rita Chiaramonte [a,*], Gianluca Testa [b], Antonino Russo [a], Enrico Buccheri [a], Massimiliano Milana [a], Riccardo Prezioso [a], Vito Pavone [b], Michele Vecchio [a,c]

[a] Department of Biomedical and Biotechnological Sciences, University of Catania, 95123, Catania, Italy
[b] Department of General Surgery and Medical Surgical Specialties, Section of Orthopaedics and Traumatology, University Hospital Policlinico "Rodolico-San Marco", University of Catania, 95123, Catania, Italy
[c] Rehabilitation Unit, "AOU Policlinico G. Rodolico-San Marco", 95123, Catania, Italy

A R T I C L E I N F O

Keywords:
Joint instability
Early diagnosis
Shoulder
Volleyball
Rehabilitation
Ultrasound

A B S T R A C T

Introduction: Sport-specific adaptations of the glenohumeral joint may arise in adolescent overhead athletes who begin high-performance sports early in life. Research mainly addresses overuse injuries, leaving gaps in prevention, with adults studied more than youths.
Objective: This study aims to investigate sport-adaptations of the glenohumeral joint in asymptomatic adolescent volleyball players to identify potential shoulder injury risk factors.
Design: Observational study.
Setting: Clinical screening campaign conducted at the Physical Medicine and Rehabilitation Unit of Policlinic Hospital in Catania, Italy.
Participants: Forty asymptomatic under-16 athletes were evaluated.
Interventions: Shoulder internal rotation (IR) and external rotation (ER), range of motion (ROM), total-rotation ROM, glenohumeral IR deficit (GIRD), general joint laxity using Beighton score, apprehension, relocation, O'Brian tests, and ultrasound (US) glenohumeral distance were tested bilaterally. Variables such as the player's position, the age they began the sport, limb dominance, weight, and height were also considered.
Results: The median US glenohumeral distance was at 0.42 $\pm$ 0.26 cm, which is consistent with the range found in non-dislocated shoulders of a healthy non-athletic population. The ER ROM was significantly greater in the dominant shoulder than the contralateral one ($P = 0.0001$), and there was a significant correlation between the ER ROM of attackers and their US glenohumeral distance ($P = 0.0413$). Furthermore, shoulder IR ROM and US glenohumeral distance were not significantly different between the dominant and contralateral limbs ($P = 0.05$). None of the athletes presented GIRD. Other tests, including the Beighton score, apprehension, and relocation tests, yielded no significant differences between the dominant and contralateral limbs.
Conclusions: Despite an increased shoulder ER in the dominant limb, the glenohumeral joint remains stable, suggesting that greater ROM in ER does not equate to instability in overhead athletes without hyperlaxity. Nevertheless, increased ER impacts glenohumeral distance in attacker volleyball players. This finding suggests that the shoulder morphological adaptation process starts early in attackers.

* Corresponding author.
E-mail addresses: ritachiaramd@gmail.com, rita.chiaramonte@unict.it (R. Chiaramonte).

https://doi.org/10.1016/j.heliyon.2024.e25401
Received 20 October 2023; Received in revised form 24 January 2024; Accepted 25 January 2024
Available online 1 February 2024

1. Introduction

Athletes' skeletal immaturity is characterized by open growth plates and increased tissue laxity [1].

During this period of immaturity, it is essential to prevent sport injuries that result from repetitive motions, especially those that persist in throwing and overhead sports. Such movements, particularly repetitive and traumatic ones, can lead to the upper limbs becoming overloaded [1–3]. Land-based sports, like volleyball, and nutraceuticals, such as carnitine supplementation, are preferable, especially at a young age, to improve physical performance and promote peak bone mass and prevent osteoporosis in the future [4–6].

The American Academy of Pediatrics advises young athletes against specializing in a single sport [7]. Early specialization limits the range of muscle groups that are engaged in young bodies and leads to repetitive movements. It can theoretically increase the risk of injuries and promote premature departure from sports [8]. Indeed, highly specialized athletes are more likely to report injuries or overuse damage compared with less specialized athletes [9]. Notably, specialized athletes had a 45–91 % higher likelihood of reporting a past injury compared with their less specialized counterparts [9].

Additionally, athletes that dedicate more than 8 months of the year to their primary sport are more prone to report overuse injuries in either in their upper or lower extremities [9]. Athletes spending more hours per week on their primary sport than their age (for instance, a 16-year-old athlete playing more than 16 h per week) are also more likely to report injuries [9]. In fact, youth athletes that exceed sport volume recommendations are 26–85 % more likely to report injuries compared with individuals who adhere to the recommendations (in terms of months per year playing their sport and hours per week playing their sport) [9].

The study aims to contribute to the so-called *pitcher's paradox* [10]. In overhead sport, a pitcher's shoulder should be flexible enough for efficient external rotation (ER), but also stable enough to prevent humeral head subluxations and related complications. This situation requires a fine balance between mobility and functional stability [10]. Consequently, athletes often show multiple adaptive changes caused by recurring microtraumatic stresses of overhead throwing [10]. These adaptations include an increase in the ER range of motion (ROM) of the dominant shoulder, also known as External Rotation Gain (ERG), a reduced Total Range of Motion (TROM), and an imbalance between the internal and external rotator muscles of the shoulder, all of which lead to decreased strength [11,12].

The goal of this study was to detect these adaptations earlier in asymptomatic adolescent volleyball attackers and defenders to determine potential risk factors for shoulder injuries.

2. Methods

2.1. Study design

The study adhered to the ethical guidelines of the Declaration of Helsinki, and notification was provided to the Italian Federation of Volleyball (FIPAV) and the institutional review board (Ethics Committee, Catania 1, No. 2023/28861). Authorization and informed consents to exam the athletes were obtained from the FIPAV.

In partnership with the FIPAV, the female volleyball players of the finalist teams of the Under-16 National Championship were screened at the Physical Medicine and Rehabilitation Unit and Orthopaedics and Traumatology Unit of the Policlinic Hospital in Catania (Italy) in May 2023. A total of 40 professional female volleyball athletes voluntarily agreed to participate in the study.

The study included female participants aged 14–16 years who were in excellent general health with no existing musculoskeletal disorders. Previous musculoskeletal injuries in shoulder were the exclusion criterion. Participants with such injuries were eligible only if they had fully recovered and returned to their respective sports. The study aimed to ensure a healthy and homogenous participant group for the investigation of sport-specific adaptations in adolescent volleyball players.

The characteristics of the participants are tabulated in Table 1.

Clinical and ultrasonography (US) assessments of the included athletes were conducted by specialists in the field of Physical Medicine and Rehabilitation, alongside resident physicians.

2.2. Anamnestic and clinical assessments

The recorded anamnestic data comprised: a) player's position, b) initiation age in sport career, c) weight, height, and body mass index (BMI), d) limb dominance, and e) previous musculoskeletal injuries. The collected clinical data included: a) active ER and IR ROM of shoulder [13], b) total ROM (TROM) (defined as the sum of ER + IR), c) difference in TROM (calculated as the difference between the TROM of the dominant and non-dominant limb), d) Glenohumeral IR deficit (GIRD) (defined as the difference between the IR of the dominant limb and the contralateral limb), e) general joint laxity based on Beighton score [14], f) apprehension test [15], g) relocation test [15], h) O'Brian test score [15]. The dominant limb was identified through the self-report and observational tasks: a) writing hand, b) throwing and reaching tasks, c) dexterity in fine motor skills, manipulating objects.

The clinical and US evaluations were standardized following a training and retraining session overseen by a senior specialist in the field of Physical Medicine and Rehabilitation. The standardized evaluations aimed to enhance the precision and uniformity of the diagnostic protocol. Notably, for the apprehension test, relocation test, and O'Brian test, physicians employed a nuanced approach, considering their results as continuous points on a scale ranging from 0 (indicating no symptoms) to 3 (indicating varying degrees of severity). This choice allowed for a more refined and detailed characterization of the athletes' health conditions, offering a comprehensive and nuanced perspective on their shoulder health.

Table 1
Characteristics of the volleyball players.

Characteristic		Number
Total number		40
Age (years)		15.02 ± 0.95
Height (cm)		166.95 ± 6.84
Weight (kg)		59.12 ± 8.68
BMI (kg/m^2)		21.22 ± 2.99
Years of experience		7.14 ± 2.70
Position played	Outside hitter	12
	Middle blocker	9
	Opposite hitter	4
	Right side hitter	1
	Libero	6
	Setter	8
Previous injuries	- None	22
	- Plantar fasciitis	2
	- Fractures of the metacarpal bones	2
	- Sprained ankle	9
	- Knee sprain	1
	- Fifth finger dislocation	1
	- Anterior tibial tendinopathy	1
	- Patellofemoral syndrome	2

Body mass index BMI; Range of motion ROM; Internal rotation IR; External rotation ER; Ultrasonography US, Total range of motion TROM, Glenohumeral internal rotation deficit GIRD.

Shoulder joint active ER and IR ROM measurements were obtained in a supine position using a goniometer; the athletes' shoulders were abducted to 90°, which ensured that scapulothoracic movement did not occur.

2.3. US assessment

The US assessment was performed according to Secko's *point-of-care ultrasonographic measures* for dislocated shoulders [16]. This method visualizes the anterior positioning of the humeral head in relation to the posterior glenoid in order to measure the median US glenohumeral distance as an indicator of stability. According to Secko's measurements [16], a normal glenohumeral distance is roughly 3 cm. The median US glenohumeral distances measured for the players were a) −1.83 cm (IQR: 1.98 to −1.41 cm) for anterior dislocations, b) 0.22 cm (IQR: 0.10–0.35 cm) for non-dislocated shoulders, and c) 3.30 cm (IQR: 2.59–4.00 cm) for posterior dislocations [16].

Each athlete underwent a real-time examination that included both clinical and US assessments with an Esaote myLabOne with a high-frequency linear-array transducer operating at 12–15 MHz (MHz). The evaluations were carried out by trained physicians who were skilled at performing measurements following a specific protocol and ensuring repeatability. Indeed, by following a specific protocol and utilizing objective and repeatable measurements, sonographers can achieve consistent and objective measurements from ultrasound images that result in minimal differences and low-variability outcomes [17]. Shoulder images were taken from a posterior view in a transverse plane. Starting from the spine of the scapula, the probe moved laterally to identify the scapular notch, the glenoid fossa, and the humeral head. This study focused on the US glenohumeral distance, which was determined by the difference between a) the distance from the posterior labrum of the glenoid (the top of the glenoid rim) to the skin; and b) the distance between the head of the humerus and the skin (Fig. 1).

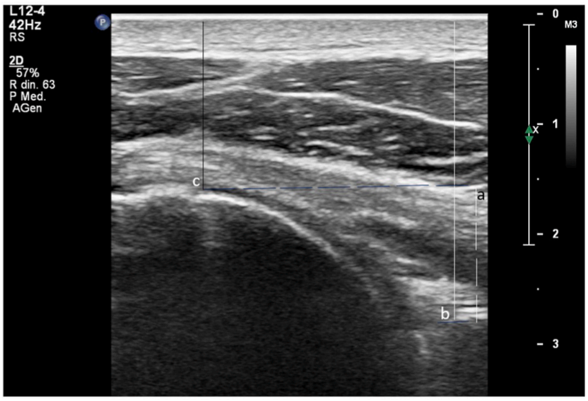

Fig. 1. US glenohumeral distance a) glenohumeral distance (white dashed vertical line); b) distance from the glenoid to the skin (white solid vertical line); c) distance from the head of the humerus to the skin (black solid vertical line).

2.4. Statistical analyses

The R Statistical Software (igraph package) was used for data analysis. Data are presented as mean ± standard deviation (SD) for normally distributed data and median (interquartile range) for non-normally distributed data. The data distribution was verified using the Kolmogorov-Smirnov test. A paired *t*-test and analysis of variance were employed to compare the results of the dominant limb with the contralateral within the same group for the apprehension test, relocation test, O'Brian test, and the IR and ER ROM. A comparison between the two groups of attackers and defenders was performed using an impaired *t*-test and the Mann-Whitney test.

For correlations, Pearson's correlation analysis assessed normally distributed data, and the Spearman-rank correlation was used for data with a non-normal distribution. Pearson's correlation examined the relationship among years of play, BMI, ROM, and US glenohumeral distance. The Spearman-rank correlation addressed the relationship between player position, Beighton score, and the relocation test with the US glenohumeral distance and ER ROM.

Measurements for both the dominant and non-dominant shoulders were considered. A p-value less than 0.05 was deemed to indicate statistical significance.

3. Results

The participants were homogeneous for age (15.02 ± 0.95 years), gender (all females), height (166.95 ± 6.84 cm), weight (59.12 ± 8.68 kg), and BMI (21.22 ± 2.99 kg/m^2). The player's level of athletic skill was consistent in terms of a) weekly training schedules (3 h a day for 6 days a week, with two months/year of rest), b) years of experience (7.14 ± 2.70 years), and c) status as a member of the national under-16 athletic team. However, the players occupied varying positions and roles on the volleyball court (Table 1).

The median value of the US glenohumeral distance was 0.42 ± 0.26 cm. This finding is consistent with the range observed in healthy and non-athletic population free from shoulder dislocation [16].

The US assessment was performed by two independent operators and interobserver agreement revealed that the weighted kappa value of 0.19493 indicated a fair strength of agreement between two physicians in US glenohumeral distance of dominant limb. The weighted Kappa value of 0.96271 indicates a very good strength of agreement in the interobserver assessment of the contralateral limb using ultrasonography (US) (Table 2).

There was no significant difference in both the IR ROM (p = 0.8502) and US glenohumeral distance (p = 0.8840) between the dominant and contralateral limbs. Similarly, all tests for hyperlaxity and shoulder instability, including the Beighton score, apprehension, and relocation test, showed no significant differences between the dominant and contralateral limbs. The ER ROM was significantly greater in the dominant shoulder than in the contralateral one (P = 0.0001; Table 2). Furthermore, a significant correlation was observed between the ER ROM of attackers and their US glenohumeral distance (P = 0.0413; Tables 3–4). In fact, in attacker

Table 2
Comparison between the dominant and contralateral limbs.

Diagnostic protocol	Parameters of assessment		Mean, SD
Shoulder ROM	IR of the dominant limb (gradians)		53.37 ± 22.02
	Contralateral IR (gradians)		53.87 ± 17.11
	ER of the dominant limb (gradians)		122.62 ± 16.33
	Contralateral ER (gradians)		105.17 ± 20.78
	TROM of the dominant limb (gradians)		176.00 ± 27.04
	Contralateral TROM (gradians)		159.05 ± 27.24
	Difference TROM (gradians)		16.95 ± 25.74
	GIRD (gradians)		0.48 ± 3.33
Tests	Beighton score		1.45 ± 0.93
	Apprehension test of the dominant limb		0.47 ± 0.64
	Contralateral apprehension test		0.52 ± 0.64
	Relocation test of the dominant limb		0.47 ± 0.64
	Contralateral relocation test		0.50 ± 0.59
	O'Brian test score of the dominant limb		0.60 ± 0.59
	Contralateral O'Brian test score		0.67 ± 0.76
US measurements	US glenohumeral distance of the dominant limb		0.422 ± 0.26
	Contralateral US glenohumeral distance		0.410 ± 0.24
	Interobserver agreement of US glenohumeral distance of dominant limb		k = 0.19493
	Interobserver agreement of US glenohumeral distance of controlateral limb		k = 0.96271
Shoulder characteristics			**Paired *t*-test**
IR difference between the dominant and contralateral limbs			P = 0.8502
ER difference between the dominant and contralateral limbs			**P = 0.0001**
US glenohumeral distance difference between the dominant and contralateral limbs			P = 0.8840
TROM difference between the dominant and contralateral limbs			**P = 0.0002**
Shoulder tests		**F-ratio**	**ANOVA**
Apprehension test core difference between the dominant and contralateral limbs		0.122	P = 0.728
Relocation test score difference between the dominant and contralateral limbs		0.0325	P = 0.857
O'Brian test score difference between the dominant and contralateral limbs		0.241	P = 0.625

Internal rotation IR; External rotation ER; Ultrasonography US.

Table 3
Comparison between attacker and defender groups.

Scale	Attackers	Defenders	Mann-Whitney test
Beighton score	1.50 ± 1.03	1.35 ± 0.74	P = 0.7846
Apprehension test of the dominant limb	0.35 ± 0.48	0.71 ± 0.82	P = 0.1444
Relocation test of the dominant limb	0.35 ± 0.49	0.72 ± 0.83	P = 0.1444
O'Brian test	0.58 ± 0.58	0.64 ± 0.63	P = 0.7776
Clinical and US characteristics	**Attackers**	**Defenders**	**Impaired *t*-test**
IR of the dominant limb	57.50 ± 22.72	45.71 ± 19.10	P = 0.520
IR of the contralateral limb	54.61 ± 18.76	52.50 ± 14.10	P = 0.7144
ER of the dominant limb	120.00 ± 17.03	127.50 ± 14.24	P = 0.508
ER of the contralateral limb	106.04 ± 21.65	103.57 ± 19.75	P = 0.7253
US glenohumeral distance of the dominant limb	0.45 ± 0.28	0.37 ± 0.23	P = 0.3601

Internal rotation IR; External rotation ER; Ultrasonography US.

Table 4
Correlation of clinical characteristics and shoulder tests with ultrasonography results in attackers and defenders.

Clinical characteristics of attackers	Correlation coefficient	Pearson's correlation
BMI and US glenohumeral distance of dominant limb	r = 0.1649	P = 0.3092
Years of game and US glenohumeral distance of dominant limb	r = −0.1071	P = 0.6025
IR and US glenohumeral distance of dominant limb	r = 0.0020	P = 0.9920
ER and US glenohumeral distance of dominant limb	r = 0.4029	**P=0.0413**
Clinical characteristics of attackers	**Rank correlation**	**Spearmann's correlation**
Beighton score and US glenohumeral distance	rho = −0.351	P = 0.0787
Apprehension test and US glenohumeral distance	rho = 0.361	P = 0.0697
Relocation test and US glenohumeral distance	rho = 0.151	P = 0.4615
O'Brian test and US glenohumeral distance	rho = 0.250	P = 0.2178
Clinical characteristics of defenders	**Correlation coefficient**	**Pearson's correlation**
BMI and US glenohumeral distance of dominant limb	r = 0.2324	P = 0.4241
Years of game and US glenohumeral distance of dominant limb	r = 0.1008	P = 0.7318
IR and US glenohumeral distance of dominant limb	r = 0.1919	P = 0.5111
ER and US glenohumeral distance of dominant limb	r = 0.3485	P = 0.2220
Clinical characteristics of defenders	**Rank correlation**	**Spearmann's correlation**
Beighton score and US glenohumeral distance	rho = 0.0668	P = 0.8206
Apprehension test and US glenohumeral distance	rho = 0.0086	P = 0.9767
Relocation test and US glenohumeral distance	rho = 0.0086	P = 0.9767
O'Brian test and US glenohumeral distance	rho = −0.0406	P = 0.8903

Body mass index BMI; Internal rotation IR; External rotation ER; Ultrasonography US.

volleyball players, greater ER impacts glenohumeral distance (Table 4). None of athletes exhibited GIRD. Notably, GIRD, defined as an IR difference greater than 5° compared with the non-dominant arm [18], combined with a loss of total rotational motion, was not significant (1.17° ± 0.61) in the sample of healthy, young volleyball players. The TROM difference significantly varied between the two sides (P = 0.0002) and appeared to be compensated for by an excessive ER ROM on the dominant side; the measured difference was approximately 17°.

There was no correlation between the clinical characteristics and US results (Table 5). indeed, weak positive correlation were

Table 5
Correlation among clinical characteristics, shoulder scores and US results.

Clinical characteristics	Correlation coefficient	Pearson's correlation
BMI and US glenohumeral distance of the dominant limb	r = 0.1649	P = 0.3092
Years of experience and US glenohumeral distance of the dominant limb	r = −0.01132	P = 0.9447
IR and US glenohumeral distance of the dominant limb	r = 0.08045	P = 0.6217
IR and US glenohumeral distance of the contralateral limb	r = -0.1339	P = 0.4101
ER and US glenohumeral distance of the dominant limb	r = −0.1029	P = 0.5274
ER and US glenohumeral distance of the contralateral limb	r = 0.06366	P = 0.6964
Clinical characteristics	**Rank correlation**	**Spearman's correlation**
Beighton score and US glenohumeral distance	rho = −0.266	P = 0.0976
Apprehension test and US glenohumeral distance	rho = 0.0663	P = 0.6846
Relocation test and US glenohumeral distance	rho = −0.0312	P = 0.8485
O'Brian test and US glenohumeral distance	rho = 0.0681	P = 0.6761
Beighton score and ER of the dominant limb	rho = 0.286	P = 0.0733
Beighton score and ER of the contralateral limb	rho = 0.808	P = 0.8081

Body mass index BMI; Internal rotation IR; External rotation ER; total range of motion TROM; Ultrasonography US.

shown between US glenohumeral distance of the dominant limb and a) BMI ($r = 0.1649$; $P = 0.3092$), b) years of experience ($r = -0.01132$; $P = 0.9447$), c) IR ($r = 0.08045$; $P = 0.6217$), and d) ER ($r = -0.1029$; $P = 0.5274$), indicating a slight tendency for increased BMI, year of game, IR and ER to be associated with greater US glenohumeral distance. Similar results were seen also for contralateral limb and a) IR ($r = -0.1339$; $P = 0.4101$), and b) ER ($r = 0.06366$; $P = 0.6964$), indicating only a minimal association between IR and ER and US glenohumeral distance.

Indeed, given the low main value of the Beighton score (1.45 ± 0.93), the shoulder ER increased even in absence of hyperlaxity and the glenohumeral joint remained stable.

4. Discussion

Based on the findings of the study, in under-16 volleyball players, the ER ROM of the dominant limb is significantly greater compared to the contralateral one. This is evident even in the absence of hyperlaxity, as indicated by a low Beighton score. Despite the ER ROM is significantly greater on the dominant side, adaptations in shoulder stability, detected by US, are observed only in attackers. Indeed, in attacker volleyball players increased ER impacts glenohumeral distance. This finding suggests that the shoulder morphological adaptation process starts early in attackers.

However, even if the ER ROM was significantly greater on the dominant side than the contralateral there were not necessarily changes in US stability in athletes without hyperlaxity. Despite an increased shoulder ER in the dominant limb, the glenohumeral joint remained stable. Indeed, the US glenohumeral distance remains within normal limits, indicating that the stability of the glenohumeral joint is still preserved. The TROM difference between the dominant and contralateral shoulders is significantly different, and it is adapted to excessive ER ROM on the dominant side (approximately 17° of difference).

In volleyball players, the dominant shoulder undergoes specific biomechanical and morphological adaptations. As adolescent female players gain experience and progress to higher levels of competition, their risk of injuries increases. This vulnerability is attributed to skeletal immaturity, combined with the escalating intensity and duration as they engage in more competitive matches [19].

Even if most young volleyball players haven't their role clearly defined by their coaches during practice, and all players tend to spend most of their time practicing overall volleyball skills without a specific court positions [20], the predominant athletic gesture characterized by overhead strength and repetitive movements, seems to induce shoulder adaptations. Possible explanation for this observation is that offensive players need greater throwing force, since they shoot from a longer distance, and they throw more often than players in other court positions [18]. This study is consistent with the current literature concerning the average years of training and values of shoulder ROM [21].

Literature showed that with an average sport experience of about 5 years, adolescent volleyball players exhibit motion adaptations [22]. In the sample of this study, with an average training duration of 7 years, initial adaptations were observed.

Overhead athletes typically exhibit significantly different shoulder ROM than non-athletes [12,23,24]. Particularly, adaptative changes in the throwing shoulders of handball players, particularly in the dominant limb, manifest before reaching skeletal maturity [25]. These adaptations optimize performance, a phenomenon known as the Pitcher's Paradox [10]. Commonly, these changes entail a reduction of IR and an increase of ER in dominant limb. Before a decrease in IR is observed, overhead athletes experience an increase in ER, leading to a corresponding rise in TROM of the dominant arm, yet TROM remains unchanged because the increase in ER is offset by the reduction of IR in the dominant limb. Subsequently, IR decreases, resulting in GIRD, without any change in TROM (because the increase of ER in compensated by the reduction of IR in the dominant limb) [18]. In this study, the players did not show GIRD, but an increase in ER had begun. Nonetheless, there was no correlation between shoulder injury and GIRD among adolescent players [20].

Specifically, athletes who exhibit 110–120° of ER and 30° of IR might still approach regular TROM values, which remain comparable to both contralateral values and normal values [21]. It appears that specific sports play a role in these adaptations. In particular, TROM is bilaterally symmetrical in professional baseball player, while it is altered by approximately 10° in elite junior tennis players [21]. As observed in tennis players, the sample of this study of under-16 volleyball players showed a 17° difference in TROM between the dominant and contralateral shoulders. Therefore, considering that individuals with a TROM difference of more than 5° between their dominant and non-dominant shoulders have an increased risk of shoulder injury [26], this increased risk may also be present among young volleyball athletes. Evidence indicated that an increased TROM might have a protective effect against injuries, whereas a decrease in TROM may cause detrimental effects to the overhead athletes. Similarly, a mild increase of ER doesn't appear to have positive or negative impact on throwing athletes; instead, excessive ER (ERG), especially when compared to the contralateral limb, could increase the risk of upper extremity injuries in overhead athletes [11].

5. Limitation

This observational study faces challenges in generalizing the findings to a broader population beyond under-16 competitive volleyball players. The study is further constrained by a limited sample size and the exclusive inclusion of female participants, hindering the generalizability of the results to broader populations. The ultrasonographic (US) assessment, a crucial component of the diagnostic protocol, was conducted by two independent operators. Although interobserver agreement was reported, variations in operator technique and interpretation may introduce potential sources of variability in the results.

Furthermore, while the study provides valuable insights into shoulder adaptations among young volleyball players, it's important to note that its design and scope might not allow for accurate predictions regarding the actual risk of future shoulder injuries in these athletes.

6. Conclusions

The results of this research highlight that, despite the absence of severe hyperlaxity, as shown by the low Beighton score, young volleyball athletes exhibit a significantly greater ER ROM in the dominant limb compared to the contralateral limb. Notably, despite these adaptations, changes in US stability of the glenohumeral joint are observed only in attacker athletes. However, these values still fall within the normal range, indicating that joint stability is preserved when adaptations predominantly affect only ER ROM.

Further research with longer follow-ups is needed to provide a more robust predictive correlation between early clinical modifications in the shoulder of young volleyball players and potential shoulder injuries.

Declaration - ethics statement

- Institutional review board: Ethics Committee "Catania 1", No. 2023/2886 (May 22, 2023) notification number.
- The authorization and informed consent for the scientific use of the data and other data were obtained from the Italian Federation of Volleyball (FIPAV) for all athletes who participated in the study.
- The authorization and informed consent for the publication of the illustrative image was obtained from the subject.
- The study complied with all regulations and adhered to the ethical guidelines of the Declaration of Helsinki.

Data availability statement

The data are available on request from the authors.

CRediT authorship contribution statement

Rita Chiaramonte: Writing – original draft, Conceptualization. **Gianluca Testa:** Writing – review & editing, Visualization, Methodology. **Antonino Russo:** Validation, Investigation, Data curation. **Enrico Buccheri:** Visualization, Formal analysis. **Massimiliano Milana:** Investigation, Data curation. **Riccardo Prezioso:** Visualization, Investigation, Data curation, Conceptualization. **Vito Pavone:** Writing – review & editing, Supervision, Conceptualization. **Michele Vecchio:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to express our profound gratitude to the Italian Federation of Volleyball (FIPAV) for their collaboration throughout this research. Special thanks to Dr. Salvatore Lutri, an expert in overhead injuries, whose invaluable insights enriched our work and whose skills as an organizer of sport competition were instrumental in the success of this study. We also extend our heartfelt appreciation to the volleyball teams who graciously participated in the evaluations, making this research both possible and meaningful.

References

[1] B.K. Tisano, A.R. Estes, Overuse injuries of the pediatric and adolescent throwing athlete, Med. Sci. Sports Exerc. 48 (2016) 1898–1905, https://doi.org/10.1249/MSS.0000000000000998.
[2] R. Chiaramonte, P. Pavone, G. Musumeci, M.D. Rosa, M. Vecchio, Preventive strategies, exercises and rehabilitation of hand neuropathy in cyclists: a systematic review, J. Hand Ther. 35 (2022) 164–173, https://doi.org/10.1016/j.jht.2021.11.003.
[3] R. Chiaramonte, M. Bonfiglio, S. Chisari, A significant relationship between personality traits and adhesive capsulitis, Rev. Assoc. Med. Bras. 66 (2020 15) 166–173, https://doi.org/10.1590/1806-9282.66.2.166.
[4] A. Zribi, H. Chaari, L. Masmoudi, W. Dardouri, M.A. Khanfir, E. Bouajina, M. Zaouali, M. Zouch, Volleyball practice increases bone mass in prepubescent boys during growth: a 1-yr longitudinal study, PLoS One 17 (4) (2022 Apr 7) e0266257, https://doi.org/10.1371/journal.pone.0266257.
[5] E. Buccheri, D. Dell'Aquila, M. Russo, R. Chiaramonte, G. Musumeci, M. Vecchio, Can artificial intelligence simplify the screening of muscle mass loss? Heliyon 9 (2023 16) e16323 https://doi.org/10.1016/j.heliyon.2023.e16323.
[6] M. Vecchio, R. Chiaramonte, G. Testa, V. Pavone, Clinical effects of L-carnitine supplementation on physical performance in healthy subjects, the key to success in rehabilitation: a systematic review and meta-analysis from the rehabilitation point of view, J Funct Morphol Kinesiol 6 (2021 4) 93, https://doi.org/10.3390/jfmk6040093.
[7] Fitness, American Academy of Pediatrics, Committee on Sports Medicine and. Intensive training and sports specialization in young athletes, Pediatrics 106 (2000) 154–157.
[8] B.K. Walters, C.R. Read, A.R. Estes, The effects of resistance training, overtraining, and early specialization on youth athlete injury and development, J Sports Med Phys Fitness 58 (2018) 1339–1348, https://doi.org/10.23736/S0022-4707.17.07409-6.
[9] E.G. Post, S.M. Trigsted, J.W. Riekena, S. Hetzel, T.A. McGuine, M.A. Brooks, D.R. Bell, The association of sport specialization and training volume with injury history in youth athletes, Am. J. Sports Med. 45 (2017) 1405–1412, https://doi.org/10.1177/0363546517690848.
[10] K.E. Wilk, K. Meister, J.R. Andrews, Current concepts in the rehabilitation of the overhead throwing athlete, Am. J. Sports Med. 30 (2002) 136–151, https://doi.org/10.1177/03635465020300011201.

[11] R.A. Keller, A.F. De Giacomo, J.A. Neumann, O. Limpisvasti, J.E. Tibone, Glenohumeral internal rotation deficit and risk of upper extremity injury in overhead athletes: a meta-analysis and systematic review, Sports Health 10 (2) (2018 Mar/Apr) 125–132, https://doi.org/10.1177/1941738118756577.
[12] A.M. Alqarni, S. Nuhmani, Q.I. Muaidi, Glenohumeral internal rotation deficit in volleyball players with and without a history of shoulder pain, Res. Sports Med. (2022) 1–10, https://doi.org/10.1080/15438627.2022.2102915.
[13] M.M. Reinold, T.J. Gill, Current concepts in the evaluation and treatment of the shoulder in overhead-throwing athletes, part 1: physical characteristics and clinical examination, Sports Health 2 (2010) 39–50, https://doi.org/10.1177/1941738109338548.
[14] B. Smits-Engelsman, M. Klerks, A. Kirby, Beighton score: a valid measure for generalized hypermobility in children, J. Pediatr. 158 (2011) 119–123, https://doi.org/10.1016/j.jpeds.2010.07.021, 123.e1-4.
[15] C.A. Guanche, D.C. Jones, Clinical testing for tears of the glenoid labrum, Arthroscopy 19 (2003) 517–523, https://doi.org/10.1053/jars.2003.50104.
[16] M.A. Secko, L. Reardon, M. Gottlieb, E.J. Morley, M.R. Lohse, H.C. Thode Jr., A.J. Singer, Musculoskeletal ultrasonography to diagnose dislocated shoulders: a prospective cohort, Ann. Emerg. Med. 76 (2020) 119–128, https://doi.org/10.1016/j.annemergmed.2020.01.008.
[17] R. Chiaramonte, M. Bonfiglio, E.G. Castorina, S.A.M. Antoci, The primacy of ultrasound in the assessment of muscle architecture: precision, accuracy, reliability of ultrasonography. Physiatrist, radiologist, general internist, and family practitioner's experiences, Rev. Assoc. Med. Bras. 65 (2019) 165–170, https://doi.org/10.1590/1806-9282.65.2.165.
[18] J. Schmalzl, H. Walter, W. Rothfischer, S. Blaich, C. Gerhardt, L.J. Lehmann, GIRD syndrome in male handball and volleyball players: is the decrease of total range of motion the turning point to pathology? J. Back Musculoskelet. Rehabil. 35 (4) (2022) 755–762, https://doi.org/10.3233/BMR-191767.
[19] J.G. Wasser, B. Tripp, M.L. Bruner, D.R. Bailey, R.S. Leitz, J.L. Zaremski, H.K. Vincent, Volleyball-related injuries in adolescent female players: an initial report, Phys Sportsmed 49 (2021) 323–330, https://doi.org/10.1080/00913847.2020.1826284.
[20] Y. Mizoguchi, K. Suzuki, N. Shimada, H. Naka, F. Kimura, K. Akasaka, Prevalence of glenohumeral internal rotation deficit and sex differences in range of motion of adolescent volleyball players: a case-control study, Healthcare (Basel) 10 (2022 11) 2263, https://doi.org/10.3390/healthcare10112263.
[21] T.S. Ellenbecker, E.P. Roetert, D.S. Bailie, G.J. Davies, S.W. Brown, Glenohumeral joint total rotation range of motion in elite tennis players and baseball pitchers, Med. Sci. Sports Exerc. 34 (2002) 2052–2056, https://doi.org/10.1097/00005768-200212000-00028.
[22] G. Harput, H. Guney, U. Toprak, T. Kaya, F.F. Colakoglu, G. Baltaci, Shoulder-rotator strength, range of motion, and acromiohumeral distance in asymptomatic adolescent volleyball attackers, J. Athl. Train. 51 (2016) 733–738, https://doi.org/10.4085/1062-6050-51.12.04.
[23] P. Lubiatowski, P. Kaczmarek, P. Cisowski, E. Breborowicz, M. Grygorowicz, M. Dzianach, T. Krupecki, L. Laver, L. Romanowski, Rotational glenohumeral adaptations are associated with shoulder pathology in professional male handball players, Knee Surg. Sports Traumatol. Arthrosc. 26 (2018) 67–75, https://doi.org/10.1007/s00167-017-4426-9.
[24] D. Challoumas, A. Stavrou, G. Dimitrakakis, The volleyball athlete's shoulder: biomechanical adaptations and injury associations, Sports BioMech. 16 (2017) 220–237, https://doi.org/10.1080/14763141.2016.1222629.
[25] W.N. Levine, M.L. Brandon, B.E. Shubin Stein, T.R. Gardner, L.U. Bigliani, C.S. Ahmad, Shoulder adaptive changes in youth baseball players, J. Shoulder Elbow Surg. 15 (2006) 562–566, https://doi.org/10.1016/j.jse.2005.11.007.
[26] K.E. Wilk, L.C. Macrina, G.S. Fleisig, R. Porterfield, C. Simpson, P. Harker, N. Paparesta, J.R. Andrews, Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers, Am. J. Sports Med. 39 (2011) 329–335, https://doi.org/10.1177/0363546510384223.