Original Research

Study of Damage to the Drawing Arm Subacromial Bursa in Recurve Archers Based on a Finite Element Model

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Abstract

Background: The purpose of this study was to simulate the drawing arm of male recurve archers by finite element method. And observe the stress changes of humerus and scapula on the subacromial bursa under different stages of special techniques. To investigate the mechanism of the subacromial bursa injury in male recurve archers. **Methods**: Collected a 22-year-old healthy men shoulder CT and MRI data, construct the bow side shoulder joint finite element model, contains the structure of the shoulder blades, clavicle, humerus, and subacromial bursa. The humerus on the drawing side of the curve was simulated to perform the raising the bow, drawing, holding and releasing actions on the scapula plane, analysis of stress changes in subacromial bursa. **Results**: The peak stress on the subacromial bursa varied greatly. From the start of raising the bow to the start of drawing, the stress peak decreased markedly from 0.280 MPa to 0.036 MPa. Then, the peak stress immediately increased to 0.347 MPa at the beginning of the holding and decreased to 0.262 MPa at releasing. **Conclusions**: The reason for the stress surge on the subacromial bursa in the holding phase is that its structure is easily squeezed by multiple surrounding tissue structures, resulting in high stress and susceptibility to damage. In combination with the depth of the structural site and the surrounding structural characteristics, this can prevent subacromial bursa injury. The results of this work are particularly relevant to the prevention of subacromial bursa injury in male recurve archers.

Keywords: recurve arch; drawing arm; shoulder; finite element method; subacromial bursa

1. Introduction

Recurve bow movement is a static process in which the whole movement is without violent collision. It requires a high level of concentration over a period of time as the athlete completes a series of rhythmic, smooth, and evenly accelerated movements of the arms to take the arrow, snap the string, pre-draw, drawing, aiming, unstringing and releasing. Shoulder injury is the most common injury amongst archers and is related to frequent shoulder activity, large load bearing, and frequent friction, pulling and extrusion between tissues [1,2]. For the bow arm, it is necessary to repeat and complete the large movement.

The subacromial bursa is one of the largest bursae in the body. It is located below the acromion, coracoclavicular ligament and deep fascia of the deltoid muscle, and above the rotator cuff and greater tubercle of the humerus [3,4]. Injuries of the subacromial bursa are mostly caused by inflammatory stimulation due to acute and chronic injuries of the shoulder, thus leading to shoulder pain and limited movement [5]. The occurrence of subacromial bursa injury is due to many factors, including special technology, exercise loads and muscle imbalance [6–8]. The cycle, time and intensity of training are closely related to an injury. In addition, increased thickness of the subacromial bursa correlates with an increased number of bursa injury cases [9].

To help improve the sense of movement, the training schedule of elite male recurve archers consists mainly of real draws. Up to 1000 times per day, the training involves repeated raising the bow, drawing, holding, releasing, and so on with no changes allowed. The shoulder side of the bow has a high frequency of monotonous repetition of action, causing increased load on shoulder muscles, early fatigue and then corresponding inflammation [10]. Although some studies have reported that male recurve archers suffer subacromial bursa injury [11], there is currently little in-depth research on the mechanism. However, bursa lesions caused by subacromial impingement syndrome [12] seriously affect the normal training of male recurve archers.

The purpose of the finite element method is to disassemble complex structures into several small units with simple shapes, allowing the distribution of parameters to be described by a straightforward mathematical model [13,14]. By fusing CT and MRI scan data, the 3D parameters of soft tissue are obtained in addition to geometric information for bone tissue, which improves the geometric similarity, boundary constraints and load similarity of the 3D finite element model [15]. To date, several research groups have applied finite element analysis [16–20].

Fig. 1. Four characteristic actions of the recurve bow (the start of raising the bow, the start of drawing, holding, the end of releasing action).

In this study, we conducted finite element analysis following 3D reconstruction of the male humerus, clavicle, scapula and subacromial bursa. The aim was to observe stress changes associated with subacromial bursa during the four characteristic actions of the recurve bow reported in previous studies (Fig. 1). In view of the lack of in-depth studies of internal changes in other sports biomechanical tests, we discuss the mechanism of injury of the subacromial bursa in male recurve archers and propose a scheme for injury prevention.

2. Materials and Methods

2.1 Subject

A healthy male club level archer was selected as the subject. He was 22 years old, 178 cm tall, and weighed 90 kg, with no shoulder pain or previous injury history, right-side is drawing arm, trained for 2 years.

2.2 Methods

To obtain subject imaging data, we used CT and MRI scanning technology in the absence of load, with the right arm in a standard anatomical position vertical to the body side of the shoulder joint. The results of CT and MRI scan were used to reconstruct 3D models of the bone and subacromial bursa, respectively. The thickness of CT and MRI images was kept below 1 mm.

The motion biomechanics analysis of recurve archers was carried out under laboratory conditions. The kinematic parameters needed for the study were obtained by an 8-lens infrared high-speed motion capture system (Qualisys-OQUS700, Sweden), with an acquisition frequency of 200 Hz. The subject was required to wear a tight top during the test and to warm up beforehand. After the stretching exercises, reflective markers were placed on the subject at surface anatomical markers. The angle variation of bow movement was recorded by sports biomechanics and used as the boundary condition of finite element simulation.

2.2.1 Reconstruction of a 3D Model of the Shoulder Joint on the Drawing Arm

ANSYS19.1 (Swanson Analysis, Houston, PA, USA) software was used for finite element analysis. The Static Structural module was used to simulate the shoulder joint with the specific motion of a recurve bow. CT and MRI medical imaging data were processed using MIM-ICS19.0 software (Materialise, Leuven, Belgium), allowing 3D model reconstruction of bone and subacromial bursa. Two-dimensional images of bone and soft tissue in each tomographic image were extracted using the software, and an initial set of 3D models was set up in reverse. After using filling, delete, packages and smoothing tools to remove noise pixels, filling the blank area, and repairing burr and sag on the surface of the model, a geometric shape and structure with real human tissue close to the 3D model was obtained. The final assembly consisted of scapula, clavicle, humerus and subacromial bursa. The processed shoulder bone and bursa models were saved in IGES format and imported into the finite element analysis software for the next step of simulation.

2.2.2 Reconstruction of the Finite Element Model of the Shoulder Joint on the Drawing Arm

This experiment focused on the biomechanical characteristics of shoulder bone and bursa at the four characteristic actions of the recurve bow and was based on previous research results [21,22]. The Static Structural module was used to perform structural mechanical simulation of the shoulder tissue loads.

Established 3D model files of shoulder bone and muscle were imported into the Static Structural module of AnsysWorkbench19.1 software (Swanson Analysis, Houston, PA, USA). Four characteristic actions were established according to the rotation angle of the humerus on the drawing arm obtained from the biomechanics test. Four corresponding simulation projects were established in the Ansys working interface. Based on the motion characteristics of the upper arm link, the humeral angle of the four characteristic moments was defined as previously reported [23–25]. Based on the humerus in standard anatomical posture and the results of biomechanical 3D photography, the coordinate data of the shoulder joint center and elbow joint center were extracted at the start of raising the bow, drawing and holding, and the releasing.

In order to reduce the calculations for finite element simulation and by referral to previous studies [26–28], we simulated biomechanical changes of the shoulder tissue structure at four characteristic moments of motion: the start of raising the bow, the start of drawing, the start of holding,

and the releasing (Fig. 2). Meanwhile, isotropic linear elastic materials were selected for both muscle and bone material properties (Table 1).
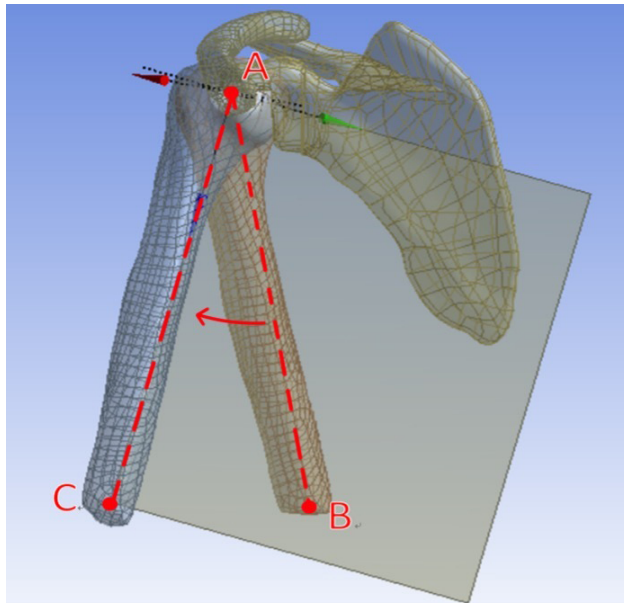
Fig. 2. Model establishment of the recurve bow characteristic actions.

Table 1. Material parameters of the shoulder finite element model.

Materials	Elastic modulus (MPa)	Poisson's ratio
Subacromial bursa	1500	0.25
Bone	7300	0.3

2.2.3 Loading Mode of the Recurve Bow Characteristic Moment Simulation

A total of 1042 nodes of scapula and clavicle were fixed and restrained. The plane ABC was established with two vectors of humeral vector AB in the standard anatomical posture and humeral vector AC at the characteristic time. The central point A of the shoulder joint was defined as the origin of the shoulder coordinate, while the X-axis of the shoulder coordinate was established with the negative direction of humeral vector AC at a characteristic time. The Y-axis of the shoulder coordinate is parallel to the normal vector of plane ABC, thus establishing the shoulder coordinate system for finite element analysis. This is used to determine the rotation axis and direction of the humerus. The humerus model with a total of 720 nodes was selected. Under the established shoulder joint coordinate system, load was applied around the Y-axis rotation angle and the humerus rotating load was measured by biomechanics testing. Two space vectors were set up based on the four

characteristic moments of raising the bow, drawing, holding and releasing, as well as the coordinates of the frame of the shoulder joint and elbow point. The formula shown below (Eqn. 1) was used to calculate the angle of the two space vectors, which was then used as the angular load of humeral rotation. The specific values are shown in Table 2.

$$\cos \theta = \frac{\overrightarrow{AB} \cdot \overrightarrow{AC}}{|\overrightarrow{AB}| \cdot |\overrightarrow{AC}|} \tag{1}$$

Table 2. Material parameters of the shoulder finite element model.

Key frames	Angular load (°)	Time setting (s)
Raising the bow start	0.220	0.005
Drawing start	0.501	0.005
Holding start	0.058	0.005
Releasing	0.004	0.005

3. Results

The peak stress on the subacromial bursa varied greatly. From the start of raising the bow to the start of drawing, the stress peak decreased markedly from 0.280 MPa to 0.036 MPa. Subsequently, the stress peak immediately increased to 0.347 MPa at the start of holding, and then decreased to 0.262 MPa at the releasing (Table 3). Compared to the initial stage of raising the bow, the stress peak decreased by 0.244 at the start of raising the bow and increased by about 0.067 at the start stage of holding. At the releasing, the stress change decreased to 0.018 of the start stage. Stress changes at each stage are shown in Figs. 3,4,5,6. At the action of the start of raising the bow, while the area of stress concentration in the subacromial bursa occurs close to the clavicle and supraspinatus, the stress maximum occurs on the contact surface between the supraspinatus and the bursa. The stress is greatest during the holding stage.

Table 3. Stress peak of the subacromial bursa at each characteristic actions of the recurve bow (MPa).

Soft tissue name	Raising the bow start	Drawing start	Holding start	Releasing
Subacromial bursa	0.280	0.036	0.347	0.262

4. Discussion

Multiple bursae in the shoulder are located between adjacent structures that require movement and serve to reduce friction between the tendon and bony structures, as well as other structures. One of the most important bursae is
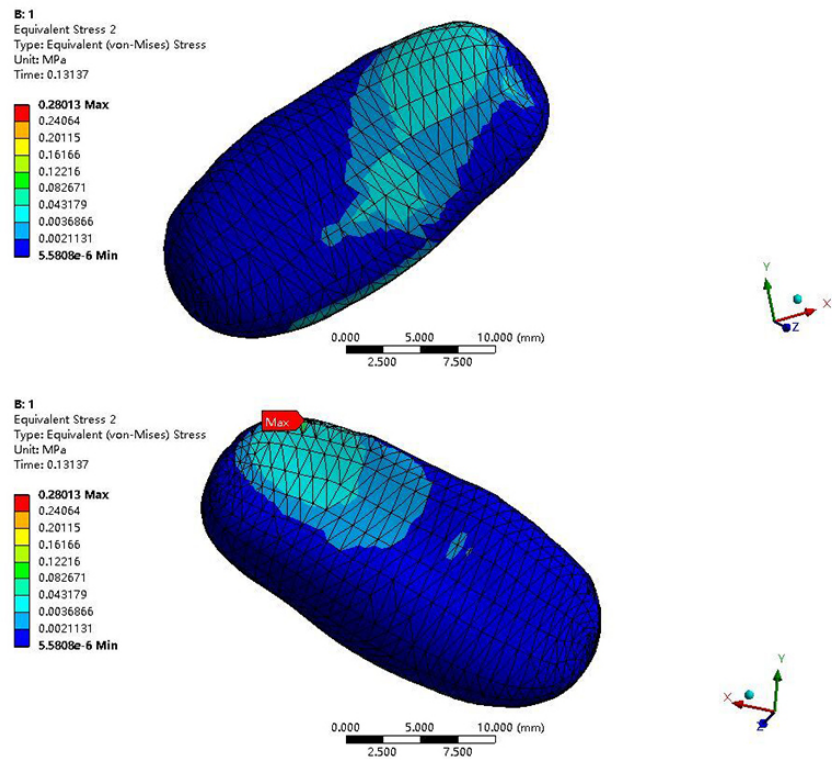
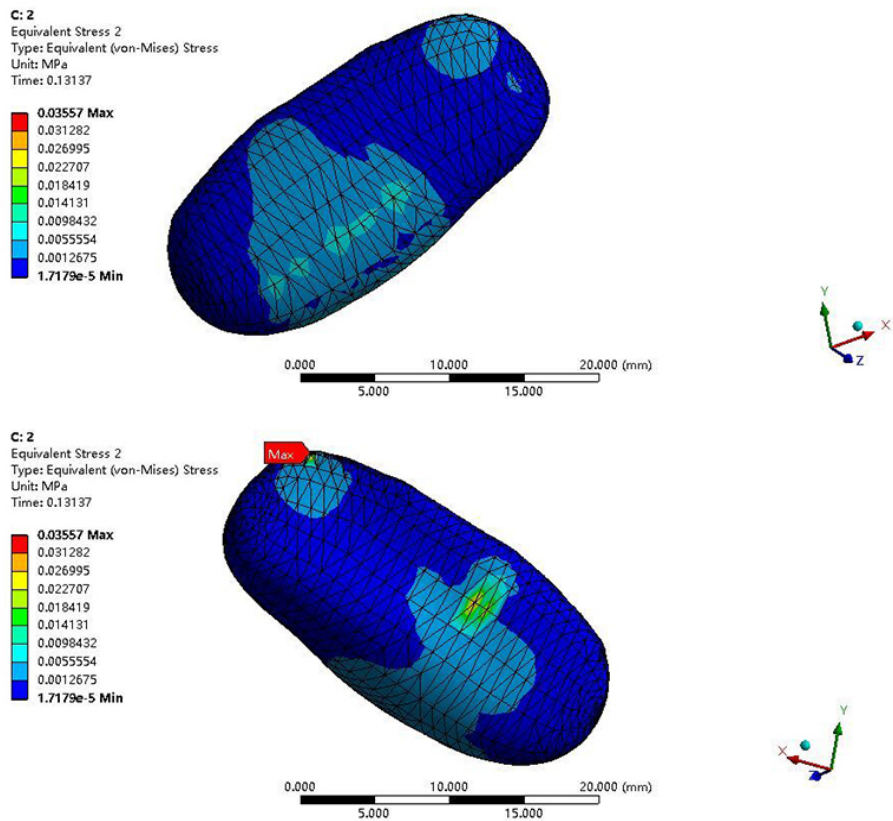**Fig. 3. Stress change at the start of the subacromial bursa raising the bow stage.**

Fig. 4. Stress change at the start of the subacromial bursa drawing stage.
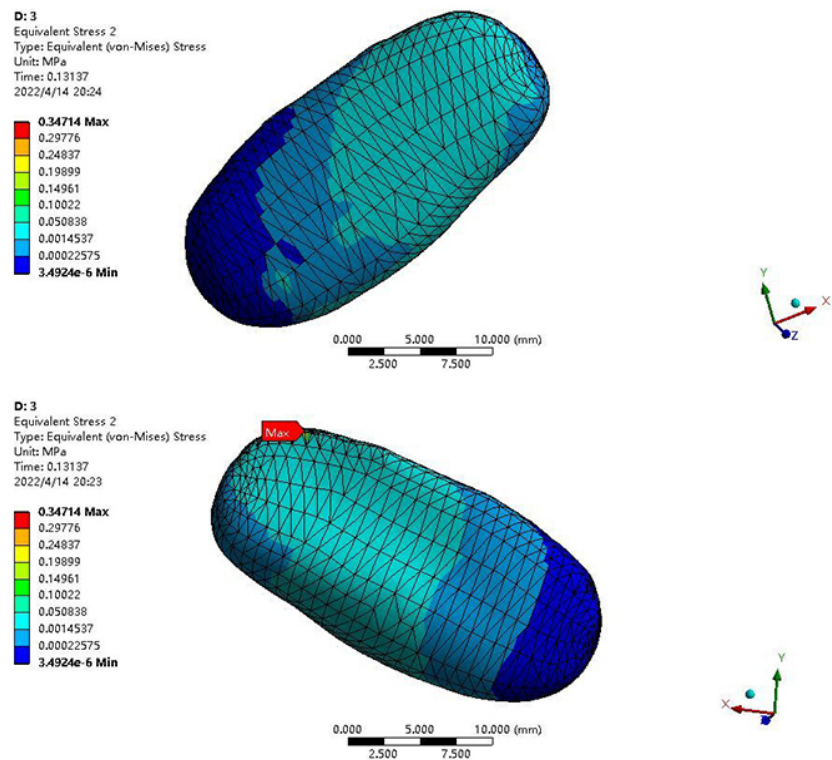
Fig. 5. Stress change at the start of the subacromial bursa holding stage.
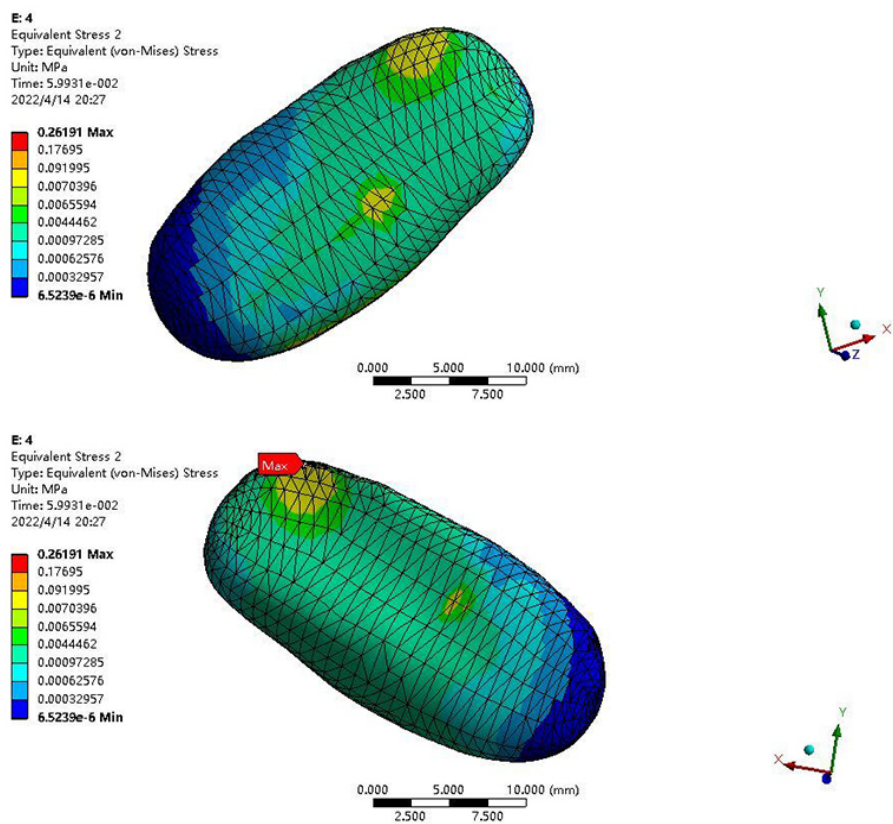

Fig. 6. Stress change at the moment of the subacromial bursa releasing stage.

the subacromial bursa. The bursa is generally not attached to the joint [29]. In this study, we performed finite element simulation of the characteristic time states of the shoulders of a male recurve archer. Changes in the equivalent stress distribution of the subacromial bursa on the draw side when completing each time phase of a recurve bow can be clearly seen. The subacromial bursa is located between the acromion and supraspinatus muscle, with the peak stress on this structure fluctuating greatly from 0.089 MPa to 0.227 MPa. At the same time, the pressure peak concentration area is relatively fixed and located at the contact surface of the supraspinatus muscle, indicating the subacromial bursa is significantly compressed by this muscle.

The distribution of stress on the surface of the subacromial bursa was found to be unstable during the entire movement technique of recurve bow, with the stress peak of the bursa decreasing at first and then increasing. The results of this study suggest that humeral movement could reduce stress on the subacromial bursa during movement from raising the bow to drawing. The dynamic structure of the humerus did not over-stimulate the subacromial bursa in the early stage of recurve bow movement, but the stress level on the bursa increased during the holding stage. The abductive position of the humerus makes it easier for the subacromial bursa to be compressed by surrounding tissues. This is because the subacromial bursa is located between the acromion, clavicle and supraspinatus muscle. Due to the large Young's modulus (a physical quantity describing the deformation resistance of solid materials) of the tissues surrounding the bursa, the surface of the bursa is more likely to be damaged by the extrusion of hard objects, leading to aggravated dysfunction. Therefore, it appears there is a higher probability of subacromial bursa injury during the holding stage of recurve bow technique than at other stages. The reason for the stress surge on the subacromial bursa in the holding phase is because it is easily squeezed by multiple surrounding tissue structures, resulting in high stress and susceptibility to damage. The depth of the subacromial bursa and the surrounding structures make it difficult to repair by traditional treatment methods such as massage and hot compress. Corrective training can be considered in order to improve the subacromial space and to release the supraspinatus muscle.

One of the main reasons for common shoulder injuries is incorrect muscle force and movement deformation during training [30]. However, male recurve archers frequently need to raise their upper limbs and repeatedly apply static force during technical training, which can easily cause friction or strain. One of the characteristics of recurve bow movement is that the archer's head rotates repeatedly to the left as the right hand draws the bow. At this point, the position of the head and neck is shifted. In order to maintain consistency in movement height, the soft tissue of the neck is often in a high state of tension and the shoulder muscles force is prone to imbalance when the bow is pulled behind

and kept full. This makes it easier to develop muscle spasm, weakness and excessive strain, especially when the movement is not standard. All of these factors can cause and aggravate subacromial bursa injury in male recurve archers. Therefore, it is necessary to carry out targeted corrective training to help improve the force and thus avoid deformation and other conditions from arising. Emphasis should be placed on improving the strength of the infraspinatus, trapezius and upper arm muscles, as well as helping the shoulder joint stabilize the strength of other rotator cuff muscles.

5. Conclusions

The reason for the stress surge on the subacromial bursa in the holding phase is that its structure is easily squeezed by multiple surrounding tissue structures, resulting in high stress and susceptibility to damage. The position of the humeral head during abduction and the space under the acromion can be improved by releasing the supraspinatus muscle. In combination with the depth of the structural site and the surrounding structural characteristics, this can prevent subacromial bursa injury. Corrective training can also improve the muscles that lead to incorrect and distorted motion of the shoulder used by the recurve archer. Because the finite element study object was a male, the results of this work are particularly relevant to the prevention of subacromial bursa injury in male recurve archers.

6. Limitation of the Study

The simulation results obtained in this research for the subacromial bursa are reliable to a certain extent, but further confirmation is needed with scientific cadaver studies.

Author Contributions

CG, KL, and JY designed the research study. GC and KL performed the research. YY and JW analyzed the data and built the model. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

Ethics Approval and Consent to Participate

The study was ethically approved by the ethical committee of Hebei Shooting and Archery Centre (Ethical approval number: 2019A63). All the study participants signed an informed consent form.

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Conflict of Interest

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