The Effect of Different Arm Angles When Throwing

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Abstract

This experiment aims to determine how various throwing angles and forearm pronation affect the strain on elbow ligaments. The study focuses on identifying which combination of arm position and rotation produces the most significant ligament strain, as indicated by stretching and the formation of microtears. An anatomically accurate left arm model was constructed using 3D-printed bones to mimic the humerus, ulna, and radius, while rubber bands served as substitutes for natural ligaments. The rubber bands were securely attached to the bones using cyanoacrylate glue to ensure realistic ligament connections. Muscles and tendons were intentionally excluded to eliminate the variable of muscle contraction, and all throws were conducted manually.

Three distinct throwing angles were evaluated: 35 degrees (overhead), 45 degrees (three-quarters), and 75 degrees (sidearm). For each angle, two throwing conditions were tested: no rotation and pronation (inward rotation). In total, six throws were performed—three with no rotation and three with pronation. The forearm's rotational movement during each throw was manually controlled to simulate the intended throwing mechanics. Ligament strain was assessed visually by examining elongation, tension, and the occurrence of microtears. Preliminary observations show that the rubber bands were not stretched or torn before the experiment was run. The results from this experiment will provide valuable insights into the biomechanics of throwing motions, potentially informing injury prevention strategies and contributing to improved sports performance and rehabilitation protocols.

1. Introduction

Baseball, a sport deeply rooted in American culture, requires athletes to perform repetitive, high-stress motions, particularly when pitching. The different types of pitches (primarily fastballs, sliders, curveballs, and changeups) each impose unique biomechanical demands on a pitcher's arm. These demands have significant implications for both performance and injury risk. Understanding the biomechanical differences among pitch types and their impact on the shoulder and elbow is essential for developing effective training, prevention, and rehab strategies. Additionally, factors such as limb length, arm angles, and height may influence injury susceptibility, making it important to examine how these elements interact with pitching mechanics.[1]

1.1. Biomechanics of Different Pitch Types

A study aimed at comparing the biomechanics of different pitch types in professional baseball pitchers found distinct differences in the forces and torques exerted on the shoulder and elbow. Sliders and curveballs generated 17-20% greater horizontal adduction shoulder force and the curveball in particular showed 13% higher elbow flexor torque compared to changeups. Specifically, shoulder and elbow forces were 10-14% higher for the fastball, slider, and curveball, while the changeup resulted in lower kinetic loads[1, 2]. This suggests that pitchers may be at a higher risk of injury when frequently throwing pitches that require higher kinetic output, or higher speed. The biomechanics of pitching vary depending on arm angle, which affects the stress on different parts of the arm. Higher arm slots place less stress on the elbow while lower arm slots shift more stress to the elbow. These variations in arm angle contribute to differences in injury risk and recovery patterns.[3]

1.2. Mechanics and Injury Risk

The pitching mechanics of youth baseball players have been studied to address the increasing incidence of shoulder and elbow injuries among young athletes. A systematic review of youth pitching mechanics revealed that during the pitching motion, the shoulder undergoes progressive external rotation, reaching a maximum angle between 166° and 178.2°, before internally rotating throughout the rest of the cycle. Elbow valgus torque peaks just before maximum shoulder external rotation, with an average torque of 18 ± 4 Newton-meters, and decreases after that.[4] These findings highlight certain phases in the pitching motion that could be targeted for injury prevention. Additionally, the relationship between torque on a tendon and injury severity is a crucial aspect of injury prevention. High torque loads can lead to microtears in ligaments, particularly the ulnar collateral ligament (UCL), which, over time, may necessitate surgical intervention.[5]

1.3. Injury Incidence in Youth vs. Professionals

Studies have shown that arm injury incidence rates vary between different levels of play. Youth players demonstrated an arm-injury incidence rate of 2.22 per 1000 athlete-exposures, teenagers and adolescents had 1.3 to 4.0 injuries per 1000 athlete-exposures, collegiate players had 1.81 per 1000 athlete-exposures, and semi-pro and professional players had 1.15 arm injuries per 1000 athletic exposures. Additionally, approximately 31% of professional/semi-pro players develop an arm injury, compared to 13% of youth players.[5, 6] These findings suggest that while professional pitchers may have superior conditioning, the repetitive high-velocity nature of their throwing mechanics leads to substantial injury risk.

1.4. Prevention Programs

Implementing prevention programs can significantly reduce the incidence of shoulder and elbow injuries among youth baseball players. A randomized controlled trial involving youth baseball teams demonstrated that an intervention program consisting of stretching, dynamic mobility, and balance training exercises significantly reduced injury rates. The incidence of injuries in the intervention group was 1.7 per 1000 athlete-exposures, compared to 3.1 per 1000 athlete-exposures in the control group.[7] This program not only reduced injuries but also improved pitching performance metrics such as ball speed. Furthermore, proper nutrition plays a crucial role in injury prevention and recovery. Adequate protein intake supports muscle repair, while nutrients such as vitamin C and collagen help maintain ligament integrity.[8] Hydration and electrolyte balance are also essential in preventing muscle fatigue, which can contribute to poor mechanics and increased injury risk.[9]

1.5. Ulnar Collateral Ligament Reconstruction (UCLR)

Ulnar collateral ligament reconstruction (UCLR), also known as Tommy John surgery, is a prevalent procedure among professional baseball players. It is an almost guaranteed procedure for a high-velocity professional or collegiate pitcher. A systematic review of UCLR outcomes revealed that Major League Baseball (MLB) pitchers had high return-to-play (RTP) rates after primary UCLR, ranging from 80% to 97% within approximately 12 months. However, return to the same level of play (RTSP) was less frequent, with rates between 67% and 87% taking around 15 months. Revision UCLR showed slightly lower RTP and RTSP rates, indicating that subsequent surgeries might lead to less successful outcomes.

These findings underscore the importance of effective injury prevention and management strategies to minimize the need for surgical interventions. One of the factors that may impact the success of a UCLR is the choice of graft. Autografts, which use tendons from the player's own body, eliminate the risk of rejection but can weaken the donor site, potentially affecting other body functions. Allografts, taken from a donor, avoid this issue but introduce the possibility of immune rejection or graft failure. Additionally, repeated surgeries may result in scarring, reduced ligament quality, or intrinsic weaknesses in the athlete's ability to recover.[10] For non-professional athletes, undergoing UCLR presents additional challenges. The cost of the surgery without health insurance can range between $15,000 and $50,000, depending on the extent of the procedure and the surgeon's reputation.[11] The recovery process, typically lasting 12 to 18 months, can be strenuous and can require extensive physical therapy. Common problems with UCLR include infection, graft inflammation, reoperation due to graft failure, and long-term stiffness.[12] Unlike professional athletes who receive the best medical support, amateur players may struggle with rehabilitation access, potentially leading to longer recovery times and lower success rates.

1.6. Next Steps

The biomechanics of different baseball pitches have profound implications for the risk of shoulder and elbow injuries. Fastballs, sliders, and curveballs generate higher forces and torques, increasing the potential for injury compared to changeups. Understanding these biomechanical differences is crucial for developing targeted prevention programs, especially for youth players. Moreover, the high stakes of UCLR highlight the need for comprehensive strategies to optimize pitching mechanics and minimize injury risks. Considering factors such as limb length, arm angles, and height can provide deeper insights into injury prevention. Additionally, proper nutrition and strength training play a key role in mitigating the long-term effects of pitching on joint health. By integrating biomechanical insights with practical training and rehabilitation approaches, it is possible to enhance player performance while safeguarding their long-term health.[13]

2. Purpose

The purpose of this experiment was to see which combination of throwing angle and forearm pronation imposes the highest strain on elbow ligaments. It is hypothesized that the sidearm throw (75 degrees) combined with pronation will result in the most significant ligament strain due to the increased valgus force applied to the elbow joint. This study anticipates that this condition will exhibit more pronounced elongation and microtearing in the rubber band ligaments compared to the other tested throwing angles. This study is significant as it directly addresses key biomechanical factors that contribute to ligament stress and injury. Findings from this experiment can provide actionable insights for coaches, sports medicine professionals, and athletes, guiding adjustments in throwing techniques to minimize injury risk. Furthermore, the results may also influence the design of rehabilitation protocols and the development of protective gear tailored to mitigate ligament strain during high-stress athletic activities.

3. Methods

3.1 Materials

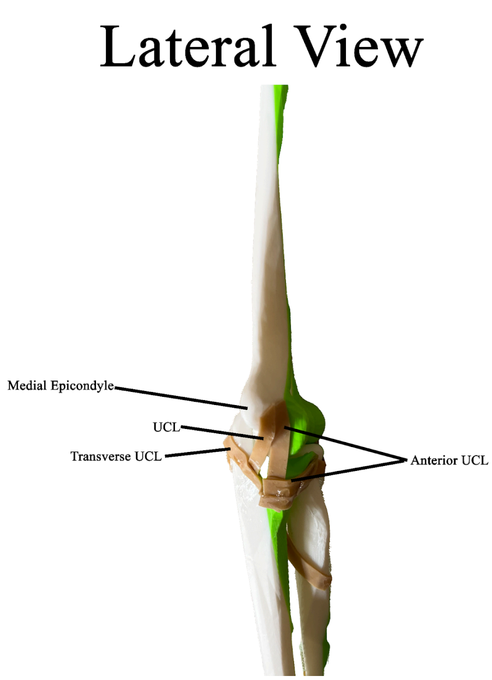
The objective of the experiment is to mimic a throwing motion with a human arm. An anatomically accurate left arm model was constructed using 3D-printed bones (humerus, ulna, and radius) to investigate the effect of different arm angles and forearm pronation on elbow ligament strain during throwing. Each of the subcomponents are listed below.

3.1.1. 3-D Printed Anatomical Arm Model

Bones representing the humerus, ulna, and radius were designed to replicate a left arm's skeletal structure. They were printed out of plastic using a 3-D printer.

3.1.2. Ligament Substitutes

Rubber bands were used to simulate the elasticity and tensile properties of natural ligaments. They were securely attached to the 3-D printed model using cyanoacrylate (CA), ensuring proper anatomical alignment. Muscles and tendons were omitted from the model to isolate the variables of arm angle and pronation.



3.1.3. Experimental Setup

The experimental setup included a manually controlled throwing mechanism, where the arm model is moved by hand to simulate a human throwing motion. Three distinct throwing angles: 35 degrees (overhead), 45 degrees (three-quarters), and 75 degrees (sidearm). Visual inspection techniques supplemented by optional video recording were used to document ligament behavior during each throw. All data was collected in a table used to detail recordings of observed strain, ligament elongation, and microtears under each test condition.

Figure 1. Lateral view of model arm

3.2. Experimental Procedure

3.2.1. Model Assembly:

I assembled the anatomical model by connecting the 3D-printed bones in their correct anatomical positions. I attached the rubber band ligaments to the bones using cyanoacrylate glue, ensuring that each ligament is placed accurately according to human anatomy, allowing adequate time for the adhesive to set.

3.2.2. Setup of Throwing Conditions:

For some throws, the forearm will be rotated using pronation (where the thumb rotates inward during the throw), as this is a common motion used in throwing.

3.3. Conducting the Throws:

I performed manual throws for each combination of throwing angle with pronation, ensuring that the force applied is as consistent as possible across trials. I used a camera with video recording capability to capture the throw for later analysis. I also randomized throws to make sure there is as little bias as possible when conducting the experiment.

3.3.1. Data Collection and Analysis:

The primary method of data collection is through a video recording that is then analyzed with Logger Pro™ to calculate percent elongation of each ligament. Initial length is with no stress, while maximum length is the most stressed the rubber band ligament gets during the throwing motion. I calculated percent elongation by this equation:

Percent Elongation = [(Initial Length – Maximum Length) ÷ (Initial Length)] × 100

This method is focused on the extent of ligament stretch and the occurrence of microtears. The initial lengths of the ligaments are: Anterior UCL: 3.9cm, RCL: 3.0cm, Annular Collateral Ligament: 9.2cm (wrapped around, 3.9cm on each side), Transverse UCL: 2.5cm, Posterior UCL: 0.7cm. The model I'm using is smaller than an adult's actual arm and ligaments because that would be too big to replicate.

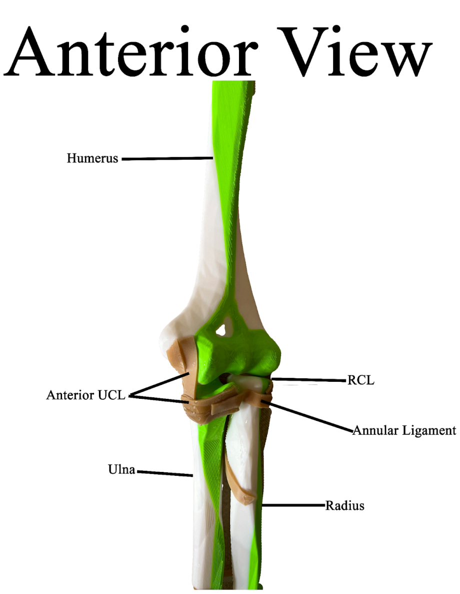
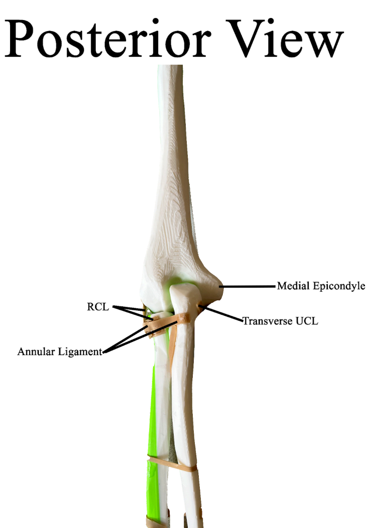


Figure 2. Anterior view of model arm

3.4. Variables

3.4.1. Independent Variables

The independent variables were throwing angle (35°, 45°, 75°) and pronation of the forearm/hand



3.4.2. Dependent and Controlled Variables

The dependent variable was the degree of ligament strain, as measured by calculated percent elongation and the occurrence of microtears in the rubber bands.The controlled variables were consistency of the manual throwing force, uniformity in the assembly of the anatomical model, use of identical rubber bands and adhesive, and environmental testing conditions (e.g., indoor setup to minimize external error).

Figure 3. Posterior view of model arm

Table 1: Results from data collection

Angle and Rotation	Observations	Experimental Elongation
35° with no rotation	**Anterior Ulnar Collateral Ligament (UCL):** Slight tension with minimal elongation; no microtearing. **Posterior and Transverse UCL:** No noticeable change. **Radial Collateral Ligament (RCL):** Remains relaxed with negligible elongation, no stress at the lateral epicondyle. **Annular Ligament:** Maintains normal elasticity around the radial head.	**Anterior UCL:** 4.018cm **RCL:** 3.006cm **Annular Ligament:** 9.211cm **Transverse UCL:** 2.500cm **Posterior UCL:** 0.700cm **Percent Elongation:** **Ant. UCL:** 3.03% **RCL:** 0.20% **Annular Ligament:** 0.11% **Transverse+Posterior UCL:** 0%
35° with pronation	**Anterior UCL:** Minor increase in tensile strain with subtle plastic deformation and a small microtear near the ulnar insertion. **Posterior and Transverse UCL:** No noticeable change. **RCL:** Slight increase in tension with minor elongation, no distinct microtearing. **Annular Ligament:** Displays mild elongation with a faint stress line.	**Anterior UCL:** 4.134cm **RCL:** 3.045cm **Annular Ligament:** 9.350cm **Transverse UCL:** 2.501cm **Posterior UCL:** 0.700cm **Percent Elongation:** **Ant. UCL:** 6.00% **RCL:** 1.50% **Annular Ligament:** 1.63% **Transverse+Posterior UCL:** 0% (0.001cm can be considered negligible)

45° with no rotation	**Anterior UCL:** Moderate elongation with light fraying. **Posterior and Transverse UCL:** No noticeable change. **RCL:** Slight stress with a minor microtear near its humeral origin. **Annular Ligament:** Begins to show a little tension and elongation.	**Anterior UCL:** 4.230cm **RCL:** 3.090cm **Annular Ligament:** 9.451cm **Transverse UCL:** 2.501cm **Posterior UCL:** 0.700cm **Percent Elongation:** **Ant. UCL:** 8.46% **RCL:** 3.00% **Annular Ligament:** 2.72% **Transverse+Posterior UCL:** 0% (0.001cm can be considered negligible)
45° with pronation	**Anterior UCL:** Clear plastic deformation with pronounced elongation and several small microtears near its ulnar insertion. **Posterior and Transverse UCL:** Moderate tension with slight elongation. **RCL:** Increased tension and minor plastic deformation at the lateral epicondyle, with occasional microtears. **Annular Ligament:** Moderate elongation with slight fiber disruption.	**Anterior UCL:** 4.375cm **RCL:** 3.165cm **Annular Ligament:** 9.650cm **Transverse UCL:** 2.535cm **Posterior UCL:** 0.703cm **Percent Elongation:** **Ant. UCL:** 12.18% **RCL:** 5.50% **Annular Ligament:** 4.89% **Transverse UCL:** 1.40% **Posterior UCL:** 4.29%
75° with no rotation	**Anterior UCL:** Marked elongation with multiple microtears. **Posterior and Transverse UCL:** Moderate microtearing—both bundles indicate significant valgus stress. **RCL:** Moderate tension with slight microtearing at the lateral epicondyle. **Annular Ligament:** Noticeable elongation and mild strain with some fiber separation.	**Anterior UCL:** 4.485cm **RCL:** 3.210cm **Annular Ligament:** 9.850cm **Transverse UCL:** 2.560cm **Posterior UCL:** 0.740cm **Percent Elongation:** **Ant. UCL:** 15.00% **RCL:** 7.00% **Annular Ligament:** 7.07% **Transverse UCL:** 2.40% **Posterior UCL:** 5.71%
75° with pronation	**Anterior UCL:** Severe elongation with extensive plastic deformation	**Anterior UCL:** 5.050cm **RCL:** 3.300cm

	and partial tearing, accompanied by prominent fraying along its medial border. **Posterior and Transverse UCL:** Significant elongation with moderate microtears. **RCL:** Notable microtearing and increased tension at its humeral attachment. **Annular Ligament:** Severe strain with clear microtears encircling the radial head.	**Annular Ligament:** 10.00cm **Transverse UCL:** 2.575cm **Posterior UCL:** 0.770cm **Percent Elongation:** **Ant. UCL:** 29.49% **RCL:** 10.00% **Annular Ligament:** 8.70% **Transverse UCL:** 3.00% **Posterior UCL:** 10.00%

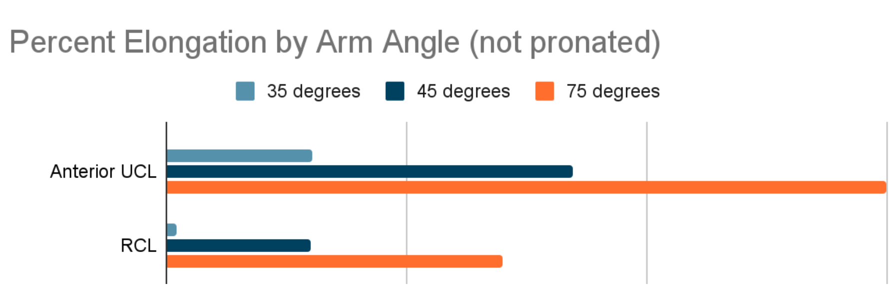
4. Results

The data collected from this experiment demonstrates clear trends in ligament strain across different throwing angles and forearm pronation conditions. As the throwing angle increased, strain on the anterior and posterior bundles of the UCL also increased, with the most significant damage occurring in the 75° pronated throw. Pronation amplified ligament stress across all angles, particularly affecting the anterior UCL, which exhibited the highest elongation—up to 29.49% at 75° with pronation—and microtearing. The posterior UCL showed moderate elongation, with up to 10.00% strain in the same condition. The radial collateral ligament (RCL) was less affected overall but showed minor to moderate elongation at higher angles and pronation, reaching 10.00% elongation at 75° pronation. The annular ligament displayed noticeable strain at extreme angles, especially with pronation, showing elongations as high as 8.70% and slight fiber separation.

A distinct pattern emerged indicating that valgus stress became more pronounced with increasing throwing angle. The anterior UCL consistently showed the highest degree of elongation and microtearing, suggesting it is the most vulnerable ligament under high-stress throwing conditions. By contrast, the transverse UCL remained largely unaffected across all trials, with minimal elongation (maximum of only 3.00% at 75° pronation), reinforcing its limited role in resisting valgus forces during throwing motions. These quantitative findings support the biomechanical risk hypothesis, confirming that high-angle, pronated throws impose the greatest strain on elbow ligaments.

4.1. Discussion

The results support the hypothesis that a sidearm throw (75°) with pronation results in the most significant ligament strain. The increased valgus force at higher throwing angles led to greater UCL elongation and microtearing, particularly in the anterior bundle, which is the primary stabilizer against such forces. Pronation further



amplified this stress, as the forearm's inward rotation created an additional destabilizing force, leading to even more pronounced ligament stretching and damage.

Figure 4. Percent Elongation by Arm Angle (not pronated)

Some limitations must be acknowledged in this study. Manual control of the throwing force introduced variability, which could have slightly influenced results. The use of rubber bands as ligament substitutes, while useful for mimicking tensile properties, does not perfectly replicate the viscoelastic behavior of real human ligaments. Additionally, the absence of muscle and tendon involvement in the model means that real-world biomechanical factors, such as muscular stabilization, were not accounted for. An unexpected finding was the strain observed in the RCL at higher throwing angles, particularly with pronation. Although the RCL is not the primary ligament resisting valgus forces, its involvement suggests that lateral elbow structures may also experience stress under throwing conditions.

The results align with existing research in sports medicine and biomechanics. Previous studies have shown that sidearm and pronated throws increase valgus stress, contributing to a higher risk of UCL injuries. Real-world data from baseball players also supports this, as sidearm pitchers have a higher prevalence of UCL injuries compared to overhead throwers. Additionally, biomechanical studies confirm that the anterior UCL is the primary stabilizer against valgus stress, which explains why it was the most affected ligament in this experiment. These findings reinforce the importance of proper throwing mechanics in reducing injury risk.

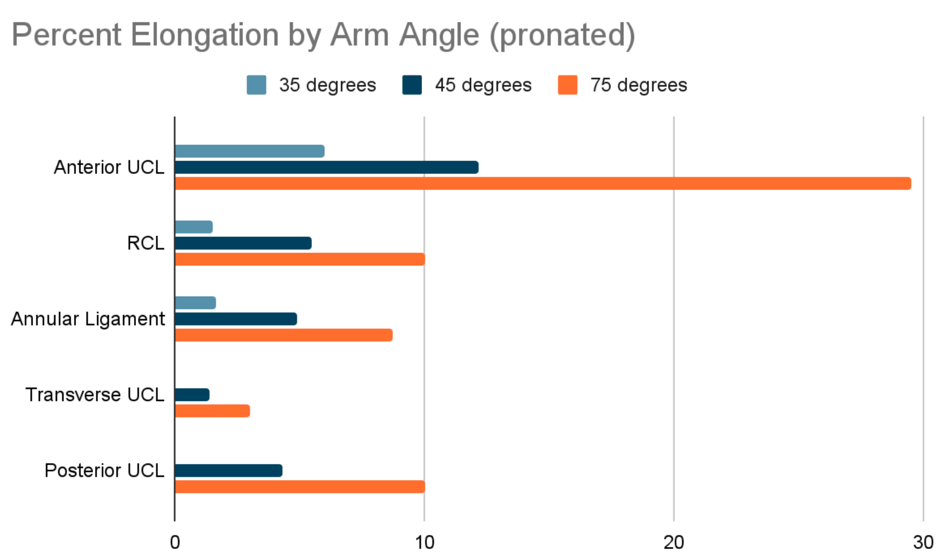


Figure 5. Percent Elongation by Arm Angle

4.2. Conclusion

This study confirmed that the combination of a sidearm (75°) throw with pronation caused the most significant ligament strain, particularly in the anterior UCL, which showed elongation as high as 29.49%. Pronation significantly increased ligament stress across all angles, while lower-angle throws (35° and 45°) produced less strain and minimal damage to ligament structures. The RCL and annular ligament experienced moderate strain, but the main areas affected were the UCL ligaments. These findings strongly support the hypothesis and highlight the increased risk of ligament injury associated with high-angle, pronated throws. This arm angle and style is closely associated with breaking balls, like sliders and curveballs. This is one of the reasons that those pitches aren't relied on that heavily in the modern baseball world. Instead, pitchers rely on fastballs and changeups partly because they can control them better since there's no need for pronation in the arm and they don't move unpredictably, but also since it puts less stress on their arm and elbow.

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