Title: The Effect of Repetitive Baseball Pitching on Medial Elbow Joint Space Gapping Associated with Two Elbow Valgus Stressors in High School Baseball Players

Running-title: Medial Elbow Under Two Valgus Stressors

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IRB/Ethical Committee Approval:

This study followed the Declaration of Helsinki and was approved by the Ethics Committee at the Saitama Medical University, Saitama, Japan (M-66).

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ABSTRACT

Background: In order to prevent elbow injury for baseball players, various methods have been used to measure medial elbow joint stability with valgus stress. However, no studies have investigated higher levels of elbow valgus stress. The purpose of our study was to investigate medial elbow joint space gapping measured ultrasonically resulting from a 30 N valgus stress compared to gravitational valgus stress with a repetitive throwing task.

Methods: 25 high school baseball players participated in this study. Each subject pitched 100 times. The ulnohumeral joint space was measured ultrasonically prior to pitching and after each successive 20 pitch block with either gravity stress or 30 N valgus stress. 2-way repeated measures ANOVA and Pearson correlation coefficient analysis were used for this study.

Results: 30 N valgus stress produced significantly greater ulnohumeral joint space gapping than gravity stress prior to pitching, and at each successive 20 pitch block ~~($p<.01$)~~. For both the two stress methods, ulnohumeral joint space gapping increased significantly from baseline after 60 pitches ~~($p<.01$)~~. There were strong significant correlations ~~between the two methods for measurement of medial elbow joint space gapping~~ between the two stress methods ($p<.001$, $r=0.727$-0.859).

Conclusions: Gravity stress and 30 N valgus stress may produce different effects with respect to medial elbow joint space gapping; however, 30 N valgus stress appears to induce greater mechanical stress, which may be preferable when assessing joint instability, but at the same time has the potential to be more aggressive. The present results may indicate that constraining factors to medial elbow joint valgus stress matched typical viscoelastic properties of cyclic creep.

Level of evidence: Level Ⅰ, Diagnostic Study

Keywords: elbow; baseball; ultrasound; medial elbow joint space gapping; repetitive pitching; valgus stress

INTRODUCTION

Baseball players risk medial elbow injury from extreme valgus stress generated across the elbow joint due to repetitive throwing.[9,13,14,33] Injury occurs due to valgus stress inducing large tensile stress on medial elbow soft tissues.[14] Previous studies have demonstrated asymmetry and long-standing changes in medial elbow joint space gapping in baseball pitchers.[7,8,12,17,28,30,31] According to a previous study of high school baseball players, pitching more than 60 times in a session caused increased medial elbow joint space gapping, with consequent increased burden on the medial elbow joint and associated tissues.[20] This study identified that medial elbow joint space gapping is increased with repetitive throwing but more detailed information is required.

Quantitative methods of assessment of medial elbow joint space gapping include the Valgus stress test using a Telos device and the gravitational effect of forearm weight inducing valgus stress at the elbow.[7,8,12,17,19,20,28,30,31] The Telos device has been widely used as a quantitative tool to assess medial elbow joint space gapping in baseball players, possibly due to the uniform condition in which elbow valgus stress can be applied.[7,8,12,31] Gravitational stress has the advantage of being able to induce joint space gapping without special equipment, again with uniform force, which has been widely used as a quantitative tool to assess medial elbow joint space gapping in baseball players.[17,19,20,30] Harada reported that both gravitational stress and the Telos device seem useful for assessment of medial elbow joint space gapping,[17] but not studies have investigated whether a stronger valgus stress would provide better data than simple gravity.

We hypothesized that more accurate data on medial elbow joint space gapping would be obtained if near maximum valgus stress is applied to gap the medial elbow joint. While the Telos device and gravity stress have been mainly used in the past as measurement methods of medial elbow joint space gapping, no report has investigated quantitatively near maximum valgus stress on medial elbow joint space gapping.

The purpose of this study was to investigate the effect of a repetitive baseball pitching task on medial elbow joint space gapping and viscoelastic properties of medial elbow joint structures induced by either 30 N valgus stress or gravity valgus stress. If more accurate data can be obtained by applying a 30 N valgus stress, it can be used as a reliable measurement method of medial elbow joint space gapping and potential medial elbow laxity. This may help develop better understanding of how to prevent elbow injury in baseball pitchers.

MATERIALS AND METHODS

Participants

This is a controlled laboratory study of investigating medial elbow joint space gapping measured ultrasonically resulting from a 30 N valgus stress compared to gravitational valgus stress with a repetitive throwing task. 25 healthy high school baseball players (mean ± SD: age, 16.6±0.7 years; height, 172.6±6.3 cm; weight, 66.1±7.1 kg; years of baseball experience, 8.8±1.9 years) volunteered to participate in this study. Participants were excluded from the study if (1) they had pain during throwing action, (2) they had a history of orthopedic shoulder, elbow or hand surgery, or (3) they had pitched in the 24 hours prior to measurement. All participants agreed to sign an informed consent declaration. This study followed the Declaration of Helsinki and was approved by the Ethics Committee at the Saitama Medical University, Saitama, Japan (M-66).

Setup and Protocol

The throwing protocol was reported in a previous study.[20] Measurement commenced after performing a preparation routine of stretching and warm-up throwing. The pitching protocol consisted of 100 fastball (20 sets of 5 pitches at ball intervals of

15 seconds at maximum effort) from the set position towards the simulated strike zone. The official baseball (MIZUNO Co., Ltd., Japan; weight 141.7-148.8g) was used during the pitching protocol. We calculated the average ball velocity for the first 20 pitches and subsequent throws that were 70% less than this value were not included.

Measurements

The ulnohumeral joint space was measured ultrasonically (Aloka Co., Ltd, Tokyo, Japan) before pitching and after every 20 pitches with the application of two different elbow valgus stresses; under gravity stress or 30 N valgus stress. Ultrasound imaging of the medial aspect of the throwing elbow was performed with the use of a 10-MHz annular array transducer. Grip strength was also measured before pitching and after 100 pitches.

Gravity stress was applied to the forearm, to strain the medial aspect of the elbow, and to assess medial elbow joint space gapping. Gravity stress used in this study has been reported as being useful in the assessment of medial elbow joint space gapping, and is similar to measurements taken when using the commonly used Telos device.[17] Participants were placed supine on the bed with the shoulder in 90˚ abduction, 0˚ horizontal abduction, with the elbow in 90˚ flexion, and the forearm in neutral position. The elbow joint lay off the out of the bed.[17,19,20,27,30] A towel roll and a digital inclinometer were used to maintain the humerus in the horizontal plane (Fig. 1A).

30 N valgus stress was applied to the ulnar styloid process at the wrist, to strain the medial aspect of the elbow, and to assess medial elbow joint space gapping. 30 N valgus stress was applied by a separate independent examiner using a dynamometer (3050 Aikoh Engineering Co., Ltd, Japan). Participants were placed supine on the bed with the shoulder in 90˚ abduction, 0˚ horizontal abduction, with the elbow in 30˚ flexion, and the forearm in supinated position. Elbow flexion was set to 30˚ to ensure that external rotation of the shoulder joint did not occur when applying valgus stress to the elbow joint. The elbow joint lay off the out of the bed. A towel roll and a digital inclinometer were used to maintain the humerus in the horizontal plane (Fig. 1B).

No participant experienced elbow pain during the examination. The time taken for all measurements was less than 5 minutes in total. The ultrasound transducer was placed on the medial aspect of the elbow in such a position that ultrasound imaging included both the top of the medial epicondyle of humerus and the medial tubercular portion of the ulnar coronoid process.[20] The degree of medial elbow joint space gapping was assessed by measuring ulnohumeral joint space between the distal-medial corner of the trochlea of humerus and the proximal edge of the medial tubercular portion of the ulnar coronoid process. The distance of the two points (the distal-medial corner of the trochlea of humerus and the proximal edge of the medial tubercular portion of the coronoid process of ulnar) on the image was measured by using the ultrasound distance measurement method (minimum unit 0.1mm). The mean of 3 trials was used for data analysis.

Grip strength of the throwing arm was measured using a grip strength tester (GRIP-D T.K.K.5401 Takei Scientific Instruments Co., Ltd, Niigata, Japan) before pitching and after 100 pitches. The mean of 3 trials was used for data analysis.

Statistical Analysis

All data was analyzed with SPSS Statistics version 22.0 (IBM Co., Japan). 2-way repeated measures of ANOVA and post hoc tests were used to compare medial elbow joint space between 6 pitching sets (before pitching, 20 pitches, 40 pitches, 60 pitches, 80 pitches, and 100 pitches) and 2 measurement methods (gravity stress vs 30 N valgus stress). The correlation between gravity and 30 N valgus stress in terms of medial elbow joint space gapping at every 20 pitch blocks was also analyzed. Paired t test was used to compare grip strength prior to pitching and after 100 pitches. Significant differences were set at a level of 0.05.

RESULTS

Descriptive statistics for average ball velocity of the entire pitch protocol is shown in Table 1. The average ball velocity of each 20 pitch block was roughly 28 m/s.

Descriptive statistics for medial elbow joint space gapping is shown in Table 2. There was a significant stress condition-pitching count interaction for the medial elbow joint space. Under gravity stress ~~(p<0.01)~~ (p=.007, .001, <.001 after 60, 80, 100 pitches, respectively) and 30 N valgus stress ~~(p<0.01)~~ (p=.005, <.001, <.001 after 60, 80, 100 pitches, respectively), medial elbow joint space gapping significantly increased after 60 pitches when compared with baseline. When comparing the 2 measurement methods, medial elbow joint space gapping under 30 N valgus stress were significantly greater than that found under gravity stress at all 20 pitch blocks ~~(p<0.01)~~ (p=.015, .002, .008, .016, .018, .007 before pitching and after 20, 40, 60, 80, 100 pitches, respectively).

The correlation coefficient for the medial elbow joint space gapping between the 2 measurement methods is shown in Figure 2. There were strong significant correlations between medial elbow joint space induced by different elbow stresses (~~p<0.01~~ p<.001, r=0.727-0.859).

Grip strength significantly decreased after 100 pitches compared with prior to pitching (mean±SD [kg]: prior to pitching; 40.0±5.5, after 100 pitches; 39.2±5.6; ~~$p<0.05$~~ $p=.037$).

DISCUSSION

Medial elbow joint space gapping and medial elbow injury have been reported at all ages from Pony and Little League to Collegiate Pitchers in the United States and Japan.[2,15,26,31] Harada et al. conducted ultrasound imaging to investigate elbow injuries for 294 baseball players (aged 9-12 years old) and showed that 60 baseball players had elbow injuries, including medial epicondylar fragmentation in 58 baseball players and osteochondritis dissecans of the capitellum in 2 baseball players.[18] Meanwhile, Hang et al. revealed that 52 percent of baseball pitchers in their study had medial elbow pain, and 57 percent had separation of the medial epicondyle.[16] These reports, indicate a high prevalence of elbow injuries among adolescent baseball players, which indicates the urgency for the development of elbow injury preventative methods in baseball.

In this study, we measured medial elbow joint space gapping using ultrasound imaging as an evaluation of the medial elbow joint. Several studies have used this method of measuring the medial elbow joint space in the past.[8,20,28] In addition, Bica et al. showed that medial elbow stress sonography is a reliable and precise method for detecting changes in ulnohumeral joint space gapping.[6] In addition, we compared medial elbow joint space gapping before and after 100 pitches in the throwers with and without an elbow brace in 2017.[20] In that crossover design study with 1 week washout period, there was no significant difference in medial elbow joint space gapping before pitching in the 2 groups, and it is clear that medial elbow joint space gapping increases as the number of throws increase.

The current study found that gravity stress or 30 N valgus stress similarly induced medial elbow joint space gapping after 60 pitches when compared to baseline measures. In addition, a strong significant correlation was between medial elbow joint gapping induced by both methods of valgus stress. Prior to data collection we hypothesized that a stronger valgus force would induce greater change in medial elbow joint space gapping compared to gravity stress. Surprisingly, both valgus stresses provided almost the same ratio when comparing rate of change in medial elbow joint space gapping. Therefore, we report that both measurement methods can be used in elbow evaluation.

Although the results for medial elbow joint space gapping induced by both measurement methods showed the same rate change over increasing pitch count, gapping induced by 30 N valgus stress was significantly greater than gravity stress after each block of 20 pitches. Clearly 30 N valgus stress has a greater mechanical stress on the medial elbow joint than gravity stress. Consequently, the soft tissues around the medial elbow joint are likely to be stretched more by 30 N valgus stress than gravity stress. This might need to be taken into consideration when undertaking serial assessment of the elbow in baseball pitchers. The testing process itself might have a deleterious effect on the elbow.

Repetitive or excessive tensile stress can overload ligament and other soft tissues causing inflammation and/or microscopic tears which may eventually lead to ligament attenuation or failure.[5,9,23] The throwing motion causes a valgus stress of about 50-120 Nm on the elbow joint during the late cocking and acceleration phases.[3,13,33] A previous anatomical study reported that the elbow ligaments and elbow muscles resist 47% and 41% respectively of external stress on the elbow joint during throwing.[24] It is therefore conceivable that a tensile stress of 23.5-56.4 Nm (47% of 50-120 Nm) is generated in the UCL during the pitching motion. A previous study reported that a load of 34.0±6.9 Nm led to failure of the UCL in cadaveric elbows, albeit of average age of 43 years.[4] It is therefore conceivable that the tensile stress on the UCL is close to the failure level of the UCL, and this occurs repeatedly during throwing. It seems reasonable to suggest that this places the thrower at high risk of UCL degeneration and tearing. Therefore, in order to prevent medial elbow joint injury, it is necessary to understand the viscoelastic properties of tendon, ligament, and other soft tissues around the medial elbow joint, and the relationship to medial elbow joint space gapping.

Ligaments and tendons have viscoelastic properties, characterized by; (1) the stress-strain curve,[10] (2) creep,[10] (3) cyclic creep,[10] (4) stress relaxation,[1] (5) cyclic stress relaxation.[1] In our results, medial elbow joint space gapping gradually increased as the number of pitches increased. Therefore, it is conceivable that results of our study demonstrate characteristics of cyclic creep. In addition, medial elbow joint space gapping at 30 N valgus stress was significantly greater than that with gravity stress at blocks of 20 pitches. Furthermore, a strong significant correlation was found between elbow joint gapping induced by both valgus stresses. Therefore, these results may be consistent with typical soft tissue stress-strain curve characteristics.

The anterior bundle of the UCL has been reported to fail at a strain of 23.6±0.9 %.[21] In our study, the increase in ratio of the medial elbow joint space gapping from first to last pitch was 25 %. As medial elbow joint space gapping increased more than the strain rate to failure for the UCL, it is likely that medial elbow joint space gapping is determined by factors other than the UCL, and will be influenced by other soft tissues such as elbow muscles and tendons.

Otoshi et al. and Udall et al. reported that medial elbow joint space gapping is controlled by the forearm flexor and pronator muscles.[29,32] Furthermore, DiGiovine reported that these muscles were active during the late cocking-acceleration phase of throwing.[11] It is believed that these muscles work to control elbow valgus stress during throwing. In our study, grip strength after 100 pitches decreased significantly compared to baseline. This potentially indicates a level of muscle fatigue with repeated pitching, which be a contributing factor to increase medial elbow joint space gapping. In this study, the number of pitches was set to 100. But if the number of pitches were to increase further, then cyclic creep and fatigue of the forearm flexor and pronator muscles will increase. It is assumed that further increase in medial elbow joint space gapping occurs, which may lead to medial elbow joint injury.

In order to prevent medial elbow injury it is important to minimize medial elbow joint space gapping. We propose the following methods may be considered. First, limiting pitching count or volume in training or during a game. A previous study showed that medial elbow joint space gapping increases after 60 pitches in high school baseball players, and it would appear that this is the point that is likely to induce damage to the elbow. Although pitching limits have been set in both Japan and the United States for adolescents as a means of preventing elbow injury (100 pitches for high school students),[22,25] based on the results of our study, this might be too much to prevent injury. Secondly, fatigue of the forearm flexor and pronator muscles is considered an important factor in injury development from repetitive pitching. Increasing endurance of these muscle may reduce the burden on the UCL, ultimately preventing medial elbow gapping. A final consideration is the use of an elbow brace during pitching. A previous study has reported that the use of an elbow brace prevents an increase in medial elbow joint space gapping with repetitive pitching.[20] A brace may be an effective method for preventing medial elbow joint injury.

There are a number of limitations to this study. First, the baseball players in our study were in a narrow age range (16.6±0.7 years old). Future studies should investigate a wider age range. Secondly, we observed the medial elbow joint space to a maximum of 100 pitches. This was based on ethical consideration with the potential for harm to the participants. Changes to medial elbow joint space with pitch count greater than 100 are unknown. Finally, the present study measured joint space gapping at 30˚ elbow flexion, which may not be ideal when comparing results with other studies that measured gapping at 90˚ elbow flexion. In our case, it was not possible to measure gapping at 90˚ as the addition of 30 N valgus stress applied to the forearm causes external rotation of the shoulder joint. This did not occur when valgus stress was applied at 30˚ flexion. We confirmed the accuracy of measuring joint space gapping at 30˚ elbow flexion in a pre-experimental phase.

CONCLUSION

We measured ultrasonically the medial elbow joint space gap induced by 30 N valgus and gravity valgus stress. The results indicate that both stresses induce similar results in terms of the rate of change medial elbow joint space gapping, although 30 N valgus stress caused more gapping than gravity stress at all successive blocks of 20 pitches. However, 30 N valgus stress appears to have a greater mechanical stress on the elbow and therefore better able to assess joint instability, but at the same time has the potential to be more aggressive. Based on an understanding of the viscoelastic properties of ligaments and tendons, it would be logical to suggest that the medial elbow joint restraints undergo tissue changes including cyclic creep. If the number of pitches continues to increase further, cyclic creep of medial elbow joint and fatigue of the forearm flexor and pronator muscles may lead to medial elbow joint injury. These factors need to be considered in developing injury prevention programs.

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Figure and Table Legends

Figure 1

Ultrasound imaging of the medial aspect of the throwing elbow was performed with the use of a 10-MHz annular array transducer. (A) Gravity stress, (B) 30 N valgus stress. Elbow stress was applied to induce strain of the medial aspect of the elbow, and to assess medial elbow joint space gapping.

Figure 2

The correlation coefficient for the medial elbow joint space gapping every 20 pitches between gravity stress and 30 N valgus stress (N=25). Strong significant correlations were found at all pitching blocks ($p<.01$).

Table Ⅰ: Average ball velocity at intervals of 20 pitches. (N=25)[a]

[a]Data are expressed as mean ± SD.

For average ball velocity every 20 pitches, there was no significant difference between baseline and at intervals of 20 pitches.

Table Ⅰ

Average ball velocity at intervals of 20 pitches. (N=25)[a]

	1-20 pitches	21-40 pitches	41-60 pitches	61-80
Average ball velocity (m/s)	28.4±2.3	28.6±2.4	28.6±2.3	28.5

[a]Data are expressed as mean ± SD.

For average ball velocity every 20 pitches, there was no significant difference between baseline and at int

Table Ⅱ : Comparison of ulnohumeral joint space gapping induced by gravity stress and 30N valgus stress prior to pitching and at intervals of 20 pitches. (N=25)[a]

[a]Data are expressed as mean ± SD.

[b]ulnohumeral joint space gapping between stress methods

Table Ⅱ

Comparison of ulnohumeral joint space gapping induced by gravity stress and 30N valgus stress prior

pitches. (N=25)[a]

	before pitching	20 pitches	40 pitches	60 pitches
Ulnohumeral joint space				
Gravity stress (mm)	5.0±0.9	5.2±0.9	5.5±0.8	5.8±0.9
p value (vs before pitching)	-	.808	.150	.007
Rate of change (%)	100	105.5±6.7	112.0±9.6	118.1±8.3
30 N valgus stress (mm)	5.6±0.9	6.0±0.8	6.2±0.8	6.4±0.8
p value (vs before pitching)	-	.361	.086	.005
Rate of change (%)	100	107.8±8.6	111.0±8.3	115.7±9.1
p value[b]	.015	.002	.008	.016

[a]Data are expressed as mean ± SD.

[b]ulnohumeral joint space gapping between stress methods

Figure 1

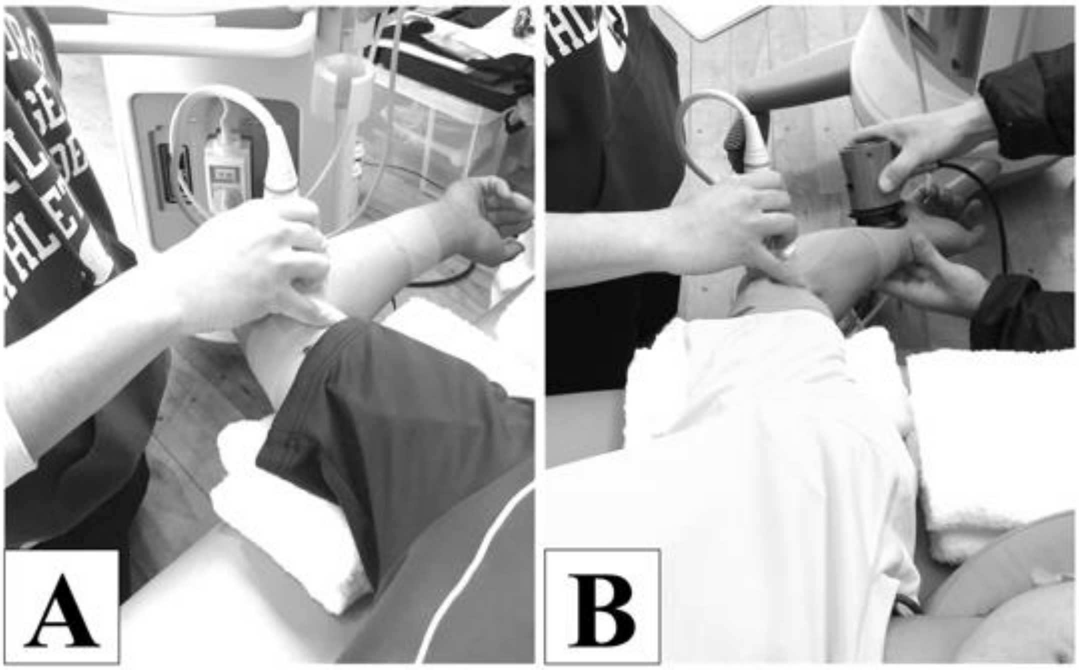
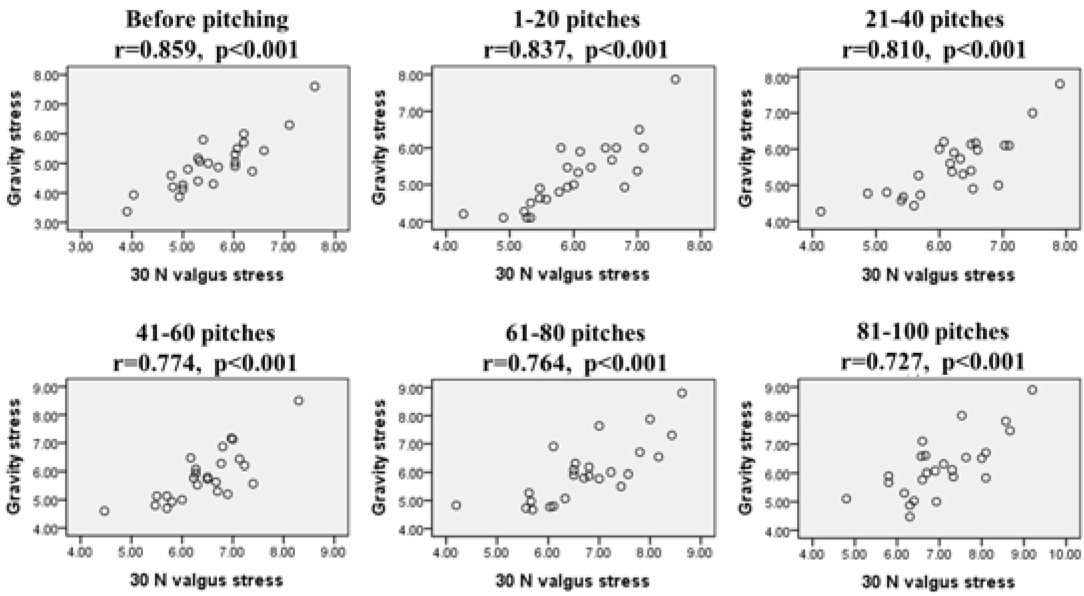

A
B

Figure 2


Before pitching
r=0.859, p<0.001
1-20 pitches
r=0.837, p<0.001
21-40 pitches
r=0.810, p<0.001
41-60 pitches
r=0.774, p<0.001
61-80 pitches
r=0.764, p<0.001
81-100 pitches
r=0.727, p<0.001
Gravity stress
30 N valgus stress