Summer 8-31-2020

Tommy John Surgery: Potential Risk Factors and Causes in Major League Pitchers

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Capstone: ECF 880 – W1

08/09/2020

Abstract

Since 1974, over 270 Tommy John surgeries have been performed on pitchers at the major league level. Thousands more surgeries have been performed on minor league, college, high school and youth pitchers. As more biomechanical and statistical research has been conducted over the past few decades, a clearer picture of some of the risks and causes that lead to serious elbow injuries in pitchers have been found. This paper explores the research surrounding several of those factors, including pitching mechanics, pitch velocity, and pitch type. Using a data set comprised of major league pitchers that have undergone Tommy John surgery between 2008 and 2018, a significant difference in velocity was seen between the Tommy John group and a control group of pitchers. No major differences in pitch type or spin rate were seen between the groups.

Acknowledgements

A special thank you to Dr. Timothy Highley, for his guidance on this project. Also, thank you to Professor Margaret McCoey, for her guidance through my two years in the Analytics program.

Ulnar Collateral Ligament Reconstruction, colloquially known as Tommy John Surgery, was first performed on its namesake, Tommy John, in 1974. Having already pitched 11 years in the major leagues, John exited a game in July of 1974 while pitching for the Los Angeles Dodgers after experiencing pain in his left elbow (Passan, J., 2016). X-Ray imaging revealed a torn Ulnar Collateral Ligament (Passan, J., 2016). After resting for a few weeks and trying ice and anti-inflammatory medication, John tried to return to the mound, but kept experiencing the same pain that caused him to leave the game a month earlier. A 31 year-old pitcher in 1974 did not have many options when it came to surgical intervention for the type of elbow injury John had sustained. Dr. Frank Jobe, an orthopedic surgeon and Dodgers' team doctor, came up with an idea of a theoretical procedure that could be performed (Passan, J., 2016). A technique used in the ankles of patients with Polio, in which the palmaris longus tendon from the wrist was removed and transferred to the ankle joint, provided Dr. Jobe with the basis for what he would try on John's elbow (Passan, J., 2016). The surgery was performed in September of 1974, and after months of improvised rehabilitation and bullpen sessions, John returned to a major league mound in May of 1976 (Passan, J., 2016). He would go on to pitch another 14 seasons in the major leagues, before retiring in 1989 at the age of 46. Although common in baseball today, performance can decline after undergoing the surgery. Pitching mechanics, pitch velocity, and pitch type are all factors that can contribute to increased stress on the elbow joint during the throwing motion. Identifying factors that may put pitchers at risk could help provide a blueprint to avoid surgery and the lengthy rehab process that follows. Figure 1 below shows the number of Tommy John Surgeries per year since the first one was performed in 1974.

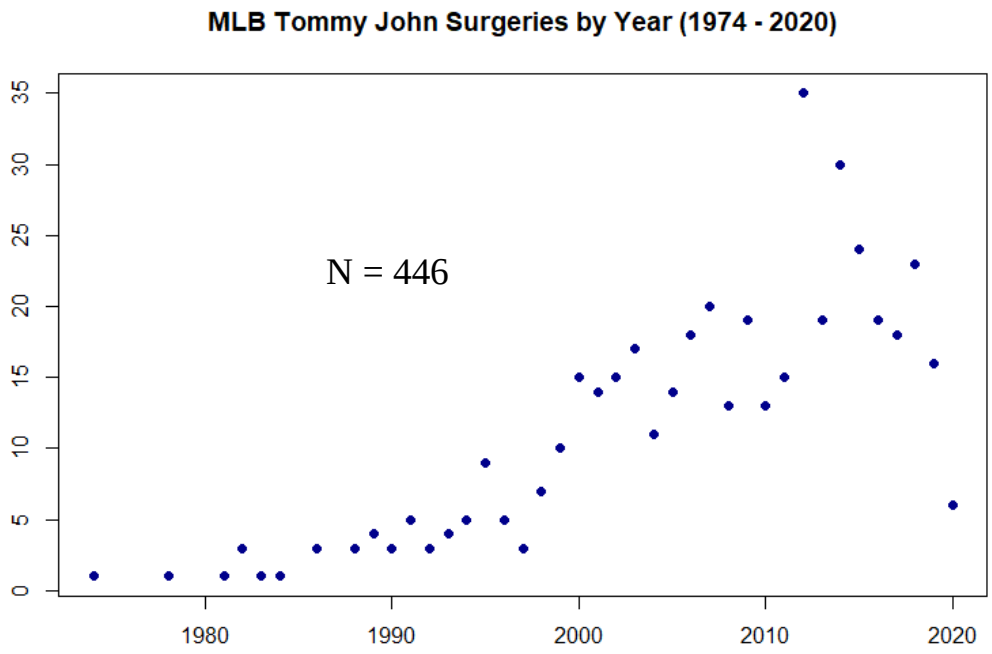

Figure 1 - Tommy John Surgeries by year

Major League Baseball pitchers make thousands of throws throughout the course of a season. A pitcher's shoulder, elbow, core muscles, and lower body all move in a synchronized fashion to enable peak velocity and performance. Not all players have the same throwing mechanics, and subtle differences in the pitching motion place stress on different parts of the kinetic chain. The pitching motion has generally been divided into 6 phases. The first phase, the windup, is the start of the motion until a 'balanced position' is achieved (Escamilla, R. F., et al., 2007). The next phase, the stride, occurs between the end of the balanced position phase and the contact of the lead foot (left foot for a right-handed pitcher) to the ground. Once the lead foot makes contact with the ground, the 'arm cocking' phase begins. In this phase, the maximum amount of shoulder external rotation is achieved (Escamilla, R. F., et al., 2007). Phase 4 then follows, and occurs from the moment of maximum external rotation to when the ball is released from the pitcher's hand. Phase 5 is the 'arm deceleration' phase, which occurs from the point when the pitcher releases the ball until the shoulder is internally rotated to its highest degree

(Escamilla, R. F., et al., 2007). The final phase of the pitching motion happens from the point of maximum internal shoulder rotation until the pitcher comes to a stop.

Pitching Mechanics

Stress on the elbow joint at various parts of the pitching motion has been studied for several years. Aguinaldo and Chambers (2009) found that torque placed on the elbow during the throwing motion is significantly affected by a combination of factors, including external shoulder rotation, flexion of the elbow, and trunk rotation. Higher elbow flexion when the ball is released decreased the amount of torque on the elbow. Trunk rotation after foot contact also 'appeared' to have less elbow valgus torque. Sidearm deliveries also exhibited higher elbow valgus loads than pitchers that threw from a ¾ arm slot (Aguinaldo & Chambers, 2009). The study by Aguinaldo and Chambers (2009) pointed to two main factors that could have contributed to that finding: 1. A sidearm delivery has a lower shoulder abduction angle. For example, if you are standing with your arms at your sides and raise them up into a 'T' position, your shoulders are at a 90 degree abduction angle. This is in the range of where a sidearm thrower releases the ball, whereas a ¾ arm slot is generally in the 120 degree range (closer to your head). 2. Sidearm deliveries tend to have later trunk rotation, creating more of a slingshot type of throwing action.

Camp et al. (2017) built upon Aguinaldo and Chambers (2009) work to study the relationship between elbow varus torque, the slot of a pitcher's arm before release, and the rotation of the throwing arm. The study included players from the major and minor leagues. Each player wore a sleeve on their throwing arm that measured torque throughout the pitching motion (Camp, C.L et al., 2017). One difference between this study and previous studies on the forces

affecting the elbow during throwing is that all throws were measured. Warm-up throws, long-toss, and throws from the pitcher's mound were all recorded in Camp's study.

The results of the study confirmed the hypothesis points that increases in arm speed and arm rotation were correlated with higher elbow varus torque. However, the hypothesis that a lower arm slot would have little effect on elbow varus torque was rejected. The increases in both arm speed and arm rotation resulted in an increase in elbow varus torque on the throwing arm (Camp, C.L, et al., 2017). Arm speed was described as '…the maximal rotational velocity of the forearm during the throwing motion' (Camp, C.L, et al., 2017). Arm speed is achieved from the point of maximum external rotation until the ball is released. Arm rotation is measured as the maximum external rotation of the arm during the 'cocking' phase of the pitching motion. Like Aguinaldo's study, Camp also discovered a correlation between torque on the elbow and a decrease in arm slot (Camp, C.L et al., 2017).

Whereas Aguinaldo's research found correlation between 6 points in the pitching motion and elbow valgus torque, Anz, Bushnell et al. (2010) focused on two main topics: elbow valgus torque and shoulder external rotation. Anz defined the steps in the pitching motion differently than Escamilla did in his study. For Anz's research, the pitching motion was broken down into 3 steps:

- Time between lead foot contact and maximum shoulder external rotation.
- Phase between maximum external rotation and the release of the ball
- Moment after the release of the ball and the maximum point of internal shoulder rotation.

Similar to previous studies on the subject, Anz et al. (2010) found higher levels of elbow valgus torque and external shoulder rotation, specifically during the cocking phase of the pitching

motion (Anz, A. et al., 2010). These results were not too surprising, considering the previous research that had shown a correlation between external shoulder rotation and higher velocity throws (Seroyer, S.T, et al., 2010). This poses a potential problem for professional pitchers, as generating high velocity is needed to get major league hitters out and perform at a high level. However, identifying players that have higher shoulder external rotation and elbow valgus load metrics could be beneficial in helping to prevent injury. Slight changes in pitching mechanics under the guidance of professional coaches and team medical personnel could reduce some of the risk of elbow injury risk associated with high-velocity pitching at the major league level. These subtle changes could also help mitigate any potential loss in velocity.

Velocity

Due to the high speeds at which pitches are thrown at the professional level, one area that has undergone increased analysis in the last decade is the effect of pitch velocity on pitcher health. Bushnell et al. (2010) studied this association by taking velocity readings from 23 pitchers and following the players over the course of 3 seasons to assess which players got injured. Of the 23 that were studied, 14 of them did not sustain an elbow injury. Other injuries, such as groin pulls and shoulder injuries were not accounted for in the study. The results indicated that players throwing at higher peak velocities are more prone to elbow injury (Bushnell, B.D. et al., 2010). The mean velocity of pitchers in the non-injured group was 85 mph, while the mean velocity of the 9 pitchers who wound up in the injured group was 89.22 mph (Bushnell B.D. et al., 2010). It should be noted that players who sustained shoulder injuries over the course of the study, which can also result from repetitive overhead throwing, were not included in the injured player group. Also of note in regards to Bushnell et al.'s (2010) analysis was the fact that spring training velocity readings were used, in lieu of regular-season, game-

action readings (Bushnell B.D. et al., 2010). Spring training may not have been the best place to obtain velocity readings, as pitchers are still building up their arm-strength and working on preparing for the season ahead. However, players are more concentrated and accessible in spring training, which allows for more analysis on a greater number of players.

Chalmers, Erickson, et al. (2016) also studied the effect of pitch velocity on elbow injuries in Major League Baseball (MLB) pitchers. Their study took into account far more subjects, 1,327, than Bushnell et al.'s (2010) study. Chalmers' group also accounted for more variables, including age, height, and pitch type (Chalmers, P., et al., 2016). The Chalmers study utilized 3 groups of MLB pitchers:

- Healthy pitchers.
- Pitchers that eventually underwent Tommy John Surgery
- Pitchers that already had Tommy John Surgery

Using both univariate and multivariate analysis techniques, pitch velocity was the main predictor for eventually undergoing Tommy John Surgery (Chalmers, P., et al., 2016). The Chalmers study, like Bushnell's, found that the peak mean velocity of pitchers that eventually underwent Tommy John surgery was higher than the healthy pitchers (93.3 mph to 92.1 mph, respectively) (Chalmers, P., et al., 2016). Interestingly, the multivariate analysis done in the study also found that peak, not mean velocity is the main driver behind Tommy John Surgery (Chalmers, P., et al., 2016).

Another study, by Slowik et al. (2019), also showed a positive correlation within a subject between throwing velocity and elbow-varus torque. Subjects in Slowik's study were fitted with motion-capture devices and observed while throwing 5 max effort pitches. Analysis was conducted between players in the study using normalized metrics to account for different

heights and weights between players (Slowik, J.S. et al., 2019). Between players in the study, only a weak relationship was evident when it came to torque on the elbow joint and the velocity of a pitch (Slowik, J.S. et al., 2019). This was an interesting finding, and one that has been shared in other studies, including the previously discussed one by Chalmers et al. (2019). One possible reason for the low correlation between players could be due to biomechanical differences between players.

However, a strong linear relationship ($R^2 = .957$) was found within players (Slowik, J.S. et al., 2019). The model used in Slowik's study proposed that an increase in pitch velocity of about 2.25 mph would equate to an increase of about 1.62 Newton-meters (Nm) of torque on the elbow (Slowik, J.S. et al., 2019). Slowik hypothesized that over the course of a season, pitchers would be wise to vary the velocity at which pitches are thrown to help reduce stress on the throwing arm.

Pitch Type

One way velocity can be varied is by throwing different types of pitches. Pitch type has become an important factor that has been discussed in regards to the increase in Tommy John surgery over the past several years. The fastball, curveball, slider, changeup, cut-fastball and split-finger fastball, among others, are all commonly thrown in a professional baseball environment. Not all of these pitches are thrown the same way, with finger pressure and wrist alignment varying from pitcher to pitcher based on feel. Escamilla, Fleisig et al. (2017) studied the mechanics of professional pitchers and the possible changes that the elbow and shoulder experience with different types of pitches.

The findings of the study were somewhat surprising when compared to traditional beliefs held by fans and coaches that breaking balls are more stressful pitches on the arm than the

fastball. Using high-speed cameras with markers placed in different areas on the upper and lower body, each of the 18 subjects in the study threw their full repertoire of pitches (Escamilla, R.F. et al, 2017). Like Aguinaldo's study discussed previously, the pitching motion was broken down into 6 steps:

- Windup
- Stride
- Arm cocking
- Arm acceleration
- Arm deceleration
- Follow-through

There were 2 phases that stood out during the comparison of pitch type; the arm cocking and arm deceleration phases. During the arm cocking step of the pitcher's delivery, elbow varus torque was found to be highest for fastballs and sliders (Escamilla, R.F. et al, 2017). For the shoulder measurements taken during the acceleration phase, results were more mixed between pitches. Horizontal adduction torque and anterior force were highest for curveballs and sliders (Escamilla, R.F. et al., 2017).

The other phase of the delivery that saw results of significance occurred during the arm deceleration phase. During that phase, flexor torques in the elbow were highest for fastballs and sliders compared to curveballs and changeups (Escamilla, R.F. et al, 2017). Proximal forces (those closest to the center of the body) on the elbow showed greater force when fastballs, sliders and curveballs were thrown (Escamilla, R.F. et a., 2017). Overall, conventional beliefs about pitch type did not hold up when compared in this study. Fastballs, curveballs, and sliders all

showed similar stresses on the arm. Compared to those three pitch types, the changeup showed the lowest injury risk (Escamilla, R.F. et al., 2017).

Taking velocity and pitch type analysis a step further, Prodromo et al. (2016) analyzed 114 cases of pitchers that underwent Tommy John surgery from 2003 to 2015. Pitch velocity and pitch type were studied in the year before surgery (2002) and compared with controls of similar age. More pitch types were compared in this study than in the previously mentioned study by Escamilla et al. (2017). Fastballs, curveballs, cut-fastballs, sliders, split-finger fastballs and changeups were all compared between the Tommy John recipients and the group of non-injured pitchers.

The results of the analysis showed similar percentages of pitch type between the two groups (Prodromo, J., et al. 2016). However, the group undergoing Tommy John surgery had higher pitch velocities for all pitch types (Prodromo, J. et al. 2016). These results are consistent with the findings mentioned previously by Bushnell et al. (2010), Chalmers, P., et al., (2016), and Slowik, J.S. et al., (2019). Prodromo et al. (2016) hypothesized that as average fastball velocity has increased over the years, from 89.9 mph in 2002 to 91.8 mph in 2014, the risk of injury to the throwing arm has also increased, placing an increased emphasis on doctors and trainers to help players return to their previous level of performance.

Return to Competition

Gibson et al. (2007) performed one of the first studies that looked at performance in the years following Tommy John surgery. Reviewing 68 pitchers that had surgery during the period 1998-2003, Gibson et al. (2007) found that by the second season after undergoing the procedure, pitchers at the major league level returned to their previous level of performance. Earned Run Average (ERA), Walks and Hits Per Innings pitched (WHIP), and innings pitched were the main

statistics used to evaluate player performance in both the injured and control group before and after surgery.

Gibson et al. (2007) also found that relief pitchers had more success in their return from injury than starting pitchers. That finding was not completely surprising, considering the fact starting pitchers tend throw more cumulative innings in a season compared to a relief pitcher. During the 2019 season, the average number of innings pitched by a starting pitcher (minimum 50 innings pitched) was 130.8 innings (FanGraphs Baseball). In contrast, the average number of innings pitched by a relief pitcher (minimum 20 innings pitched) was 45.9 innings (FanGraphs Baseball). The decreased workload by relief pitchers and the shorter outings they tend to have could help contribute to their success in the season following surgery. However, the effect of pitching multiple innings on consecutive days was not taken into account for relief pitchers in Gibson et al.'s (2007) study.

Erickson et al. (2014) studied 179 major league pitchers that had Tommy John surgery. Pitchers that pitched at least one game in the MLB before and after having the surgery were included. The study found an 83% return to competition among those players included in the dataset (Erickson et al., 2014). From 2000 to 2012, an increase in the number of surgeries performed was found. This could be the result of a few factors, including expansion (two major league teams were added to the league in 1998), and better diagnostic testing. Adding two teams added approximately 24 additional pitchers to the league, thus increasing the sample size of players that might require elbow surgery.

Erickson et al. (2014) also found that in the season before surgery, pitchers experienced a reduction in the number of games and innings pitched. This result suggests performance begins to decline prior to finally needing elbow surgery. The aforementioned result matches findings by

Ciccotti et al. (2014) that showed repeated stress to the elbow joint over several years by professional pitchers. A number of players had their non-throwing and throwing arms tested over the course of 10 years using ultrasound in Ciccotti et al.'s (2014) analysis. Changes in the thickness of the ulnar collateral ligament and calcification in the joint were found (Ciccotti, M. et al., 2014).

As performance begins to drop and athletes experience pain, a player may end up on the Injured List (IL) and conservative treatment such as rest and rehabilitation may be tried first. In the first and second years after surgery, the number of games played and innings pitched decreased (Erickson et al, 2014). Performance in metrics such as ERA and WHIP were found to improve (Erickson et al., 2014). Teams tend to be more conservative with pitchers returning from a major arm surgery. Due to the lengthy recover period from Tommy John surgery, innings limits have been put in place by teams in order to closely manage the workload of a post-operative pitcher. One highly publicized example of this practice occurred during the 2012 season, when Washington Nationals pitcher Stephen Strasburg was limited to roughly 160 innings pitched after having Tommy John surgery at the end of the 2010 season. Strasburg reached his innings limit in September of 2012 and was withheld from participating in the post-season (Svrluga, B. (2015, Sep 08). Star pitchers also tend to command large multi-year contracts, so teams do their best to protect their investment in the player's performance.

Mackhni et al. (2014) performed another comprehensive study on return to pitching at the major league level after Tommy John surgery. Using player data from 1999 to 2011, the study found that 80% of players that underwent Tommy John surgery came back to pitch in at least one major league game (Mackhni, E.C. et al., 2014). This was similar to Erickson et al.'s (2014) rate of 83%. Also noted in the results was the fact that reinjury to the throwing arm among players

that had the procedure was more than 50% (Mackhni, E.C. et al., 2014). This could be due to some players returning too soon from the IL into a competitive game setting. The average return to a major league game was over 16 months (Mackhni, E.C. et al., 2014). The time of 16 months between the date of surgery and return to competition is in the range of the current recommended recovery time by medical professionals (Erickson, B. J, et al., 2016). Returning to the major leagues can be more difficult and take longer due to the high level of competition and the importance of each game.

Several metrics were used to assess pre and post injury performance, including but not limited to, ERA, WHIP, percentage fastballs thrown, and average fastball velocity. A study by Pareek, A. et al. (2019) showed only average fastball velocity, deemed a 'traditional statistic' in the study, to be a significant factor in measuring performance. However, the sample size in Mackhni et al.'s (2014) study was significant, which could lend more credence to the more traditional statistics they used in their analysis.

Pareek, Leontovich, et al. (2019) studied traditional and advanced baseball statistics in non-injured pitchers to try and "…determine the normal variability of basic and advanced pitching statistics in non-injured Major League Baseball (MLB) pitchers (Pareek, A. et al., 2019). The traditional stats used included, among others, ERA, strikeouts, walks and batting average against. They also studied more advanced statistics, including spin rate, velocity from pitcher to plate, and release position vertical. The results of Pareek, A. et al.'s (2019) study concluded that average fastball velocity, which was considered a traditional statistic in their analysis, was the only measure that had a low enough variability to be considered significant (Pareek, A. et al., 2019). When it came to advanced baseball statistics, several metrics showed lower variability, thus making them more apt to help assess performance. Those metrics included

release position from plate, release speed and spin rate (Pareek, A. et al., 2019). The study also cautioned that proper sample sizes should be used in conjunction with the significant statistics in helping to determine the pre-injury and post-injury level of performance (Pareek, A. et al. , 2019).

To further the study of pitcher performance after Tommy John surgery, Erickson et al. (2016) conducted a study involving the number of pitches and innings thrown in the years after surgery. The analysis showed that the amount of innings and pitches thrown in the years following Tommy John surgery does not increase the risk of needing a second Tommy John surgery in major league pitchers (Erickson, B.J. et al, 2016). The data set for Erickson et al.'s (2016) study included all pitchers that have undergone the procedure from its inception in 1974 until 2015. A comparison was then done between pitchers that did not require a second procedure with pitchers that did undergo a second surgery. Position (starter or relief pitcher), cumulative number of innings, and cumulative number of pitches in the season following the first Tommy John procedure did not affect the risk for needing a second Tommy John surgery (Erickson, B.J. et al., 2016). Predicting which pitchers might need to have a second procedure could be helpful in extending the careers of players that have already had one surgery.

Predictors

The analyses discussed so far have been somewhat limited in the variables used to predict Tommy John surgery in MLB pitchers. Most of the studies have focused on a few factors such as velocity, pitch type, biomechanical factors, or a combination of those three variables. Whiteside et al. (2016) attempted to rectify this using several variables and two different machine learning methods. Twelve variables were analyzed, including age, height, mass, position (starter or relief

pitcher), average days between games, average pitches per game, and average pitch speed, among others (Whiteside et al., 2016).

Using Naïve Bayes and a linear support vector machine classifier, Whiteside et al. (2016) input their 12 variables into each algorithm with the classifier being a pitcher that would eventually need Tommy John surgery. Both the Naïve Bayes and support vector are 'supervised', meaning the algorithms are first trained on training data to 'learn' the predicted classification. Test data is then input into the algorithm to determine whether a player will need Tommy John surgery based on the 12 input variables.

The results of Whiteside et al.'s (2016) machine learning study echo many of the points of previously mentioned studies and also raise some new questions. The accuracy of the Naïve Bayes and support vector models were 72% and 75%, respectively (Whiteside et al., 2016). Less rest between games, more pitches per outing, higher velocity, a more overhand delivery, and shorter height all increased the chances of needing Tommy John surgery (Whiteside et al., 2016). Higher velocity has been shown in several of the aforementioned studies to increase elbow surgery risk. However, the overhand delivery factor predicted in Whiteside et al.'s (2016) study contradicts the result from Aguinaldo & Chambers (2009), which showed pitchers throwing with a sidearm delivery showed more stress on the elbow joint than pitchers throwing from a higher arm-slot.

Although promising, caution should be taken when using machine learning algorithms to predict potential injuries. The Naïve Bayes classification model has drawbacks. The 'Naïve' part of the name given to the model stems from the fact that all variables are treated independently of one another (Pavithra et al., 2018). When dealing with a complex activity such as throwing a

baseball in a professional environment, assuming independence among all variables used in the model may not be prudent due to the kinetic-nature of the throwing motion.

Likewise, the linear support vector has drawbacks. A linear support vector is a 'black box' algorithm, meaning the inputs and outputs of the process are known, but the mathematics involved in the predictive transformation are often very difficult to understand (Lantz, B., 2019). The basic idea behind the linear support vector machine is that a multidimensional surface is used to divide the data points into different classes. In the case of Whiteside et al.'s (2016) study, the two classes were 'Surgery' and 'No Surgery'. An example of what a two-dimensional support vector looks like is provided in Figure 2 below (Pavithra et al., 2018). The shapes in the figure represent different classes, in Whiteside et al.'s case, these would be the 'Surgery' and 'Non-Surgery' classes.

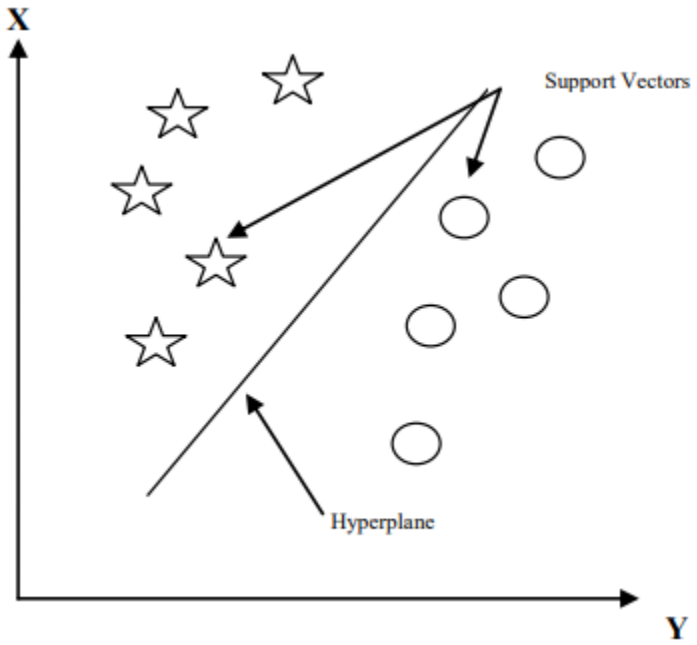

Figure 2 – Support Vector Example

Dataset

For this project, the list of players who have undergone the procedure was obtained through a publicly available dataset from baseball writer and analyst John Roegele. The dataset

contains the names of over 1,000 players at the high school, college, minor league and major league levels that have had Tommy John Surgery. The list of players was narrowed down to only those players that have made at least one appearance in a Major League Baseball game between 2008 and 2018. The reason for narrowing down the list of subjects is due to how long publicly available pitch data has been recorded. PITCHf/x, developed by Sportvision, a sports telecast special-effects company, developed and implemented the camera-tracking system in Major League Baseball ballparks starting in the 2006 playoffs (Fast, M., 2010). The system was implemented for the majority of teams during the 2007 season but was phased out in 2017 in favor of Statcast (Fast, M., 2010). The dataset also includes the pre-Tommy John averages of players that underwent the procedure during the 2018 season. Recovery time is typically in the 12 to 18 month range, so players undergoing the procedure in late 2018 may not have had sufficient time to return to competition and accumulate innings pitched, partly due to the reduced schedule of games in 2020. Players that have undergone more than one Tommy John surgery were excluded from the analysis. This is because the rate of return to competition is significantly more volatile if a second procedure is required and could affect the analysis (Erickson, B.J. et al., 2016).

The dataset from Roegele included some attributes that were not applicable to this analysis and were thus removed. The removed columns included Country, High School, College, and Surgeon(s). No statistical information was used from Roegele's dataset. The data set included each player's Major League Baseball Advanced Media ID (MLBAMID) and Fangraphs ID (FGID).

Process

To make it easier to join Roegele's dataset to different databases, columns were added to the dataset. These columns included identification fields for the Baseball Reference ID and Retro Sheet ID. These values were obtained from the Chadwick Baseball Bureau Register, a comprehensive listing of professional players from the MLB, minor leagues, and some foreign leagues. The dataset is publicly available and is updated on a regular basis (Chadwick Bureau, 2020). To obtain the Baseball Reference ID and Retro Sheet ID, a VLookup was performed in Microsoft Excel on the modified Roegele dataset using the MLB Advanced Media ID as the common field between datasets.

To obtain pitch velocity and pitch type data, the publicly available website Fangraphs.com, a baseball research and analysis site, was used. Utilizing the Pitching Leaderboards dashboard on the site, single-season data for each year from 2008 to 2018 was exported to Excel. The dashboard was filtered on pitch type to return the velocity, pitch type, and percentage of each type of pitch per player and season. The pitch types categorized by Fangraphs include fastballs, sliders, cut-fastballs, curveballs, split-finger fastballs, changeups and knuckleballs. Fangraphs also categorizes an 'unknown' pitch type. Occasionally, the technology used to track pitches will not know what type of pitch is thrown. This could be the result of a pitch being too slow to accurately categorize, or random quality control errors in the technology. As a result, the 'unknown' pitch type was excluded from this analysis in both the Tommy John case and control group. The knuckleball was also excluded from the analysis due to a lack of pitchers utilizing the pitch.

Once the Fangraphs data was exported to Excel, two tables were created in Microsoft SQL Server Management Studio 18 using the Table Designer function. The first table, 'TJ_Surgery', shows the data from Roegele's Tommy John recipient list, including player name,

MLBAMID, BBREFID, FGID, Tommy John Surgery Date and Return Date. The second table, 'Pitch_Velocity_Type', shows the Fangraphs data, including relevant ID's, Name, Year, pitch type and percentage for fastballs, sliders, curveballs, cut-fastballs, changeups, split-finger fastballs. These two tables were added to an existing database that was downloaded, called the 'Lahman Baseball Database' (Lahman, S., 2020). The Lahman Baseball Database, created by Sean Lahman, a USA Today reporter, is a freely available, historical database for baseball statistics and demographic information (Lahman, S., 2020). The two newly created tables, 'TJ_Surgery' and 'Pitch_Velocity_Type', were added to Lahman's database to allow all tables to be joined so specific statistical information could be obtained by player and year. The tables were joined together on each players MLBAMID or BBREFID.

The data set for pitchers undergoing Tommy John surgery contained 169 players that were 21 + years of age. The data set was obtained by querying the aforementioned Lahman database, combined with the two newly created tables. The SQL 'AVG' function was used to obtain averages for each pitch type, as well as for the percentage each pitch was thrown. The SQL 'AVG' function excludes 'NULL' values, so any players that had a 'NULL' value for a certain pitch type were excluded from the overall average for that pitch velocity or percentage. All players in the data set pitched in at least one game between the 2008 and 2018 season. Each player's age was calculated by using their age as of July 1st of a given season, which is considered the player's 'Baseball Age'. Each player was then put into a group, 'Age Range', so that comparisons between control pitchers in a similar age group could be done. There were 4 levels of age ranges:

- 21 – 24
- 25 – 28

- 29 – 32
- 33 +

The control group for the analysis contained 2,017 pitchers that were 21 + years of age and was also obtained using the Lahman database and the 'TJ_Surgery' and 'Pitch_Velocity_Type' tables. The control group consisted of players that pitched in a major league game between the 2008 and 2018 season and did not have Tommy John surgery. Players that might have had other elbow or shoulder injuries or surgeries on their throwing arm during that time were included in the group. The MLB Health and Information Tracking System (HITS) contains information related to player injuries that are not limited to Tommy John Surgery, but the database is not publicly available.

Spin rate data was obtained by scraping the Baseball Savant website using the readr, baseballr and dplyr packages in R Studio (RStudio, 2020). The data for spin rates included the 2015 to 2018 seasons. Using the dplyr package, the data was grouped by season, player, pitch type and mean spin rate for each pitch type. Statcast provides more pitch types than were available for the velocity analysis. The pitch types used in the spin rate analysis were as follows:

- Four-seam fastball (FF)
- Two-seam fastball (FT)
- Sinker (SI)
- Cut-fastball (CT)
- Split-finger fastball (FS)
- Curveball (CU)
- Changeup (CH)
- Slider (SL)

After the players and seasons were grouped together, the data was written to a .csv file. From there, a new table called ‘Spin_Rate’ was created in the Lahman database. Using SQL queries, 3 datasets were formed:

- Pre TJ Spin
- Post TJ Spin
- Control Group Spin

Each data set was broken down into 3 age ranges:

- 21 – 24
- 25 – 28
- 29 - 32

The hypothesis for each of these cases was that velocity, pitch type and spin rate would all be significantly different between the Tommy John group and the Control group.

As Pareek et al. (2019) described in their analysis of statistics used to measure pre and post injury performance, spin rate was one metric that showed a low enough variability to be used in player analysis. Spin rate, which was introduced to the public when Statcast was implemented in place of Pitchf/x in 2015, measures the revolutions per minute of each pitch that is thrown (Sawchik, T., 5 Oct 2018). Pitches with higher spin rates appear differently to batters than pitches of equal velocity with lower spin rates, resulting in more swings and misses (Sawchik, T., 5 Oct 2018).

Results

A two-sample t-test was conducted in R Studio using the t.test function to determine if the difference in means between velocity and pitch type between the pre Tommy John and

control groups was significant. Mean fastball velocity was higher in the pre Tommy John group for each age category except the 33 + age group. The Pre TJ groups had higher mean velocity in 14 out of 24 cases.

Mean Velocity (MPH) by Age Group and Pitch Type

	21-24		25-28		29-32		33+	
	Pre TJ N=95	Control N=720	Pre TJ N=58	Control N=896	Pre TJ N=12	Control N=245	Pre TJ N=4	Control N=156
Fastball	93.1	92.4	92.3	91.6	91.4	90.9	88.8	89.4
Cutter	87.9	87.8	87.8	87.8	88.1	87.6	82.8	86.8
Slider	84.0	83.6	83.8	83.3	82.7	83.0	80.0	82.3
Split Finger	84.7	84.9	85.1	84.5	83.3	84.7	78.4	83.6
Curveball	78.2	77.4	77.3	77.2	77.4	76.5	73.1	75.2
Changeup	84.8	83.9	84.2	83.7	83.3	83.2	80.9	81.9

P-Values of less than .05 were seen in 9 out of 24 velocity groups, indicating the difference in mean fastball velocity was significant between the pre Tommy John and Control groups. Pitchers between 21 and 28 years of age had 6 of the 8 lowest p-values.

Velocity P-Values by Age Group and Pitch Type

= P-Value <= .05

	21-24	25-28	29-32	33+
Fastball	0.00019	0.00004	0.134	0.401
Cutter	0.826	0.908	0.369	0.004
Slider	0.077	0.008	0.590	0.047
Split-Finger	0.809	0.158	0.081	0.001
Curveball	0.009	0.811	0.070	0.080
Changeup	0.0002	0.028	0.787	0.252

For pitch type, the percentages of pitches thrown between each group was similar, with the exception of the cut fastball, which had a higher percentage thrown by the Control group in each age category. None of the p-values in any age group were significant (<= .05), indicating

we cannot reject the null hypothesis that the percentage of pitch type is equal between the two groups.

AVG % of Pitch Type by Age Group

	21-24		25-28		29-32		33+	
	Pre TJ N=95	Control N=720	Pre TJ N=58	Control N=896	Pre TJ N=12	Control N=245	Pre TJ N=4	Control N=156
Fastball	0.63	0.63	0.60	0.61	0.57	0.58	0.59	0.57
Cutter	0.12	0.17	0.15	0.20	0.16	0.21	0.12	0.21
Slider	0.20	0.20	0.22	0.22	0.21	0.22	0.24	0.23
Split Finger	0.13	0.12	0.12	0.13	0.13	0.15	0.15	0.16
Curveball	0.14	0.13	0.14	0.14	0.14	0.14	0.14	0.13
Changeup	0.11	0.12	0.10	0.12	0.11	0.12	0.11	0.11

Pitch Type P-Values by Age Group and Pitch Type

= P-Value <= .05

	21-24	25-28	29-32	33+
Fastball	0.7813	0.4363	0.569	0.384
Cutter	0.040	0.0003	0.003	0.019
Slider	0.701	0.613	0.727	0.338
Split-Finger	0.805	0.781	0.727	0.837
Curveball	0.503	0.886	0.751	0.395
Changeup	0.053	0.001	0.594	0.906

Likewise, the data for spin rates was compared between pre Tommy John and Control groups. The Tommy John group had higher spin rates in 14 out of the 21 age/pitch type categories. However, only one of the categories had a p-value of <= .05, meaning the null hypothesis that spin rates are equal between the two groups could not be rejected.

Mean Spin Rate (RPM) by Age Group and Pitch Type
2015 - 2018

	21-24		25-28		29-32	
	Pre TJ N=25	Control N=720	Pre TJ N=28	Control N=896	Pre TJ N=10	Control N=245
Four-Seam FB	2,265	2,216	2,252	2,236	2,272	2,233
Two-Seam FB (Sinker)	2,199	2,139	2,173	2,158	2,174	2,159
Cutter	2,150	2,264	2,194	2,266	2,330	2,298
Split Finger	1,482	1,426	1,496	1,495	1,427	1,492
Slider	2,243	2,245	2,168	2,236	2,245	2,252
Curveball	2,322	2,353	2,249	2,347	2,379	2,338
Changeup	1,819	1,735	1,797	1,751	1,790	1,748

Spin Rate P-Values by Age Group and Pitch Type
2015 - 2018
= P-Value <= .05

	21-24	25-28	29-32
Four-Seam FB	0.066	0.3908	0.331
Two-Seam FB (Sinker)	0.050	0.446	0.719
Cutter	0.087	0.100	0.343
Split Finger	0.595	0.997	0.865
Slider	0.973	0.109	0.943
Curveball	0.525	0.181	0.755
Changeup	0.057	0.231	0.717

Comparisons for pre and post Tommy John numbers among players showed that many velocity numbers did increase for players that underwent the surgery. However, this does not mean that getting the surgery will lead to an increase in velocity. As stated previously, research suggests the extensive rehab that players undergo after surgery, along with overall increased fitness during the rehab process help contribute to the increased velocity figures post-surgery.

Also, velocity readings prior to surgery can go down, as players experience elbow and pain as the ligament weakens.

Mean Velocity (MPH) by Age Group and Pitch Type (Pre and Post TJ)

	21-24		25-28		29-32		33+	
	Pre TJ N=95	Post TJ N=15	Pre TJ N=58	Post TJ N=44	Pre TJ N=12	Post TJ N=40	Pre TJ N=4	Post TJ N=17
Fastball	93.1	93.6	92.3	92.5	91.4	91.9	88.8	90.6
Cutter	87.9	85.5	87.8	86.7	88.1	87.6	82.8	86.7
Slider	84.0	84.5	83.8	84.3	82.7	83.7	80.0	81.9
Split Finger	84.7	NA	85.1	85.6	83.3	85.6	78.4	81.8
Curveball	78.2	78.4	77.3	78.1	77.4	77.5	73.1	75.5
Changeup	84.8	86.2	84.2	84.8	83.3	84.2	80.9	81.4

Discussion

The average age of players drafted out of high school and undergoing Tommy John surgery was 26.6 compared to 27.7 for college draftees. These average ages coincide with the lower p-values for velocity in players between 21 to 28 years of age. For comparison, the percentage of college, high school and international players that underwent Tommy John surgery (2008 - 2018) and the percentages of each group in the league (2008 - 2018) are listed below.

	TJ Surgery	League Demographics
College	54%	52%
High School	24%	26%
International	23%	22%

One area to look at in regards to surgery among the college group is the workloads of college and minor league pitchers. Average college pitcher innings per season closely match those of minor league players. From 2017 to 2019, Division I college baseball starters (minimum 30 innings pitched) averaged 76.5 innings and relievers averaged 61.6 innings. A pitcher was deemed a ‘starter’ if half of their appearances or more were starts. During the 2019 minor league

season, full season affiliate (A, A+, AA, AAA) starters averaged 77.6 innings (minimum 30 innings pitched) and relievers averaged 50.6 innings for the season.

The biggest difference between college and professional pitchers appears to be in regards to pitch count. Schifman (2016) compared the number of pitches thrown between major league pitchers and college pitchers in the regular and post-season from 2012 to 2015. Major league pitch counts are remarkably consistent in both the regular season and post-season, with most pitchers throwing around 100 pitches per start. The range of college pitcher pitch counts was more widespread, with more starts of less than 100 pitches but also a higher number of starts throwing more than 120 pitches (Schifman, 2016). Schifman (2016) looked at the percentage of starts of 115 or more pitches by major league and college players. MLB pitchers had 115 pitches or more in 4.4% of regular season starts and 6.1% in post-season starts. A college junior threw 115 pitches or more in 9.9% of regular season starts and 16.7% of post-season starts (Schifman, 2016).

Days of rest also play a part in minor league and college pitching. Major and minor league starting pitchers tend to stick to the same schedule of one day of pitching followed by 4 days of rest. For college pitchers, days of rest can vary. A teams best starter will typically pitch every Friday during the regular season. Results from Schifman's (2016) analysis showed that during the post-season, days of rest for college pitchers decreased both in starts of less than 115 pitches and starts throwing more than 115 pitches.

Player location (U.S. only) was also compared to see if players in warmer parts of the country are more prone to having Tommy John surgery than players in colder states. The reasoning is that players in warmer climates play baseball more often and are more susceptible to

injury due to the repetitive stress placed on their joints. Based on a previous study by Erickson et al. (2014), there were 11 states deemed ‘warm weather’ for the analysis:

Warm Weather States	
California	Louisiana
Arizona	Mississippi
New Mexico	Alabama
Hawaii	Georgia
Texas	South Carolina
	Florida

All 39 other states were deemed ‘cold weather’. A chi squared test was used to see if there was a significant difference between Tommy John players that attended high school in warm weather states versus cold weather states. As shown in the comparison below, there were no significant differences between Tommy John recipients in warm weather states versus cold weather states.

Observed		Expected	
Warm Weather	Cold Weather	Warm Weather	Cold Weather
65	70	67.5	67.5
48%	52%		

Chi Squared Value	Critical Value (95% Confidence)
0.67	5.991

Conclusion

The increase in the number of Tommy John surgeries in the past 30 years has placed more focus on potential risks and causes of elbow injuries in pitchers. Based on the information reviewed in this project, pitching mechanics and pitch velocity both play significant roles in the stresses placed on the elbow during the pitching motion. Aguinaldo and Chambers (2009) found

that throwing from a sidearm delivery placed increased stress on the elbow joint. Anz et al. (2010) also found that increases in shoulder external rotation led to higher torque on the elbow.

For velocity, players in this project between the ages of 21 and 28 years old had mean velocity differences that were significant between the case and control groups. Studies by Bushnell et al. (2010), Chalmers, P., et al., (2016), and Slowik et al. (2019) also reported similar findings when it came to velocity between groups of players.

Results from players polled in 2012-2013 showed that about 25% of major league players and 15% of minor league players had Tommy John surgery at some point in their career (MLB Pitch Smart, 2020). The need to lessen the amount of surgeries has many advantages. The 12 to 18th month recovery can sometimes affect two valuable performance years in a player's career. A player does not reach free agency until after their 6th season in the major leagues, and a lengthy surgery can impact the amount of money a player makes going forward. From the teams perspective, players in the major leagues are there presumably because they provide the team the best chance to win. Having a key player unavailable for any length of time can affect team performance and potential postseason play, where additional money and national exposure can help increase a team's revenue. Continuing research into the biomechanics of pitching and analysis of player data will hopefully lead to more definitive solutions and programs aimed at preventing serious arm injuries.

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