Predicting the Risk of ACL Injuries

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Abstract

BACKGROUND: Anterior cruciate ligament (ACL) injuries are common injuries among active adolescents. These injuries can be prevented through targeted physical training, but there are no user-friendly tools to identify athletes who are at a high risk of sustaining an ACL injury. One previously proposed tool is the ACL risk nomogram that relies on several imaging-based measurements to predict the risk of an ACL injury.

OBJECTIVE: The goal of this project was to (a) determine the accuracy of a previously published ACL risk nomogram in predicting the risk of an ACL injury, (b) determine individual measurements that are predictive of a person's risk of an ACL injury, (c) create a more accurate formula in predicting the risk of an ACL injury.

METHODS: The study population included a de-identified dataset of 44 subjects (mean age 23 years, 43% female) with bilateral measurements of tibia length, knee valgus motion, knee flexion range of motion, mass and quad ham ratio. Using a previously published nomogram, each subject's ACL injury risk percentile for each knee (dominant and non-dominant) were calculated and compared with the knee moment (i.e., knee abduction torque). Multivariable linear regression was performed using the R statistical package.

RESULTS: The strongest predictors of ACL injury risk were knee valgus motion, mass and tibia length. Two factors in traditional nomogram did not have significant correlation with knee moment. Only 41% of the variability in the ACL risk can be determined by the nomogram.

CONCLUSION: Previously published ACL risk nomogram is not an accurate tool in predicting the risk of an ACL injury. Further research in larger samples is warranted to develop user-friendly ACL risk prediction tools.

Background

There are four primary ligaments in the knee. The ACL, which stands for anterior cruciate ligament, is the most commonly injured ligament. The ACL is one of the two cruciate ligaments, which cross each other to form an "X" with the anterior cruciate ligament in the front and the posterior cruciate ligament in the back. They control the back and forth motion of the knee. The ACL runs diagonally in the middle of the knee and prevents tibia from sliding out in front of the femur, as well as provides rotational stability to the knee.

There are several causes of ACL injuries. These include physical strains such as changing direction rapidly, stopping suddenly, slowing down while running, landing from a jump incorrectly or direct contact or collision.

Studies show that female athletes have a higher incidence of ACL injury than male athletes. There are several proposed mechanisms to explain this difference including differences in physical conditioning, muscular strength, neuromuscular control, pelvis and lower extremity (leg) alignment, and increased looseness in ligaments due to the effects of estrogens on ligament properties.

Nomograms are diagrams representing the relations between numeric variables that correlate to a score. The previously published ACL risk nomogram examined in this study (Hewett et al 2010) includes tibia length, knee valgus motion, knee flexion range of motion, mass and quad ham ratio. Based on the nomogram, the patient's risk percentile for experiencing an ACL injury is calculated.

Problem

Many athletes, especially females, experience ACL injuries. Targeted physical therapy and training can potentially reduce the risk of ACL injuries in high risk athletes, but there are no good methods to determine which athletes are at a high risk of having an ACL injury.

Purpose

The purpose of this study was to determine the accuracy of a previously published nomogram in predicting the risk of sustaining an ACL injury. The researcher examined the predictive accuracy of individual components of the nomogram, and finally, created a more accurate formula for predicting the risk of an ACL injury.

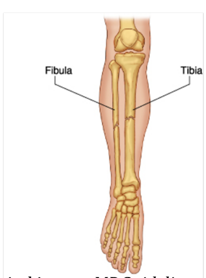
Materials

The materials used in this study were (a) a blinded dataset that included bilateral patient level data on tibia length, knee valgus motion, knee flexion range of motion, mass, ham ratio, (b) **R program** (www.r-project.org) and (c) Computer.

Methods

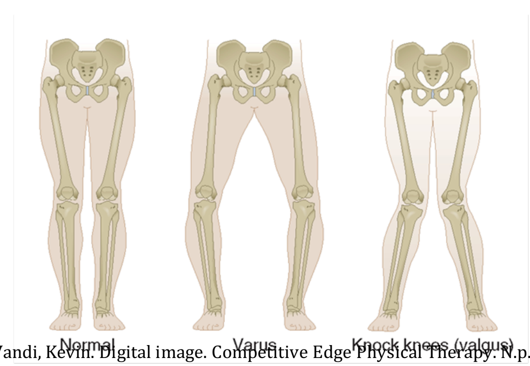
The study included 44 healthy participants with a mean age (SD) 23 (3.6) years (min: 16, max 32) and 43% were female. All participants underwent bilateral ACL testing with 5 measurements of tibia length, knee valgus motion, knee flexion range of motion, mass, and quad:ham ratio. These 5 measurements were then used to calculate nomogram scores for each knee. Each knee was scored either a 1 or a 0; 1 if the nomogram percentage is 0.9 or greater, 0 otherwise.

Tibia length



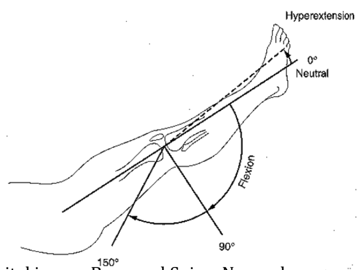
Digital image. *MDGuidelines*. Reed Group, n.d. <http://www.mdguidelines.com/images/Illustrations/fr_tibia.jpg>.

Knee Valgus Motion: abnormal outward turning of a knee



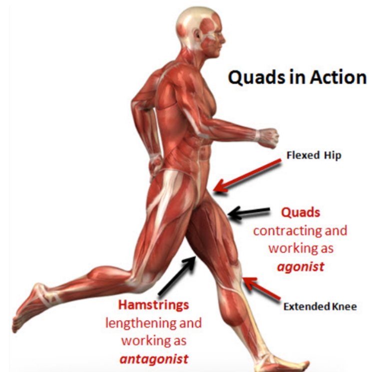
Vandi, Kevin. Digital image. Competitive Edge Physical Therapy. N.p., n.d. Website. <http://what-when-how.com/wp-content/uploads/2012/05/tmpa83a73_thumb2.png>.

Knee Flexion Range of Motion: The full movement potential of a joint



Digital image. Bone and Spine. N.p., n.d. Web. <http://boneandspine.com/wp-content/uploads/2015/09/knee-range-of-motion.gif>.

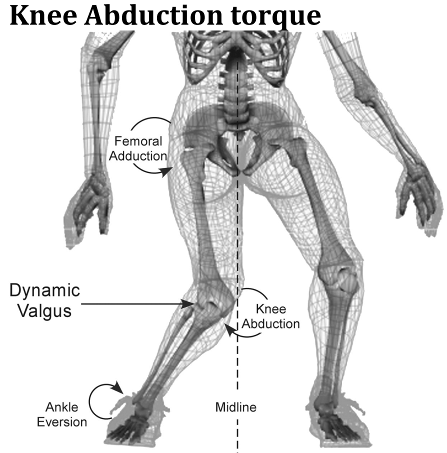
Ham Ratio: Quadriceps muscle runs along the front of the upper thigh. Hamstring is the muscle at the back of the upper part of the leg



Digital image. *Style HU Men*. Style Magazin, n.d. Web. <http://2.bp.blogspot.com/-TpOC4my_NBc/T0J-MhEv29I/AAAAAAAAF88/dYLv7QzFwmg/s1600/Hamstring-Quad4.jpg-calves.jpg

The risk of ACL injury (outcome) was measured by knee abduction torque. This was labelled as knee moment in the dataset. Knee abduction torque is the load that is created when one pivots at the knee in such a way that the ankle moves laterally away from the centerline of the body while the knee more or less stays in place. Visually this is best represented by the knock-kneed effect that is highly prevalent in young girls. The knee is meant to function more like a hinge than anything else. Ideally, the knee's motion should be constrained to the sagittal plane by the musculature. The less muscular control over the knee that an athlete has, the more likely that the knee experiences motion in the frontal plane (i.e., knee abduction torque). Greater frontal plane motion equates to greater stress on the ligaments and greater risk for ACL injury. Knee abduction torque (or Knee moment) was classified into 3 categories as follows:

Knee Abduction torque



http://strengthcoachconcepts.com/images/userPics/tinymce/F4.large.jpg

Category	Knee abduction torque (Knee moment) value	Explanation
High risk (2)	> 25.25 Nm	High risk of ACL injury
Medium risk (1)	15.4 – 25.25 Nm	high risk for patella femoral pain injury.
Low risk (0)	<15.4 Nm	Low risk of ACL injury

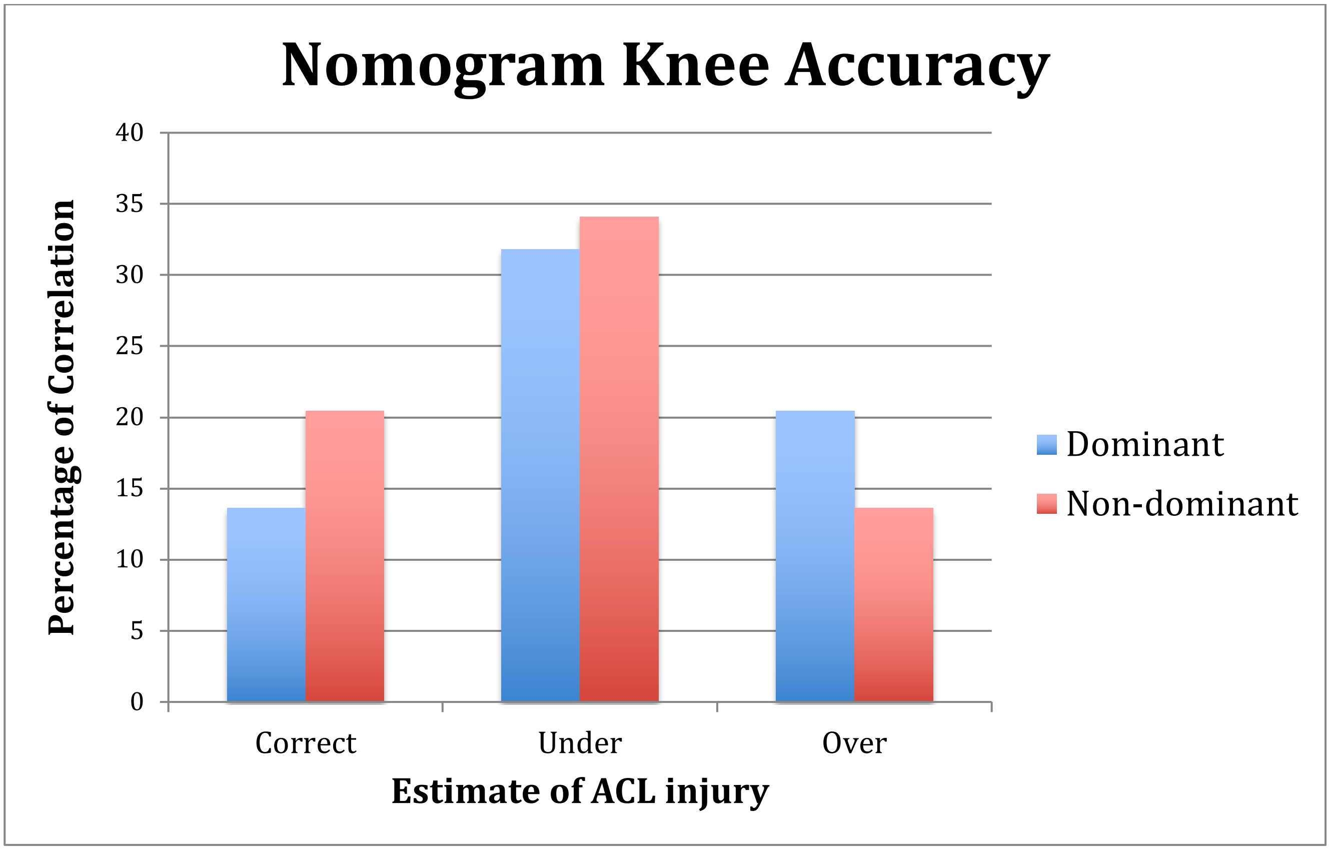
Then the researcher calculated and compared the "Nomogram Risk" and the "ACL Risk". Regression lines between knee moment and each of the 5 component scores and the total nomogram score were plotted. Using multivariable linear regression in R (www.r-project.org), a formula was derived predicting knee moment as the outcome (Formulas in appendix). The researcher then plotted the correlation between the knee moment and the predicted score from the model.

Example of what dataset looks like:

Mass	Mass SCORE	Tibia Length	Tibia Length SCORE	Keen Valgus Motion	Knee Valgus Motion SCORE	Knee Flexion ROM	Knee Flexion ROM SCORE	Quad Ham Ratio	Ham Ratio SCORE	Total Score
84.3	26	38.5	52	-10.06628305	46	-77.05877833	4	1.969802555	9	137
74.8	21	34	33	-22.95943943	58	-76.26830987	4	1.832061069	8	124
105.0	32	39	53	-3.913529984	18	-79.14363209	3	1.93592233	9	115

132		0.97	1=2 6	1	-57.3432049	2
92		0.58	Under 14	0	-52.387175	2
138		0.98	Over 6	1	-29.7063418	2
114		0.82	Under 1=1 3	0	-16.8181741	1
136		0.98		1	-20.8719038	1
93		0.58		0	-26.7608172	2
115		0.82		0	-53.4883716	2
70		0.22		0	-8.58981652	0
83		0.45		0	-12.1106507	0
98		0.74		0	-13.5151323	0
83		0.47		0	-9.26073094	0
90		0.55		0	-15.0216251	1
82		0.47		0	-10.7466496	0
126		0.95		1	-13.5565368	0

Results



Nomogram

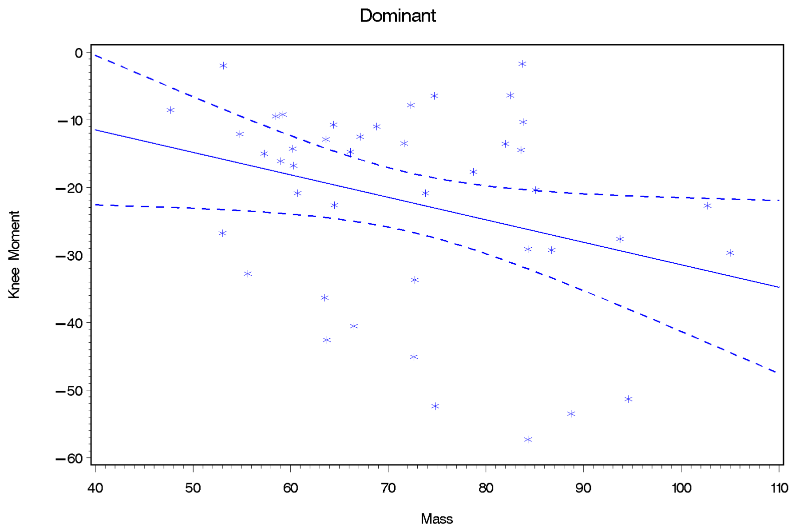
- Dominant (total=44) *See Figure above*
  - Correct- 6 (1=2) 13.64%
  - Under- 14 (0=1, 2) 31.82%
  - Over- 9 (1=0, 1) 20.45%
  - 0 Correlation- 15 (0=0) 34.09%
- Non-Dominant (total=44) *See Figure above*
  - Correct- 9 (1=2) 20.45%
  - Under- 15 (0= 1, 2) 34.09%
  - Over- 6 (1= 0) 13.64%
  - 0 Correlation- 14 (0=0) 31.82%

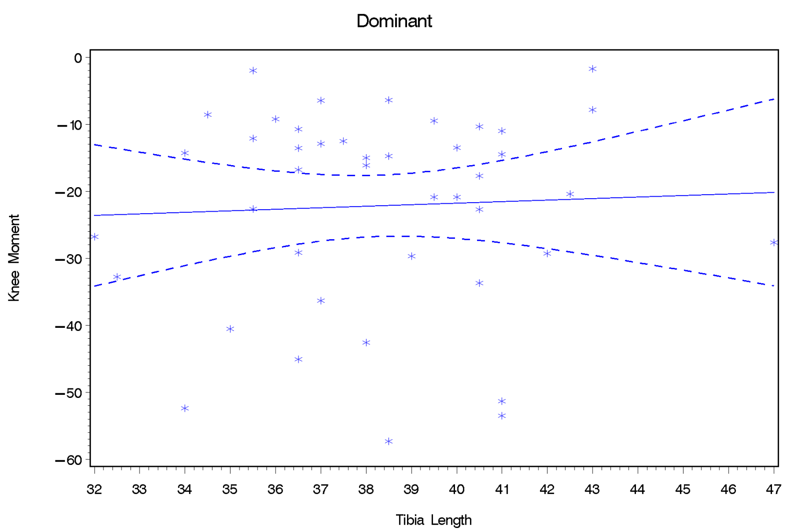
For the dominant knee, the nomogram correctly predicted the risk of ACL injury in 13.64%, under-estimated with a zero in 31.82%, over-estimated in 20.45% and had a zero to zero correlation (indicates that both nomogram and knee moment predict a low to little risk of injury or pain) in 34.09%. For the non-dominant knee, the nomogram correctly predicted the risk of ACL injury in 20.45%, under-estimated with a zero in 34.09%, over-estimated in 13.64% and had a zero to zero correlated in 31.82%. This data shows that the nomogram is not very accurate and only correctly identified subjects 17.05% of the time. The most important concern is in the under-estimates because it would represent a subject who is considered at no to little risk of an ACL injury but is physically is at high risk for patella femoral pain and/or at high risk of ACL injury.

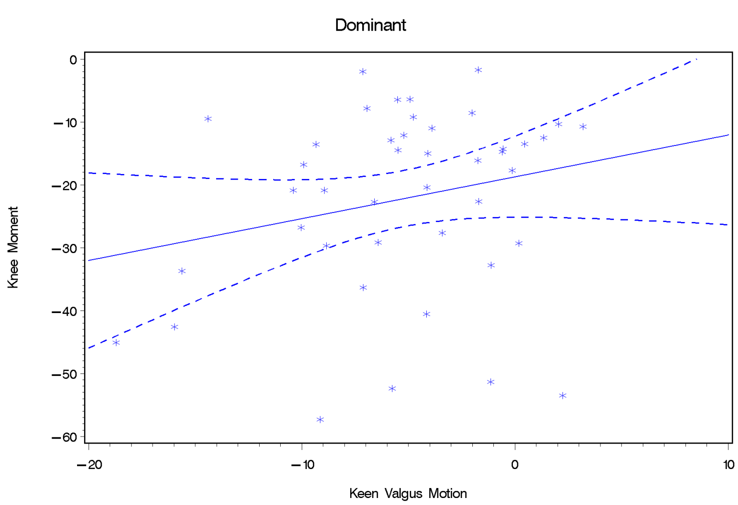
The following regression plots show the correlations between various measures. There are 7 plots each for the dominant and the non-dominant knee. The initial 5 figures show the correlation between each of the 5 nomogram measurements (x-axis) and knee moment (y-axis). The next 2 figures show the correlation between the total nomogram score and the predicted value of knee moment on the x-axis and the knee moment on the y-axis. Of note, the correlations are largely similar for the dominant and the non-dominant knees. The factors that correlate with knee moment are mass, tibia length and knee valgus motion. These 3 factors are used in the prediction formula (predicted value of knee moment).

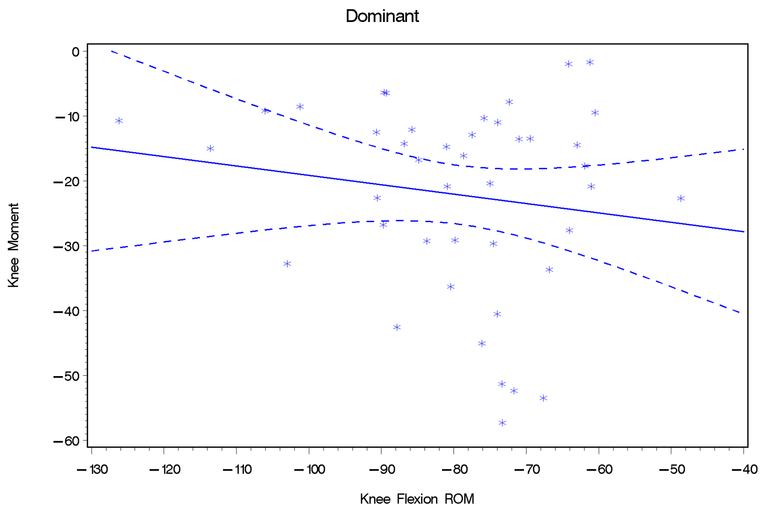
What is notable is the difference between the figure depicting the correlation between the total nomogram score and knee moment, and the figure depicting the correlation between the predicted value of knee moment and the knee moment. The predicted value of knee moment is based on 3 measurements included in the final model. The trend line of the correlation between the total nomogram score and knee moment has a negative slope. In contrast, the trend line of the correlation between the predicted value of knee moment and knee moment has a positive slope. This difference indicates that the knee moment (i.e., ACL injury risk) as predicted by the total nomogram score is quite different than what is predicted by 3 of the 5 nomogram measures. Since the predicted value of knee moment is informed with the data, it provides a better fit and a more accurate prediction of the knee moment.

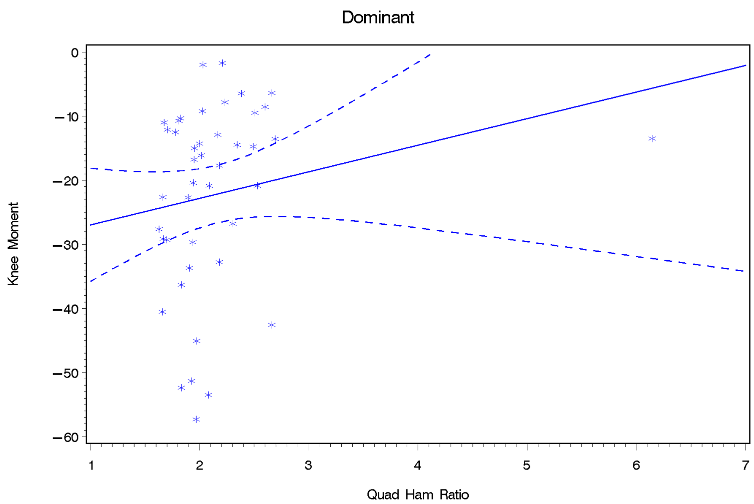
Dominant Knee Correlation (Factors)



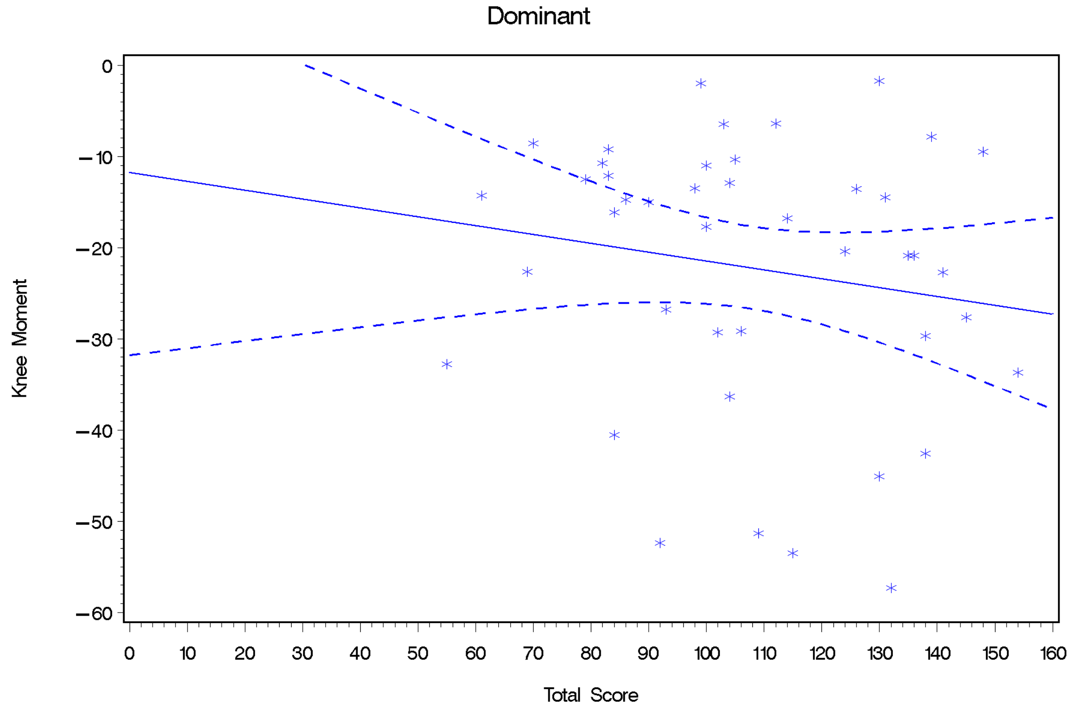


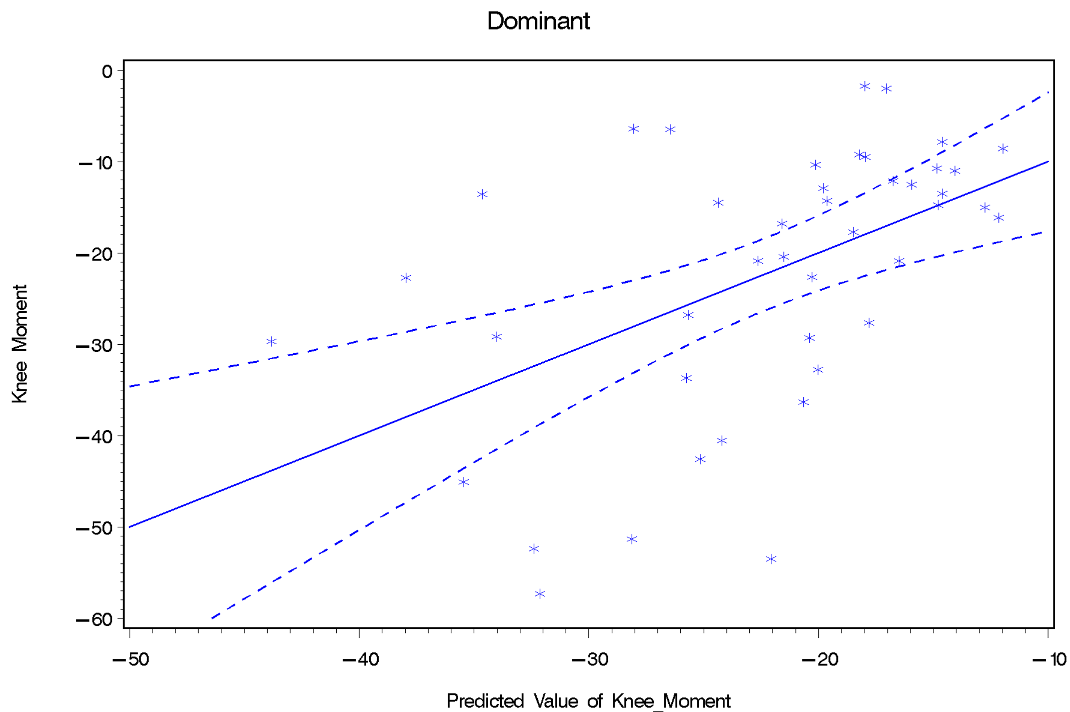



Dominant
Knee Moment
Knee Flexion ROM
0
−10
−20
−30
−40
−50
−60
−130
−120
−110
−100
−90
−80
−70
−60
−50
−40

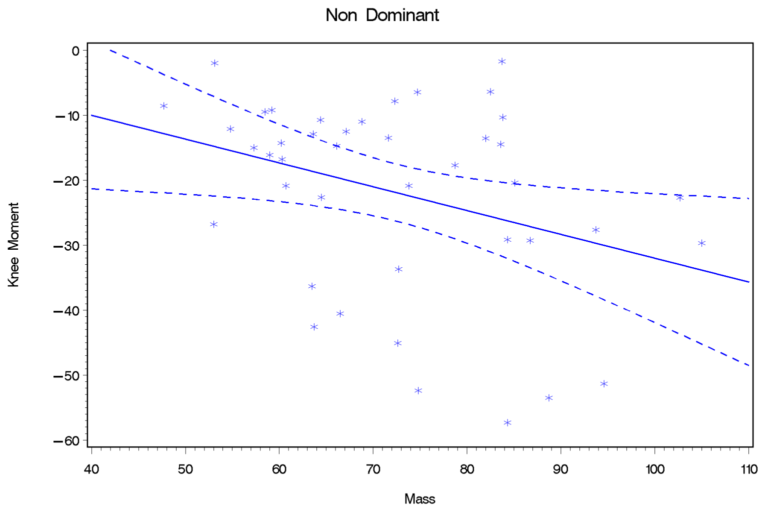

Dominant
Knee Moment
Quad Ham Ratio
0
−10
−20
−30
−40
−50
−60
1
2
3
4
5
6
7

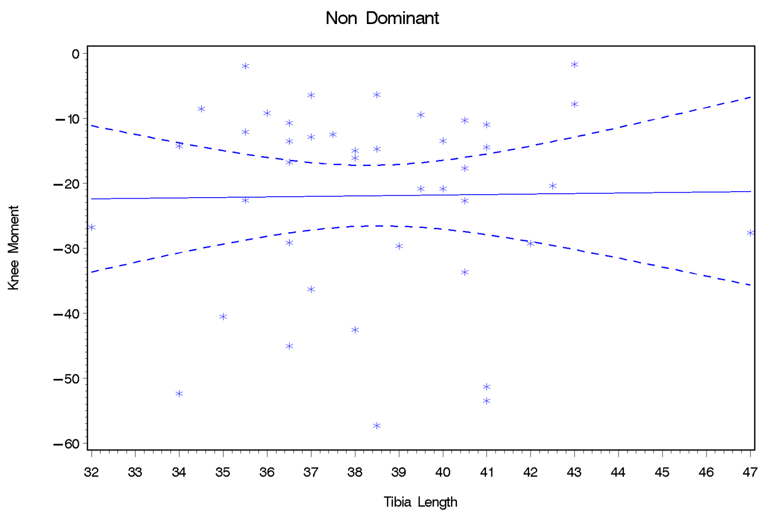
Dominant Knee Correlation (Predictions)

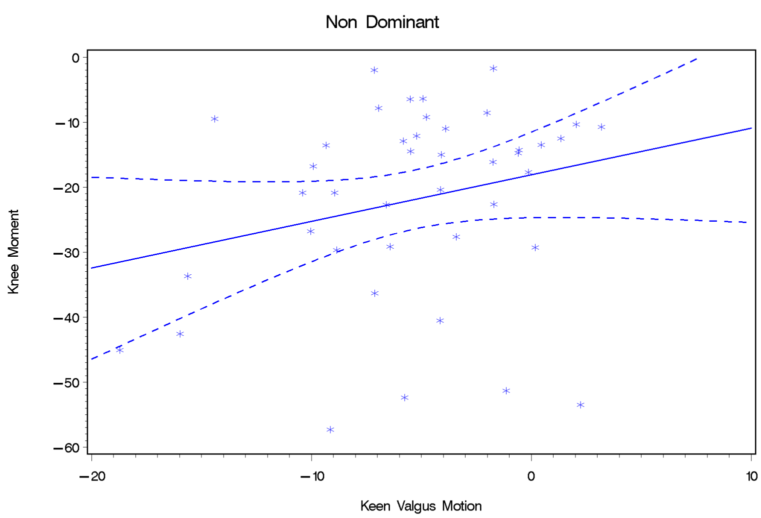


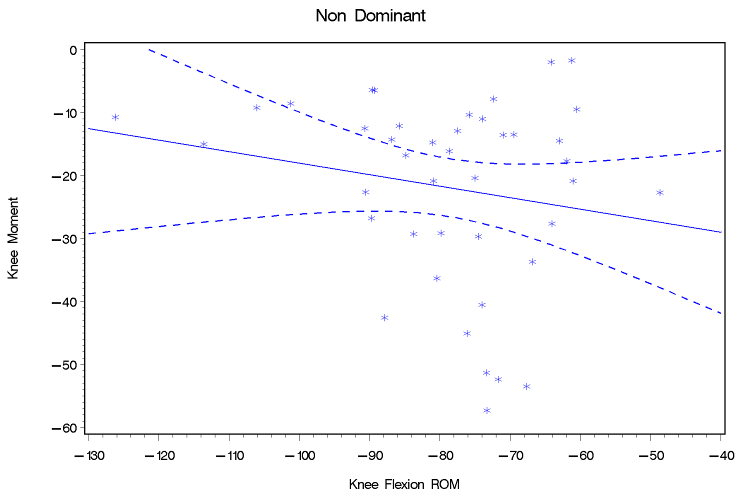


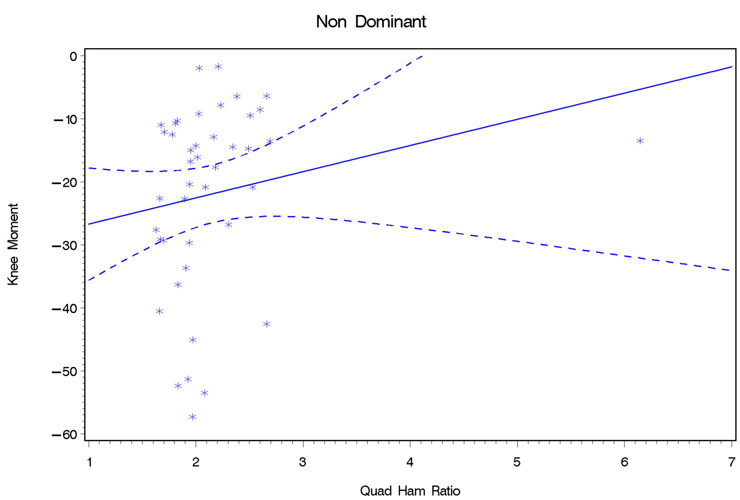
Non-dominant Knee Correlation (Factors)



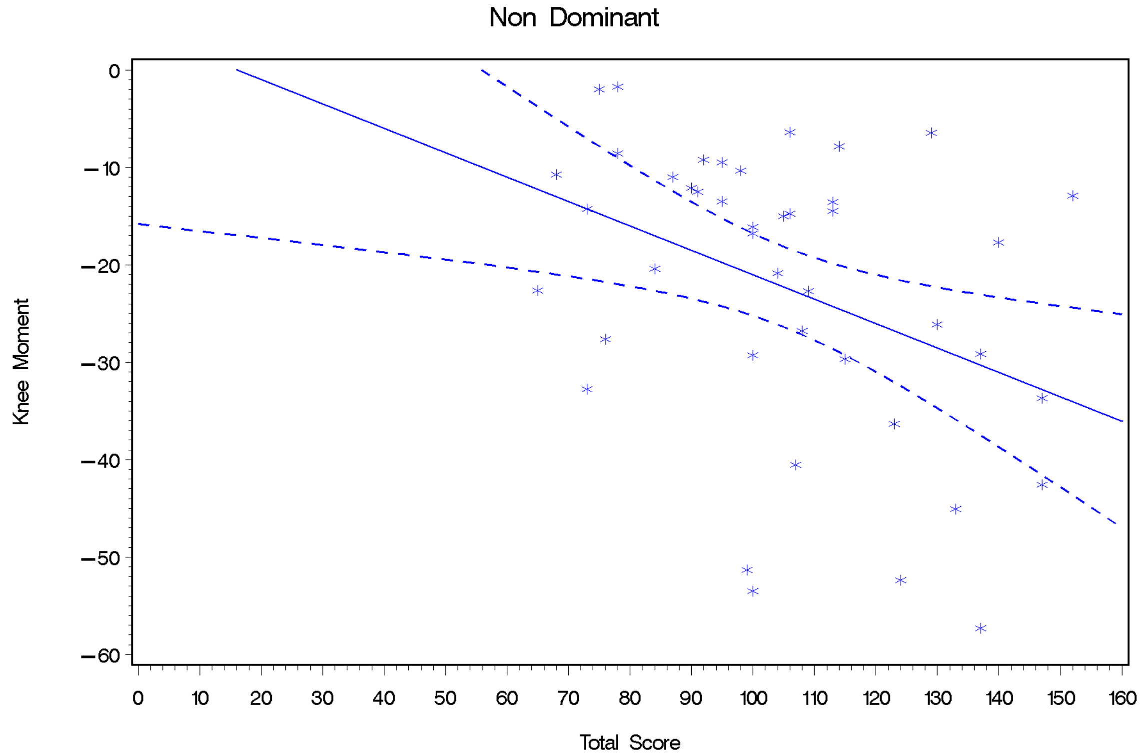


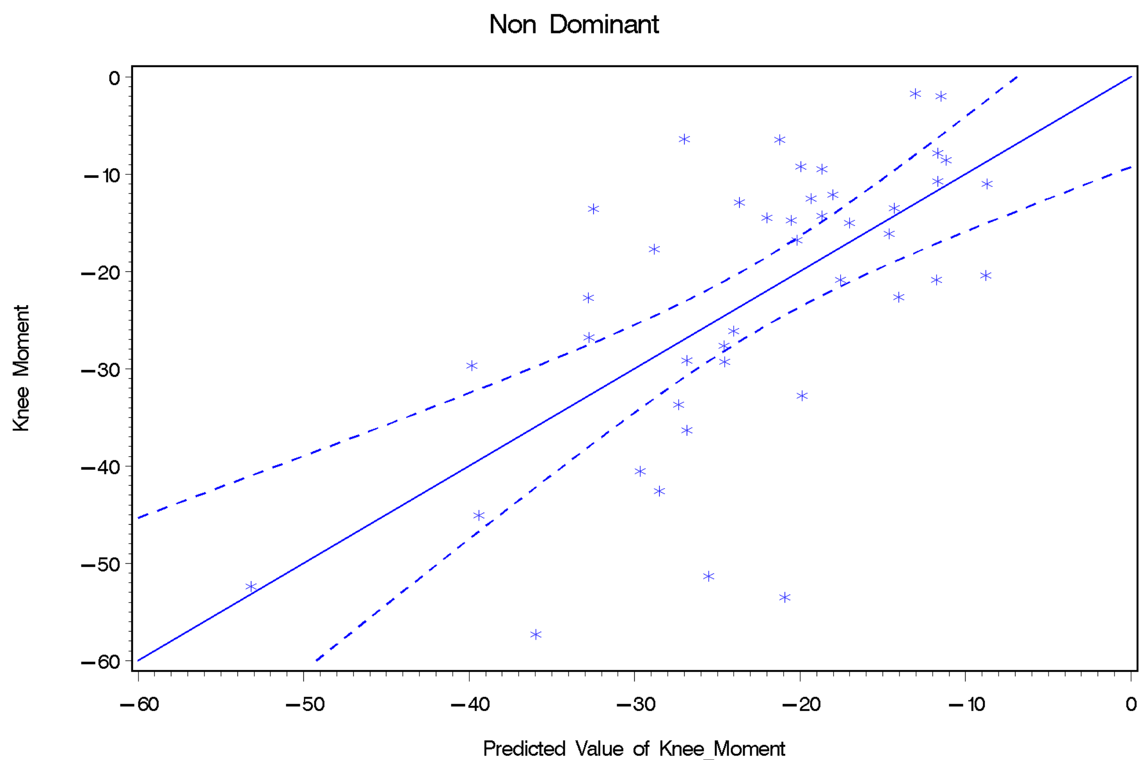



Non Dominant
Knee Moment
0
−10
−20
−30
−40
−50
−60
−130
−120
−110
−100
−90
−80
−70
−60
−50
−40
Knee Flexion ROM


Non Dominant
Knee Moment
0
−10
−20
−30
−40
−50
−60
1
2
3
4
5
6
7
Quad Ham Ratio

Non-dominant Knee Correlation (Pedictions)





Conclusions

This study examined the accuracy of a previously published nomogram (5 measures) in predicting the risk of sustaining an ACL injury as measured by knee moment (i.e., knee abduction torque) in 44 subjects with bilateral measurements. Of the 5 knee measures included in the nomogram, only 3 were associated with the risk of ACL injury: knee valgus motion, mass and tibia length. Two other measures of the nomogram (knee flexion range of motion and quad/ham ratio) did not have a significant correlation with the risk of ACL injury. The nomogram explained only 41% of the variability in the risk of ACL injury. Therefore, it is not possible to have an accurate prediction of the risk of an ACL injury with the 5 measures included in the nomogram.

Future directions

In future studies, the researcher would like to collect data from a larger sample of subjects to generate more precise estimates. The researcher also plans to examine the potential predictive value of other factors (e.g., height, age, BMI, activity levels, previous history, radiographic markers) not included in the current analysis.

Sources-Works Cited

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Bates, Nathaniel A., PhD, and Timothy E. Hewett, PhD. "Motion Analysis and the Anterior Cruciate Ligament: Classification of Injury Risk." *Knee Sure* (2015): n. pag. Print.

Hewett, Timothy E., PhD, Gregory D. Myer, MS, and Kevin R. Ford, MS. "Biomechanical Measures of Neuromuscular Control and Values Loading of the Knee Predict Anterior Cruciate Ligament Injury Risk in Female Athletes." *The American Journal of Sports Medicine* 33 (n.d.): n. pag. Print.

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Appendix

Dominant Knee

```
                            The REG Procedure
                              Model: MODEL1
              Dependent Variable: Knee_Moment Knee Moment
                        Stepwise Selection: Step 3
Variable Keen_Valgus_Motion Entered: R-Square = 0.2582 and C(p) = 2.8429

                          Analysis of Variance
                                   Sum of          Mean
  Source                 DF       Squares        Square  F Value  Pr > F

  Model                   3    2348.36556     782.78852     4.52  0.0081
  Error                  39    6748.52411     173.03908
  Corrected Total        42    9096.88966

                      Parameter    Standard
Variable               Estimate       Error  Type II SS F Value Pr > F

Intercept             -46.37995    26.72825   521.03132    3.01 0.0906
Mass                   -0.62057     0.18907  1864.12222   10.77 0.0022
Tibia_Length            1.89685     0.85607   849.54903    4.91 0.0326
Keen_Valgus_Motion      0.70833     0.40282   535.05054    3.09 0.0865
                Bounds on condition number: 1.6755, 13.079
------------------------------------------------------------------------
 All variables left in the model are significant at the 0.2000 level.
No other variable met the 0.2000 significance level for entry into the model.

                     Summary of Stepwise Selection
     Variable           Variable                             Number
Step Entered            Removed            Label             Vars In

   1  Mass                                                        1
   2  Tibia_Length                          Tibia Length          2
   3  Keen_Valgus_Motion                    Keen Valgus Motion    3

                     Summary of Stepwise Selection
            Partial      Model
       Step R-Square    R-Square      C(p)       F Value    Pr > F

         1    0.0980      0.0980      7.0121        4.45    0.0409
         2    0.1013      0.1993      3.8432        5.06    0.0300
         3    0.0588      0.2582      2.8429        3.09    0.0865
```

Non Dominant Knee

The REG Procedure
Model: MODEL1
Dependent Variable: Knee_Moment Knee Moment
Stepwise Selection: Step 3
Variable Tibia_Length Entered: R-Square = 0.4079 and C(p) = 2.7340

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	3658.46200	1219.48733	8.96	0.0001
Error	39	5309.50500	136.14115		
Corrected Total	42	8967.96700			

Variable	Parameter Estimate	Standard Error	Type II SS	F Value	Pr > F
Intercept	-27.59948	24.79253	168.71345	1.24	0.2724
Mass	-0.60075	0.16773	1746.40136	12.83	0.0009
Tibia_Length	1.43146	0.77440	465.17831	3.42	0.0721
Keen_Valgus_Motion	1.27628	0.33287	2001.33932	14.70	0.0004

Bounds on condition number: 1.7427, 13.527

All variables left in the model are significant at the 0.2000 level. No other variable met the 0.2000 significance level for entry into the model.

Summary of Stepwise Selection

Step	Variable Entered	Variable Removed	Label	Number Vars In
1	Keen_Valgus_Motion		Keen Valgus Motion	1
2	Mass			2
3	Tibia_Length		Tibia Length	3

Summary of Stepwise Selection

Step	Partial R-Square	Model R-Square	C(p)	F Value	Pr > F
1	0.2104	0.2104	11.3269	10.92	0.0020
2	0.1457	0.3561	4.0400	9.05	0.0045
3	0.0519	0.4079	2.7340	3.42	0.0721