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Characterizing the recovery trajectories of knee range of motion for one year after total knee replacement

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ABSTRACT

Design: Retrospective analysis of routinely collected clinical data.

Objective: This study modeled the recovery in knee flexion and extension range of motion (ROM) over a 1-year after total knee replacement (TKR).

Background: Recovery after TKR has been characterized for self-reported pain and functional status. Literature describing target knee ROM at different follow-up periods after TKR is scarce.

Methods: Data were extracted for patients who had undergone TKR at a tertiary care hospital at 2, 8, 12, 26, and 52 weeks after TKR. A linear mixed effects growth model was constructed that investigated the following covariates age, sex, pre-TKR range, body mass index, duration of symptoms, and their interaction with weeks post-TKR.

Results: Of the 559 patients included (age 64.8 ± 8.5 years), 370 were women and 189 were men. Knee ROM showed the greatest change during the first 12-weeks after TKR, plateauing by 26-weeks. For an average patient, knee flexion increased from approximately 100º 2-weeks post TKR to 117º 52-weeks post TKR. Knee extension increased from approximately 3º knee flexion 2-weeks post TKR to 1º flexion 52-weeks post TKR.

Conclusions: The results showed that the maximum gains in knee ROM should be expected within the first 12 weeks with small changes occurring up to 26 weeks after TKR. In addition, age and pre-surgery knee ROM are associated with the gains in knee ROM and should be factored into the estimation of expected knee ROM at a given follow-up interval after TKR.

INTRODUCTION

The rates of total knee replacement (TKR) surgeries performed each year have seen a substantial increase over the past 2 decades in the USA (Cram et al., 2012; Kurtz et al., 2005). These rates are expected to increase by 3 million procedures per year by year 2030 compared to 400,000 procedures that were performed in the year 2003 (Kurtz, Ong, Lau, Mowat, & Halpern, 2007). It is widely accepted that the TKR surgery poses a significant burden to socioeconomic and healthcare systems (Patel, Pavlou, Mujica-Mota, & Toms, 2015; Peel et al., 2015; Piscitelli et al., 2012). The cost of managing a primary TKR can be as high as $57,000 with high out-of-pocket expenses ("Comprehensive Care for Joint Replacement (CJR) Model," 2015). With the advent of advanced surgical techniques, length of stay in acute care immediately following TKR has substantially reduced (Kehlet & Thienpont, 2013), in many cases patients are discharged on the same day of surgery (Berger, Kusuma, Sanders, Thill, & Sporer, 2009; Berger et al., 2005). This would logically place more emphasis and expectations on home-based rehabilitation, inpatient rehabilitation facilities, and/or outpatient physical therapy as the primary means of improving lower extremity functions following TKR. Therefore, it is essential for physical therapists to be familiar with the rehabilitation needs and expected trajectory of recovery along the continuum in individuals who undergo TKR.

Knee range of motion (ROM) is arguably one of the most common measures used by physical therapists as well as orthopedic surgeons to gauge the recovery in patients following TKR (Mont, Banerjee, Jauregui, Cherian, & Kapadia, 2015). In particular, changes in active and/or passive ROM of knee flexion, knee flexion contracture, and active knee extension are closely monitored. It is unclear whether achieving greater knee ROM after TKR is critical for improvement in the quality of life or satisfaction after the TKR. Some research has clearly indicated that post-operative recovery of knee ROM after TKR is strongly associated with patient satisfaction (Ali et al., 2014; Kim, Chang, Kang, Kim, & Seong, 2009; Williams et al., 2013), others disagree with this notion (Devers et al., 2011; Miner, Lingard, Wright, Sledge, & Katz, 2003). Nonetheless, it is clear that attaining adequate ROM of knee flexion and extension precedes the gains in performing activities of daily living (ADL) and instrumental activities of daily living (Devers et al., 2011; Mai et al., 2012; Miner et al., 2003).

The optimal knee flexion ROM required to achieve a satisfactory level of functioning after TKR has been defined to be as low as 95º (Miner et al., 2003) to as high as 130º (Devers et al., 2011) depending on which specific function needs to be completed satisfactorily. Optimal knee flexion required to perform specific functions can also depend on cultural attributes of patients where they may kneel or sit cross-legged for eating or praying. Physical therapists being one of the primary caregivers addressing deficits in the knee ROM after TKR should dedicate due attention in monitoring the changes in knee ROM in a patient after TKR. Evidence-based information regarding expected improvements in the knee ROM over the continuum of care after TKR can facilitate delivery of physical therapy in a multitude of ways. For example, it can assist physical therapists in setting treatment goals, communicating with the surgeons and the insurance companies regarding anticipated recovery of a patient, monitoring the outcomes, and most importantly engaging in a meaningful discussion with the patients and their caregivers in aligning their expectations regarding the rehabilitation outcomes. Recovery trajectories defining expected changes in intensity of knee pain (Page et al., 2015), functional independence (Bindawas et al., 2014), and activity limitations and societal participation (Davis et al., 2011; Riddle, Perera, Stratford, Jiranek, & Dumenci, 2013) have all been defined.

Stratford et al (2010) provided the expected recovery trajectory of knee flexion and extension ROM over a 1-year period after TKR. Their research outlined specific strategies in determining whether a patient is meeting expected recovery targets for the knee ROM after TKR, how physical therapists can calculate error associated with a single ROM measurement and the amount of change they would want to see in the measured ROM, and importantly what should be the reassessment interval for that patient to assess such change. One of the key limitations of their work, however, was that the knee ROM trajectories were modeled based on a smaller sample of 74 patients. The purpose of this research study was to build on the preliminary work by modeling knee flexion and extension ROM recovery trajectories over a 1-year period post TKR using a much large sample.

METHODS

This was a sample of convenience and included all patients who met the eligibility criteria. Data for the patients who underwent TKR for osteoarthritis (OA) of the knee at the Department of Orthopedic Surgery, Cabell Huntington Hospital (CHH), Huntington, West Virginia between February 2009 and February 2014 were extracted from existing electronic patient charts. All the data were extracted by three entry-level physical therapy students. A standardized 'Data Extraction Form' was developed for the purposes of this study. Prior to initiating the data extraction process, pilot testing of this form occurred where all the three students extracted data on the same set of 5 patients to ensure consistency in reading and extracting information from the medical charts. The data were extracted from the practice of one orthopedic surgeon (AO). As per this surgeon's protocol, patients were discharged to inpatient rehabilitation unit from the acute inpatient orthopedic unit once they were medically stable. Also, most patients were allowed weight-bearing on the operated lower extremity within the limits of their pain tolerance. Patients undergoing TKR revision or bilateral TKR at the time of surgery and those with cognitive impairments were excluded. The study protocol was approved by the Institutional Review Board at Marshall University.

The Data Extraction Form captured the information concerning the anthropometric, demographic, and health variables for each patient extracted from their pre-operative visit. The variables included age, sex, marital status height, weight, duration of symptoms, the presence of diabetes, hypertension, depression, LBP, or other health conditions. Body mass index (BMI) was calculated from the height and weight of a patient. Patients with BMI of ≥30 were considered obese. Comorbidity count was calculated as reflective of the number of medical conditions present other than those listed above. For the purposes of data extraction, the joint being replaced was considered as the unit of analysis.

Study Design

We applied a fixed occasion study design with knee flexion and extension ROM assessed at 2, 8, 12, 26, and 52 weeks after TKR. These assessments corresponded to scheduled follow-up appointments with the surgeon.

Knee Joint Range of Motion

All measurements were obtained by the same surgeon (AO) using the standardized techniques (Norkin & White, 2016). For assessing knee flexion, patients were positioned in supine on an examination table with the operated knee fully extended and hips in neutral flexion and abduction. The fulcrum of the goniometer was placed over the lateral epicondyle of the femur. The proximal and distal arms were placed along the lateral midlines of femur and fibula respectively with the goniometer reading 0° starting position. Patients were asked to flex their knee as much as possible with the orthopedic surgeon applying overpressure before recording the joint angle for knee flexion. For assessing knee extension, patients were placed in the same starting position as that described for assessing knee flexion with the goniometer placed along the same landmarks. Patients were asked to extend the knee as much as possible with the orthopedic surgeon applying overpressure before recording the joint angle for knee extension. ROM was recorded as degrees of knee flexion or hyperextension if the range exceeded zero degrees.

Data Analyses

Data were analyzed using STATA version 14.2. Patients' characteristics and variable values were summarized as means and standard deviations for continuous data, and proportions or counts for categorical data.

To obtain an impression of the change in knee flexion and extension over time, we plotted knee ROM against weeks post-TKR. Based on the observed curves coupled with a fixed occasion design, we applied a linear mixed effects model. A mixed-effects model is a linear model in which some parameters have both fixed and random effects. For the analysis of longitudinal data, the fixed effects parameters describe the average change in the population of interest and their model coefficients are interpreted similarly to those of multiple regression. The random effects describe the growth of individuals and these are represented as deviations from the corresponding fixed effects terms. The variances of the random effects terms were also obtained and interpreted as the extent to which individuals' parameters (i.e., intercepts and slopes) differed.

Our approach to model building was to sequentially evaluate random intercept and random slope models with independent, exchangeable, and unstructured variance structures. Separate models were generated for dependent variables knee flexion and extension. In addition to weeks post-TKR, coded as a dummy variable in accordance with our fixed occasion design, candidate variables included age, sex, pre-TKR range, BMI, duration of symptoms, and their interactions with weeks post-TKR. A manual backwards elimination approach was applied to identify the most parsimonious growth models for knee flexion and extension. A variable was maintained in the model if its coefficient's 95% confidence interval excluded the value of zero. Once the final model for each analysis was identified, we performed residual analyses that included an assessment of the normality and occasion specific homogeneity of variances. Owing to the relatively large sample size, our assessments were based on inspection of the residual plots. When we suspected deviations from the requisite assumptions, we applied robust variance estimates.

RESULTS

Characteristics of Patients

A total of 624 patients had undergone primary TKR at the Department of Orthopedic Surgery, CHH between February 2009 and February 2014. Sixty-five patients did not have sufficient follow-up data for the knee ROM and were excluded from the study. Of the remaining 559 patients that were included in the study (age 64.8 ± 8.5 years), 370 were women and 189 were men. In the cohort, 281 patients underwent a right TKR and 278 patients had left TKR. Table 1 shows the characteristics of patients that met the inclusion criteria and were included in the study.

Modeling Knee Flexion ROM

Our initial flexion model contained weeks post-TKR only and included random intercept and slope terms with an unstructured covariance structure. Level 1 residuals were consistent with a normal distribution and were homogeneous across occasions. Level 2 residuals displayed a modest negative skew; however, they were reasonably consistent with a normal distribution. A summary of this model's coefficients and variances components are displayed in the second column of Table 2. Applying the fixed coefficients in this model as an example, a patient's predicted flexion range is obtained by substituting the post-TKR occasion of interest into the following expression:

Flexion range = 99.87+11.48(week8)+14.52(week12)+16.38(week26)+17.54(week52),

where the week of interest takes on the value of "1" and all other weeks are assigned a value of "0". The constant term of 99.87 represents the predictive range at 2-weeks post-TKR. For example, the predicted range for a patient at 12 weeks post-TKR would be 114.39 (i.e., 99.87 + 14.52). Figure 1a displays the flexion growth curve for the weeks only model.

When potential covariates were evaluated, we found that age, pre-TKR range and the interaction of weeks and pre-TKR added to the predictive accuracy of the previous model containing weeks only. The result from this analysis is presented in column three of Table 2. Predicted flexion growth curves for pre-TKR ranges from 70 to 110 degrees for a 65-year old (approximate mean age in our sample) are displayed in Figure 1b. These curves were obtained by applying the coefficients in column three of Table 2. To obtain a predicted value for a patient with an age different from 65, one would determine the difference in years, multiply this by the age coefficient of 0.17, and add or subtract it to the value reported on the appropriate curve in Figure 1b. For example, suppose a 70-year-old patient had a pre-TKR flexion range of 110 degrees. This person's predicted range at 12-weeks post-TKR would be approximately 118.5 degrees (117.6 + 0.17(70-65)).

Modeling Knee Extension ROM

Similar to the initial flexion model, the initial extension model contained weeks post-TKR only and included random intercept and slope terms with an unstructured covariance structure. The distribution of Level 1 residuals displayed were somewhat leptokurtic; however, they were reasonably consistent with a normal distribution. The variance of Level 1 residuals were reasonably homogeneous; however, there appeared to be slightly greater variability at earlier occasions post-TKR. The Level 2 intercept residuals displayed a positive skew and the Level 2 slope residuals were leptokurtic. Given these findings, the extension models applied a robust variance estimate. This model's coefficients are reported in column four of Table 2. Figure 2a displays the growth curve for the weeks only model.

The only significant covariate to enter the extension model in addition to weeks was pre-TKR extension. With this covariate in the model, the unstructured covariance structure performed no better than an independent covariance structure. Accordingly, the final extension model applied random intercepts and slopes with variables weeks post-TKR and pre-TKR extension range, and an independent covariance structure. Coefficients for this model are reported in column five of Table 2. Predicted extension growth curves for pre-TKR extension ranges from 0 to 20 degrees are shown in Figure 2b.

DISCUSSION

Having the ability to determine if a patient is meeting expected recovery targets for the knee ROM following TKR can greatly assist physical therapists in setting treatment goals, monitoring progress, and making discharge decisions. Our investigation was built on previous work that examined the recovery trajectories in knee ROM after TKR (Stratford, Kennedy, & Robarts, 2010), albeit using a much larger cohort. The present study provided the trajectories of improvement in knee ROM at 8, 12, 26, and 52 weeks after TKR. The results indicated that the greatest recovery in knee ROM should be expected within 12 weeks after TKR with very small further gains in both knee flexion (up to 3º) and extension (0.75º) ROM up to 52 weeks after TKR. Lastly, the results also highlighted that age and pre-surgery knee ROM are associated with the gains in knee ROM and should be factored into the estimation of expected knee ROM at a given follow-up interval after TKR. In instances where the pre-surgery knee ROM is not known, the weeks-only model could be used to estimate the expected knee ROM at a given follow-up interval.

Research assessing the outcomes of TKR mostly describe recovery in self-reported pain and function as well as physical performance tests (Artz et al., 2015; Bindawas et al., 2014; Davis et al., 2011). However, there is a growing consensus that reports of pain and functional recovery do not provide accurate representation of actual gains in functional ability (Mizner et al., 2011; Pua et al., 2013; Stevens-Lapsley, Schenkman, & Dayton, 2011; Stratford, Kennedy, Maly, & Macintyre, 2010). In particular, the patient may overestimate his/her functional ability in the early phase after TKR when pharmacological pain management may allow them to experience greater confidence in mobility and functions. It has also been shown that performance measures provide a more accurate representation of person's overall activity level (Stratford & Kennedy, 2006). It needs to be emphasized here that gains in knee ROM do not necessarily capture recovery in functional performance after TKR. In particular, the relationship between knee ROM and measures assessing functional performance is frequently discordant in patients with TKR (McClelland, Feller, Menz, & Webster, 2017; Zeni & Snyder-Mackler, 2010). The association between knee ROM and patient satisfaction after TKR has also been shown to be poor (Meneghini et al., 2007; Narayan, Thomas, & Kumar, 2009). Nonetheless, rehabilitation practitioners commonly utilize the gains in the knee ROM to gauge the recovery after TKR. Assessment of knee ROM is also an integral component of scoring systems used by surgeons to assess the recovery after TKR (Mont et al., 2015). Lastly, the changes in knee ROM are directly measurable and allow physical therapists to contextualize overall recovery in a patient. Therefore, results of this study have excellent clinical utility for the physical therapists in accurately tracking recovery in knee ROM for patients at various time points after TKR.

Our finding that the maximum recovery in knee ROM occurs during the first 12 weeks (up to 114º for knee flexion and -2º of extension) after TKR with small gains observed until 52 weeks (up to 3º and 1º additional gains for knee flexion and knee extension respectively) is consistent with previous research that found similar recovery profiles (Cupido, Peterson, Sutherland, Ayeni, & Stratford, 2014; Mizner, Petterson, & Snyder-Mackler, 2005; Stratford, Kennedy, & Robarts, 2010; Thomsen, Husted, Otte, Holm, & Troelsen, 2013). Interestingly, research examining the trajectories of improvement in self-reported pain and functions reported the maximum gains to occur in the 3 months after the TKR (Davis et al., 2011; Lenguerrand et al., 2016). Since the increase in ROM precedes the improvement in functional ability (Devers et al., 2011; Meneghini et al., 2007), it is reasonable to expect concurrence in the recovery of ROM and measures of pain and functions. Similarly, functional performance also shows a maximum change in the initial 12-16 weeks after surgery. Measures assessing functional performance such as Timed up and go test, 6-minute walk test (6MWT), and Stair test all showed maximum recovery in the first 12 weeks after TKR (Kennedy, Stratford, Hanna, Wessel, & Gollish, 2006). Kennedy et al. (2008) further substantiated that the maximum gains in the 6MWT occurred in the first 12 weeks with small gains observed up to 26 weeks. In summary, most recovery across different indices of functions occurs in the first 12-16 weeks after TKR. Therefore, physical therapists should closely monitor the gains in their patients during this phase.

The results of this study concur with Stratford et al (2010) in that pre-surgery knee ROM has a significant association but of small magnitude with knee ROM assessed after TKR. For example, a 10º higher knee flexion ROM pre-surgery can result in an additional gain of 2.5º and 10º higher knee extension ROM pre-surgery can result in an additional gain of 1.2º after TKR. The new finding in our study was that age at the time of surgery was associated with post-TKR knee flexion ROM but not knee extension ROM. Interestingly, being 10 years older resulted in an additional gain of 1.7º knee flexion post TKR. This was an unexpected finding since older age has been shown to be negatively associated with self-reported pain and function (Mehta, Perruccio, Palaganas, & Davis, 2015; Schroer, Diesfeld, LeMarr, Morton, & Reedy, 2016). However, the clinical relevance of this finding is limited due to the smaller magnitude of the association between age and recovery in knee flexion post TKR.

The maximum knee flexion at 1 year follow-up has been observed to be as low as 98º (Rajan, Pack, Jackson, Gillies, & Asirvatham, 2004) to as high as 130º (Bin & Nam, 2007). The extent of recovery in knee ROM over a longer term after TKR depends on several factors such as age, pre-surgery knee ROM, and most importantly, implant design (Bin & Nam, 2007). Previous research has clearly established the required knee ROM in order to successfully perform functional activities such as walking (<90º), climbing stairs or sitting down/getting up from a chair (between 90º-120º), or entering a bathtub (135º) (Rowe, Myles, Walker, & Nutton, 2000). Knee flexion ROM of at least 110º or greater is required for optimal performance in functional activities following TKR (Devers et al., 2011; Meneghini et al., 2007) with knee flexion >120º not yielding additional functional gains (Meneghini et al., 2007; Thomsen et al., 2013). In theory, most patients achieved the required knee ROM to transition to functional tasks at 12 weeks (expected knee flexion being 113º accounting for lower bound of CI shown in table 2) after the TKR.

One of the limitations of this study is that the trajectories in improvements of self-reported pain and functional status after TKR were not examined nor did we assess whether such recovery is concurrent or follow the recovery in knee ROM. Our analyses were based on the data available from follow-up visits to an orthopedic clinic after TKR where such assessment were not performed for all the patients. Secondly, our results are limited to tertiary care hospital located in rural part of the USA. We cannot confirmatively deduce whether the knee ROM outcomes are similar between the large urban health centers and hospitals located in rural areas. However, self-reported functional outcomes have been found to be similar between the urban and rural health centers (Gandhi, Tso, Davis, & Mahomed, 2009); therefore, we would cautiously argue that no differences between the knee ROM should be expected between patients operated in urban center versus those operated in rural centers. Thirdly, there is a potential for measurement error in the assessment of knee ROM between patients and follow-up visits. However, we consider this error to be random versus systematic given that one orthopedic surgeon collected all the data using standardized techniques described earlier in this manuscript. Lastly, we did not calculate sample size estimates since our sample was that of convenience. The relatively large sample (N=559) assessed in the study, however, should lend credence to the findings of our study.

CONCLUSION

The results of this study concur with previous research that the maximum gains in knee ROM should be expected within the first 12 weeks after the TKR with very minimal changes occurring up to 26 weeks after TKR. The conditional model consisting pre-surgery ROM and age provides marginally better estimates for the expected knee ROM after TKR; however, the weeks only model is sufficiently precise and can be used to determine the expected knee ROM in a given patient especially when pre-surgery knee ROM is not available to the therapist. Future research should focus on validating the recovery trajectories found in this study in a variable occasion design where the assessments are not conducted at similar follow-up intervals after TKR.

DECLARATION OF INTEREST

Dr. Ali Oliashirazi is a constultant for DePuy Synthes.

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TABLE 1. Characteristics of the Patients (N = 559)

Variable	N	Mean ± SD, Median (IQR), or Percentage
Age (years)		64.8 ± 8.5
Sex		
Women	370	66.2 %
Men	189	33.8 %
Duration of symptoms (weeks)		36 (6, 72)
Comorbidity Count		2.8 ± 2.6
Side of Surgery		
Right	281	50.3 %
Left	278	49.7 %
Obesity		
No (BMI < 30)	254	45.4 %
Yes (BMI ≥ 30)	305	54.6 %

SD, standard deviation; IQR, 25% and 75% quartile range; BMI, Body Mass Index

TABLE 2. Estimated Fixed and Random Effects Coefficients for Knee Flexion and Extension Models

	Flexion ROM		Extension ROM	
Model	Weeks Only 550 patients 4.2/patient*	Weeks, Age, Pre-surgery ROM 171 patients 4.3/patient	Weeks Only 550 patients 4.2/patient	Weeks & Pre-ROM 239 patients 4.2/patient
	Regression Coefficients 95% CL†	Regression Coefficients 95% CL	Regression Coefficients 95% CL	Regression Coefficients 95% CL
Fixed Effects				
Week 8	11.48 (10.84, 12.13)	-1.43 (-7.87, 5.02)	-0.37 (-0.75, 0.01)	-0.69 (-1.30, -0.08)
Week 12	14.52 (13.87, 15.16)	0.79 (-5.65, 7.23)	-1.02 (-1.38, -0.65)	-1.14 (-1.74, -0.54)
Week 26	16.38 (15.59, 17.07)	1.15 (-5.92, 8.22)	-1.38 (-1.75, -1.00)	-1.60 (-2.21, -0.98)
Week 52	17.54 (16.7, 18.3)	4.25 (-4.54, 13.24)	-1.74 (-2.12, -1.36)	-1.87 (-2.55, -1.18)
Pre-surgery ROM		0.17 (0.09, 0.25)		0.13 (0.06, 0.20)
Week 8 x Preflex		0.13 (0.06, 0.20)		
Week 12 x Preflex		0.13 (0.06, 0.21)		
Week 26 x Preflex		0.15 (0.07, 0.23)		

Week 52 x Preflex		0.13 (0.03, 0.23)		
Age		0.17 (0.06, 0.29)		
Constant	99.87 (99.07, 100.65)	71.46 (60.89, 82.09)	2.76 (2.40, 3.12)	1.55 (0.58, 2.51)
Random Effects				
Weeks Variance	0.01 (0.01, 0.01)	0.01 (0.01, 0.02)	0.0009 (0.0002, 0.0035)	0.0015 (0.0003, 0.0069)
Constant Variance	57.64 (49.68, 66.89)	38.00 (28.56, 50.29)	8.67 (6.63, 11.32)	7.81 (4.77, 12.78)
Covariance	0.32 (0.19, 0.45)	0.34 (0.15, 0.53)	-0.05 (-0.099, -0.006)	
Residual Variance	25.91 (24.00, 27.98)	23.31 (20.34, 26.72)	5.47 (4.45, 6.72)	6.20 (4.86, 7.90)

*Average number of measurement occasions per patient

FIGURE 1a. Knee flexion growth curve (weeks only model)

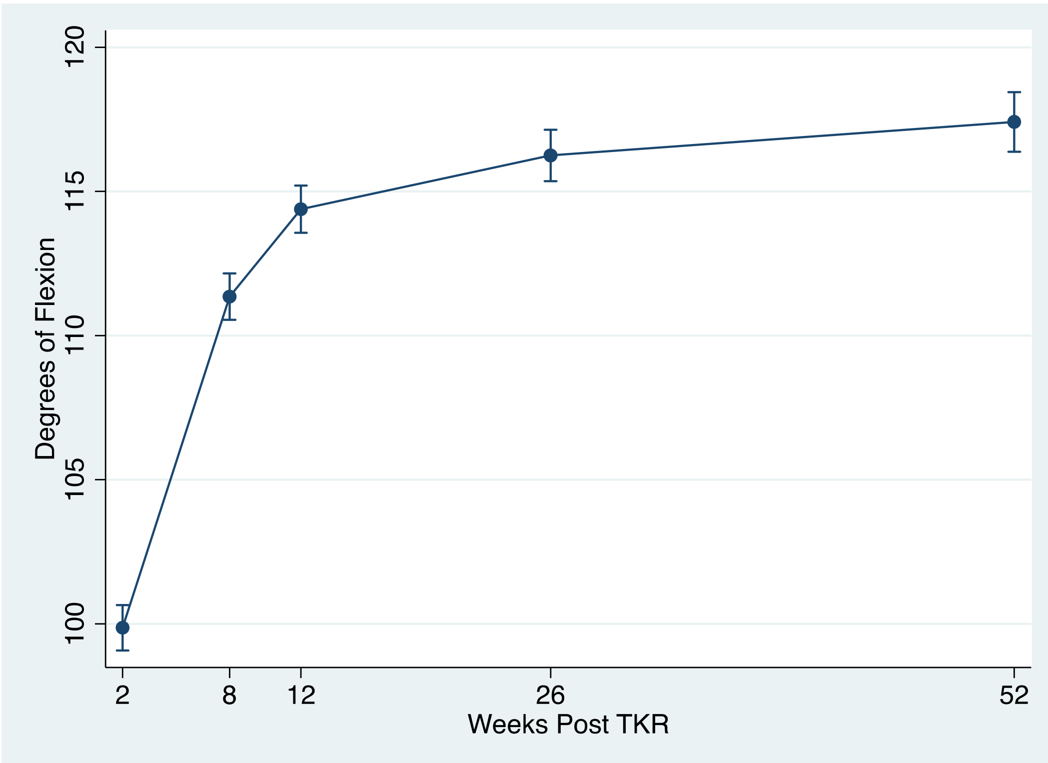

Figure 1b. Knee flexion growth curves (weeks, pre-flexion (preflex), age, weeks by pre-flexion interaction)

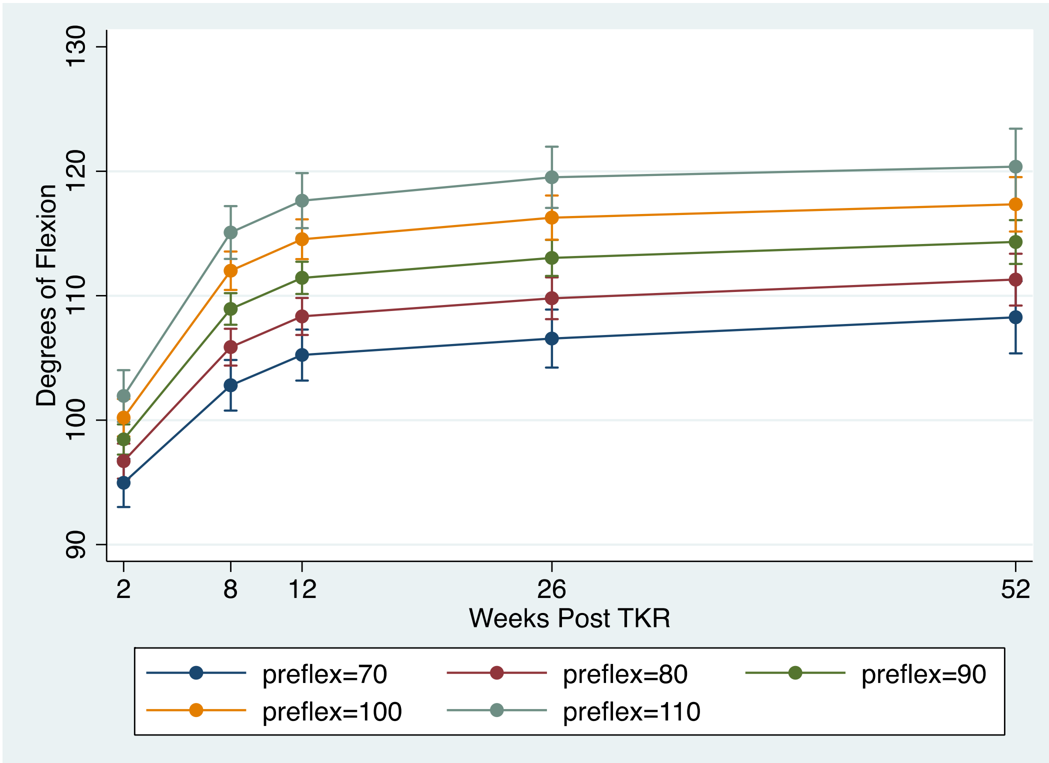

FIGURE 2a. Knee extension growth curve (weeks only model)

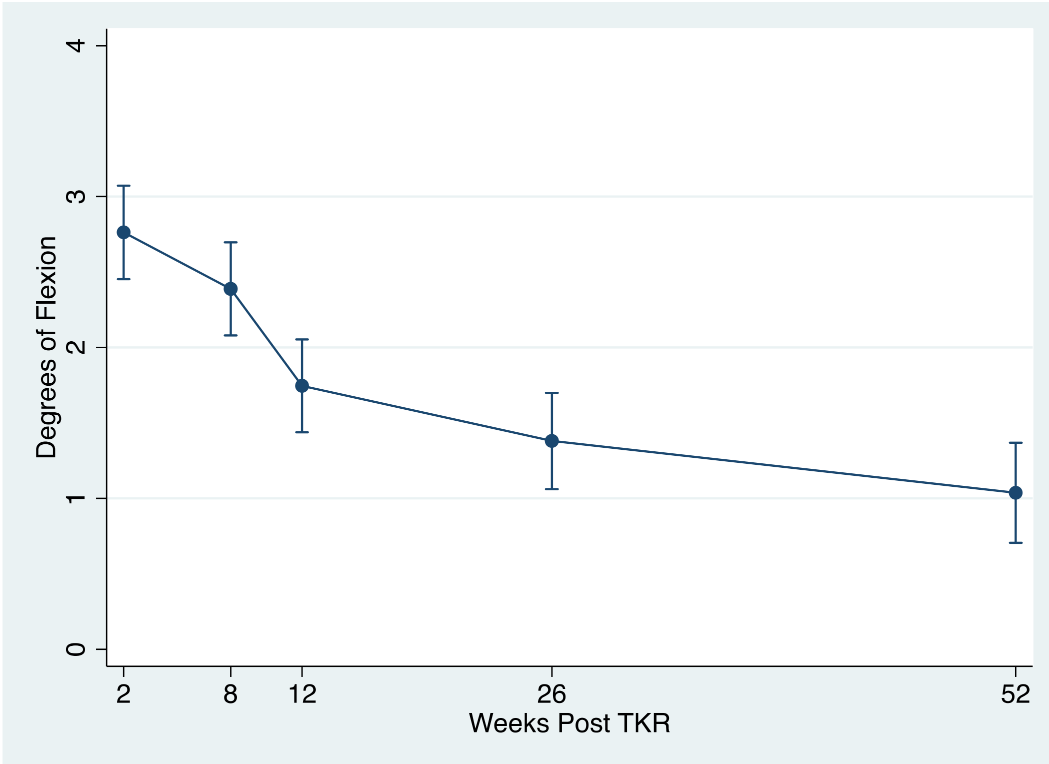

Figure 2b. Knee extension growth curves (weeks, pre-extension (preext))