Original Article

Clinical and Biomechanical Outcomes following Knee Extensor Mechanism Reconstruction

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Purpose: To evaluate clinical and biomechanical outcomes after knee extensor mechanism reconstruction (KEMR). **Methods:** Patients who underwent KEMR at our institution from 2011 to 2018 were identified. Patient-reported outcomes (Kujala, Lysholm, Tegner Activity Scale) were compiled at clinical follow-up. Isokinetic testing was conducted using the BioDex system 4 pro dynamometer at slow (60°/s), intermediate (180°/s), and fast (300°/s) speeds in a 9-patient subset. **Results:** From 2011 to 2018, 12 patients (12 knees, 10 male, 5 right, mean age: 54.3 ± standard deviation: 15.2 years) with KEM injuries requiring tendon reconstruction with a 1-year minimum follow up were identified. Postoperative follow-up was 42.6 months (range: 12.0-93.0 months). Procedures included patellar (7) and quadriceps tendon reconstruction (5). Postoperative versus preoperative Tegner Activity Scale scores demonstrated significant improvement (3.5 ± 2.5 vs 1.5 ± 1.2, n = 8, P = .05). Postoperative versus preoperative Kujala scores significantly improved (70.3 ± 11.7 vs 43.6 ± 15.7, n = 8, P = .010). There was significant improvement in preoperative to postoperative KEMR extension lag (29.4 ± 22.2° vs 0.83 ± 1.9°, P = .002). Clinically, there was no difference in passive range of motion between the operative and contralateral knee. BioDex testing demonstrated decreased maximum work generated from the operative versus contralateral knee at slow (70.4 ± 30.4 Joules vs 101.9 ± 40.6 J; P = .028), intermediate (52.0 ± 45.4 J vs 69.8 ± 63.7 J; P = .038), and fast (43.8 ± 41.7 J vs 57.5 ± 53.8 J; P = .050) speeds. Range of motion was less in the operative versus contralateral knee at all speeds: P = .011, .038, and .024. The average peak torque generated per body weight was smaller in the operative versus contralateral knee at slow speed (P = .038). **Conclusions:** Patients undergoing KEMR in this study have significantly improved clinical outcomes despite having strength deficits that persist postoperatively. **Level of Evidence:** Therapeutic Case Series, Level IV.

The majority of knee injuries compromising the extensor mechanism (quadriceps tendon, patella, and patellar tendon complex) function are often amenable to direct repair.[1-4] Delay in treatment after quadriceps or patellar tendon rupture, tendinopathy-associated rupture, degenerative rupture, failed tendon/patella direct repair, or extensive soft-tissue defects in the setting of fractures/bone loss are all associated with poor outcomes after attempted direct tendon repair.[5-7] In these scenarios, knee extensor mechanism reconstruction (KEMR) is one of the few solutions capable of restoring knee function.[3,8-10] Many KEMR techniques have been described, including reconstruction with hamstring autograft,[9,11-13] bone–patellar tendon–bone autograft,[14] Achilles tendon allograft,[15-17] quadriceps advancement flap,[18] and quadriceps allograft.[19]

Given the sparsity of this injury and reconstructive surgery, there have been few reports on postoperative strength or biomechanical testing despite positive patient outcomes from clinical and subjective measures.[3,8,9,14,20] Maffulli et al.[3] reported decreased strength postoperatively in patients who underwent KEMR at follow-up with reduced thigh muscle volume; however, the authors only assessed isometric strength to failure. As previous reports have suggested, the clinical applicability and relevance of static isometric testing with respect to athletic knee function is inferior to isokinetic testing.[21,22] Although there is some value in knee extensor maximum

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static strength measurements provided by traditional load-to-failure testing, these data are not representative of KEM activity during failure/rupture related injuries.[22-24] Belhaj et al.[20] performed a study assessing isokinetic strength after acute and chronic patellar tendon rupture repairs; however, they compared acute and chronic subject knee strength together rather than apart. One case report to date assesses knee extensor mechanism isokinetic strength testing at follow-up after KEMR with subjective recovery of strength; however, no objective measures are reported.[14]

Given the varying functional requirements of the knee during activities of daily living versus various rigorous athletics, a quantifiable biomechanical study assessing KEMR is of considerable value. The purpose of this study was to evaluate clinical and biomechanical outcomes after KEMR. We hypothesized that patients would have satisfactory clinical outcomes and biomechanical outcomes after KEMR.

Methods

Patient Selection

This retrospective study was approved by the institutional review board (protocol PRO S1500628) in which all participants provided informed written consent before participation in biomechanical testing. We reviewed our cases from 2011 to 2018 to identify patients suffering traumatic falls resulting in disruption of the knee extensor mechanism treated with KEMR. Our inclusion criteria involved any patient undergoing graft-augmented KEMR with a minimum of 1-year clinical follow-up. Any patient with history of a previous total knee arthroplasty was excluded from the study. Indications for KEMR included significant soft-tissue defects, degenerative/fibrotic soft-tissue changes, or a combination of both. Follow-up was recorded as the last clinical visit for each patient in the postoperative period. Preinjury Tegner Activity Scale scores were obtained by asking patients their functional status before initial failure of the KEM from each patient at the time of surgery. Patient-reported outcomes validated for knee injuries (visual analog scale pain score, Kujala score, Lysholm score, Tegner Activity Scale score) were determined retrospectively at last follow up.[25,26] Preoperative Kujala and Tegner Activity Scale scores also were obtained in an 8-patient subset retrospectively. Clinical range of motion (ROM) was determined using a goniometer. Minimal clinically important difference rate was calculated using a predetermined Kujala score difference threshold (9.5 points) from existing literature in reference to patellofemoral pain syndrome.[27,28]

Surgical Techniques

For all procedures, incision and surgical dissection were carried out overlying the quadriceps tendon, patella, or patellar tendon with adequate exposure of the tendinous defect in each patient. Any scar, degenerative soft tissue, and pathologic tendon was debrided until healthy tendon edges were dissected free and adequate patellar excursion was achieved. Graft length was measured out and tensioned to allow appropriate patellar excursion and knee ROM during time of fixation. Intraoperative fluoroscopic confirmation of normal patellar height and direct visualization of appropriate patellofemoral tracking was confirmed with excellent reconstruction integrity in each case.

Postoperative Rehabilitation Protocol

Postoperative rehabilitation protocol began with partial weightbearing with a hinged knee brace locked in extension for during ambulation. Gradual advancing of passive/active ROM to 30° flexion over the first 2 weeks adding 15° each week afterward until 90° was reached at 6 weeks from surgery. Then discontinuation of the brace and advancement of ROM with graduation to weightbearing as tolerated at the 12-week mark.

Biomechanical Testing

At the time of last follow-up, 9 patients received biomechanical testing of their KEM using the BioDex system 4 pro dynamometer (Biodex Corp., Shirley, NY), which has been validated for isokinetic testing of velocity, torque, and position measurements for the knee joint.[29] Patients were instructed appropriately and performed practice trials with the contralateral knees in the dynamometer before starting recorded trials to ensure proper device use and trial validity. The dynamometer was set to 3 speeds at which patients performed leg extension maneuvers in isokinetic fashion: slow (60°/s), intermediate (180°/s), and fast (300°/s). Patients performed 5 repetitions per leg on the slow speed, 10 repetitions on the intermediate speed, and 15 repetitions on the fast speed. The average maximum work generated per repetition (Joules), average peak torque generated per body weight (%), average ROM arc (degrees), and average time to maximum torque (milliseconds) was measured at all 3 speeds for the operative and contralateral knees.[29]

Statistics and Analysis

When possible, patients underwent biomechanical testing at the time of last clinical follow-up at a minimum of 1 year using the BioDex dynamometer (Biodex Corp.) to assess KEMR function. Patient-reported outcomes were compared in a paired fashion between preoperative and postoperative or preinjury and postoperative values depending on data availability. Biomechanical outcomes were compared in a paired fashion between the operative and contralateral knee for each patient across the 3 speeds separately. Nonparametric (Wilcoxon signed-rank) and parametric (Student *t* test) tests were both performed for all continuous variables analyzed. A P value less than .05 was deemed significant. The comparison was deemed significant only if the nonparametric P value was less than .05. Descriptive statistics for central tendency were calculated as means and dispersion was calculated as range or standard deviation.

Results

Operative Details

In patellar tendon reconstruction cases, grafts used included Achilles tendon–bone plug allograft (n = 3), hamstring autograft (n = 3), and tibialis anterior allograft (n = 1). In quadriceps tendon reconstruction cases, grafts used included Achilles soft-tissue allograft (n = 3) and a hamstring allograft (n = 2). Of the aforementioned KEMR cases, 6 patients also received quadriceps V-Y advancement flaps (Fig 1).

Patients 1-3 Operative Details: Patellar Tendon Reconstruction

An Achilles allograft was prepared with calcaneal bone plug by tubularizing the graft via whip stitch suturing. The tibial tubercle was exposed, and a trough was created with osteotomes to allow for fixation of the Achilles allograft (Fig 1). The bone plug was subsequently contoured, and a single lag screw was used for distal graft fixation keying into the tibial tubercle trough. Using the Krackow technique, the soft-tissue end was sutured onto the patellar periosteum and proximal patellar tendon stump (patients 1 and 2) or fixed into the inferior patellar pole with 3 suture anchors (Arthrex, Naples, FL) (patient 3).

Patient 4 Operative Details: Patellar Tendon Reconstruction

Ipsilateral hamstring tendon was harvested and tubularized, leaving the distal insertion site intact. A lateral-to-medial 5-mm tunnel was drilled in the patella, with care taken not to violate the anterior and posterior patellar cortices. A separate 5-mm tunnel was drilled slightly posterior to the tibial tubercle, with care taken to avoid fracturing the anterior cortex (Fig 1). The hamstring graft was guided through the patellar and subsequently tibial drill holes. The graft was fixed within the bone tunnels with PEEK (polyether ether ketone) interference screws (Arthrex) proximally and distally. Finally, the patellar tendon edges were both sutured together and to the graft.

Patient 5 Operative Details: Patellar Tendon Reconstruction

Ipsilateral hamstring tendon was harvested and tubularized at both ends. The graft was sutured to the proximal and distal patellar tendon stumps using the Krackow method while incorporating the patellar and tibial periosteum and paratenon with further sutures.

Patient 6 Operative Details: Patellar Tendon Reconstruction

A tibialis anterior allograft was tubularized at both ends. A lateral-to-medial 6-mm tunnel was drilled in the patella taking care not to violate the anterior and posterior patellar cortices. A separate 6-mm tunnel was drilled slightly posterior to the tibial tubercle, with care taken to avoid fracturing the anterior cortex. The tibialis anterior graft was guided through the patellar and subsequently tibial drill holes in a figure-of-eight fashion and tensioned to approximate the torn patellar tendon edges. The graft was sutured to the tendon edges, the patellar and tibial periosteum, and the paratenon for further fixation.

Patient 7 Operative Details: Patellar Tendon Reconstruction

A quadriceps V-Y advancement was performed (Fig 1). Ipsilateral hamstring tendon was harvested and tubularized, leaving the distal insertion site intact. A lateral-to-medial 5-mm tunnel was drilled in the patella, with care taken not to violate the anterior and posterior patellar cortices. Three suture anchors (Arthrex) were drilled and fixed into the inferior aspect of the patella and the suture ends were weaved through the proximal and distal patellar tendon edges using the Krackow method to approximate the tear. The hamstring graft was guided through the patellar drill hole and fixed to the lateral tibial tubercle with a soft-tissue anchor (Arthrex) along with suture to the tibial periosteum (Fig 1).

Patients 8-10 Operative Details: Quadriceps Tendon Reconstruction

A quadriceps V-Y advancement was performed (patients 8 and 9). An Achilles soft-tissue allograft was prepared by tubularizing the graft via whip stitch suturing. The graft was passed through the proximal quadriceps tendon stump in a figure-of-eight fashion. The graft–tendon fixation was reinforced with suture along with the figure-of-eight, whereas the graft ends were fixed to the superior pole of the patella with suture anchors (Arthrex) using a Krackow suturing configuration.

Patients 11-12 Operative Details: Quadriceps Tendon Reconstruction

A quadriceps V-Y advancement was performed (patient 11). A hamstring allograft was tubularized with whip stitch suturing. A lateral-to-medial 5.5-mm tunnel was drilled in the patella, with care taken not to violate the anterior and posterior patellar cortices. The graft was passed through the proximal quadriceps tendon stump in a Pulvertaft fashion, with care taken to anchor the graft–tendon interface with suture reinforcement while the graft ends were fixed to the superior pole of the

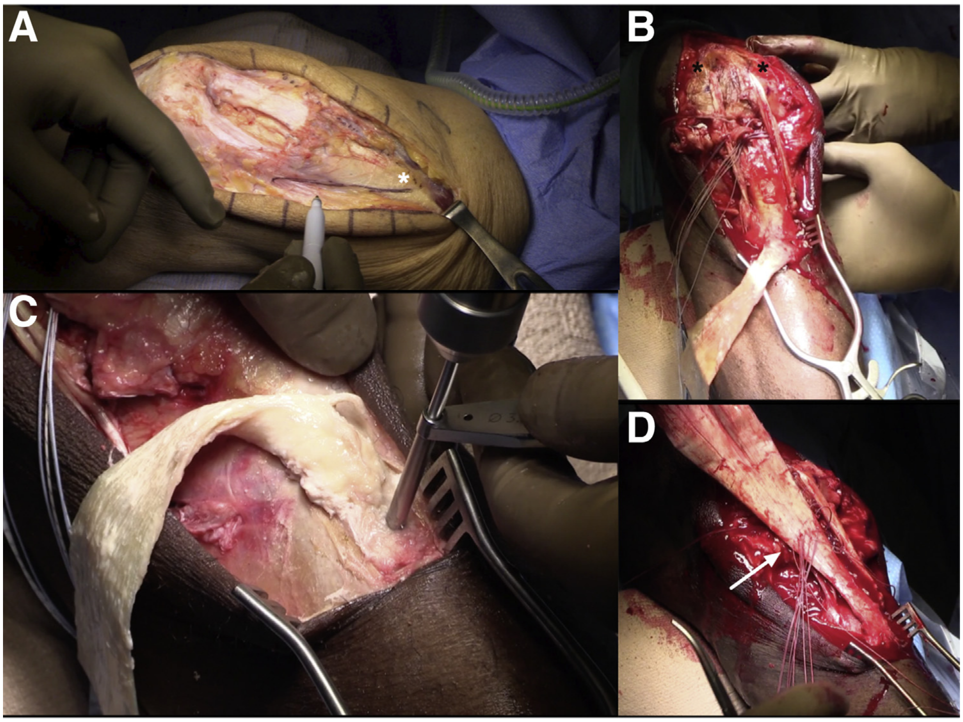

Fig 1. Surgical techniques for knee extensor mechanism reconstruction. A, Outline for a left knee quadriceps V-Y advancement flap with existing central defect at the tendon–patella interface; white star indicates the apex of the planned V-Y flap. B, Left knee fixation of Achilles tendon–bone plug allograft to the trough developed in the tibial tubercle. C, Left knee ipsilateral hamstring autograft is freed and passed through the proximal pole of the patella through a transosseous tunnel (black stars) and fixed at the tibial tubercle distally under tension with suture anchor. D, Left knee Achilles tendon–bone plug allograft is sutured into the proximal patellar tendon stump and patellar periosteum (white arrow) to reinforce tissue augmentation during reconstruction.

patella with suture anchors (BioComposite; Arthrex, Naples, FL; patient 11). The quadriceps tear was sutured together after adequate approximation using the Krackow method (patient 11). To bridge the soft-tissue defect, Achilles tendon soft-tissue allograft was tubularized with whip stitch suturing using SutureTape (Arthrex) and sutured to the proximal quadriceps tendon stump while being fixed to the patella with suture anchor (Arthrex) on the medial and lateral aspect of the centrally fixed hamstring graft (patient 12).

Clinical Outcomes

A total of 12 patients (mean age: 54.3 years ± standard deviation: 15.2 years, range: 35-80 years; 12 knees, 10 males, 5 right knees) were identified who met the study inclusion and exclusion criteria, of whom 9 patients underwent successful BioDex dynamometer (Biodex Corp.) testing at last visit. All patients except one received KEMR after failed KEM direct repair (all biomechanical outcomes were performed on KEMR cases with a history of direct repair failure). The average time between direct repair and revision KEMR was 17 ± 34.8 months (range: 1-120 months). Average postoperative follow-up was 42.6 ± 25.3 months (range: 12.0-93.0 months). No patients had reconstruction failure. Ten of twelve patients had no clinical evidence of extensor lag against resistance. The remaining 2 patients had a lag of 5° each at last follow-up. There was significant improvement in preoperative to postoperative KEMR extension lag (29.4 ± 22.2° vs 0.83 ± 1.9°, P = .002). There was no difference in preoperative to postoperative passive ROM arc as detected through physical examination (127.5 ± 8.4° vs 123.3 ± 11.9°, P = .17). Tabulated outcomes of each patient identified via the aforementioned surgical technique descriptions are presented in Table 1.

Patient-Reported Outcomes

Postoperative versus preoperative Tegner Activity Scale scores demonstrated significant improvement (3.5 ± 2.5 vs 1.5 ± 1.2, n = 8, P = .050). Postoperative versus preinjury Tegner Activity Scale scores were significantly decreased (3.9 ± 2.6 vs 5.8 ± 2.5, n = 12, P = .011). Average postoperative Kujala score across all patients was 70.8 ± 13.3. Postoperative versus preoperative Kujala scores significantly improved (70.3 ± 11.7 vs 43.6 ± 15.7, n = 8, P = .010). Average postoperative visual analog scale pain score across all patients was 2.0 ± 2.4. Average postoperative Lysholm score across all patients was 80.5 ± 13.4. Minimal clinically important difference was met in 75% of our 8-patient subgroup.

Biomechanical Outcomes

There was significantly decreased maximum work generated per repetition from the operative versus contralateral knee at slow (70.4 ± 30.4 Joules vs 101.9 ± 40.6 J; P = .028), intermediate (52.0 ± 45.4 J vs 69.8 ± 63.7 J; P = 0.038), and fast (43.8 ± 41.7 J vs 57.5 ± 53.8 J; P = .050) speeds. The ROM arc was smaller in the operative versus contralateral knee at slow (79.0 ± 7.4° vs 86.2 ± 9.8°, P = .011), intermediate (80.8 ± 12.5° vs 86.8 ± 11.8°, P = .038), and fast (79.1 ± 12.8° vs 85.7 ± 11.7°, P = .024) speeds. The

Table 1. Patient-Specific Patient-Reported Outcomes

ID	Age, y	Sex	Preoperative Kujala	Postoperative Kujala	Postoperative VAS	Postoperative Lysholm	Preinjury Tegner	Postoperative Tegner	BioDex Data Available?	Follow Up, y
1	46	M		72	5	62	7	3	No	1.50
2	44	F	33	84	2	80	3	3	Yes	4.02
3	36	M		77	0	89	10	9	Yes	4.18
4	35	F	24	62	0	70	3	3	Yes	5.15
5	53	M	42	47	3	54	8	2	No	1.04
6	53	M		90	2	90	9	9	Yes	3.60
7	41	M	32	78	6	84	6	4	Yes	5.65
8	73	M	51	63	0	77	2	1	Yes	5.20
9	80	M	50	63	1	84	5	3	Yes	1.16
10	70	M	75	83	0	97	4	4	Yes	1.81
11	46	M	42	52	6	80	6	1	Yes	4.40
12	69	M		78	1	100	6	5	No	1.00

F, female; ID, patient identification as specified in Methods; M, male; VAS, visual analog scale.

average peak torque generated per body weight was smaller in the operative vs contralateral knee only at slow speed (25.4 ± 10.0% vs 35.0 ± 15.1%, $P = .038$). There was no difference identified in time to maximum torque across all speeds (Table 2, Fig 2).

Discussion

Our results support the hypothesis that although clinical outcomes after KEMR are excellent in terms of patient function and clinical examination, patients with KEMR have residual biomechanical deficits in maximum work generation, ROM arc, and peak torque per body weight at long-term follow-up. Specifically, we demonstrate this extensor strength and ROM discrepancy between the operative and contralateral knee across 3 different grades of isokinetic resistance.

One previous study has assessed the biomechanics of patellar tendon reconstruction with ipsilateral hamstring graft.[3] Similar to the results of our study, Maffulli et al.[3] demonstrated at long-term follow up after patellar tendon reconstruction, the operative knee was weaker in isometric strength testing and muscle volume in comparison with the contralateral knee. However, the biomechanical apparatus used assessed a static, load-to-failure scenario with progressive force application, lacked ROM analysis, and also lacked dynamic strength assessment alongside acceleration.[3] The reliability of isokinetic testing as a measure of physiological knee extensor strength versus isometric testing has been demonstrated in the literature.[21,30] By providing dynamic isokinetic strength testing at 3 different interval speeds, our study demonstrates operative knee weakness at multiple physiological levels of activity, providing insight into how KEMR affects daily ambulatory as well as greater-level athletic function.

Belhaj et al.[20] successfully assessed KEMR isokinetic testing reporting reduced ROM arc, extension peak torque, and flexion peak torque in the operative knee

Table 2. BioDex Outcomes

	Operative Knee*	Contralateral Knee*	Nonparametric P Value†
Maximum work per repetition, J			
Slow	70.4 ± 30.4	101.9 ± 40.6	**.028**
Intermediate	52.0 ± 45.4	69.8 ± 63.7	**.038**
Fast	43.8 ± 41.7	57.5 ± 53.8	**.05**
Range of motion, °			
Slow	79.0 ± 7.4	86.2 ± 9.8	**.011**
Intermediate	80.8 ± 12.5	86.8 ± 11.8	**.038**
Fast	79.1 ± 12.8	85.7 ± 11.7	**.024**
Peak torque per body weight, %			
Slow	25.4 ± 10.0	35.0 ± 15.1	**.038**
Intermediate	19.8 ± 10.4	23.6 ± 15.6	.11
Fast	22.6 ± 9.0	24.6 ± 12.1	.48
Time to maximum torque, milliseconds			
Slow	544 ± 359	652 ± 281	.21
Intermediate	377 ± 152	358 ± 159	.59
Fast	331 ± 110	343 ± 135	.57

NOTE. Boldface indicates statistical significance ($P < .05$).
*Mean ± standard deviation.
†Wilcoxon signed-rank test.

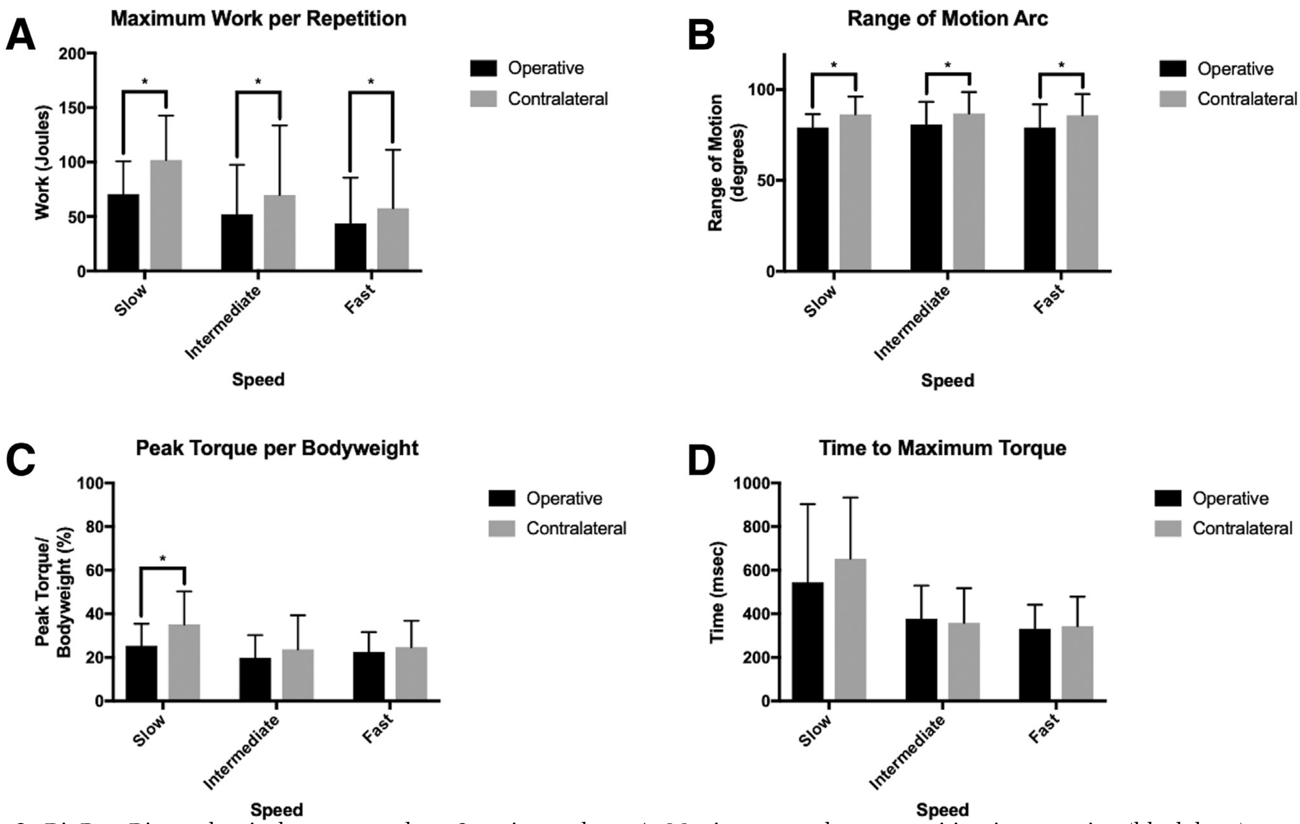

Fig 2. BioDex Biomechanical outcomes data, 9-patient subset. A, Maximum work per repetition in operative (black bars) versus contralateral (gray bars) knees across slow ($P = .028$), intermediate ($P = .038$), and fast ($P = .05$) speeds. B, Range of motion arc in operative (black bars) versus contralateral (gray bars) knees across slow ($P = .011$), intermediate ($P = .038$), and fast ($P = .024$) speeds. C, Peak torque per body weight in operative (black bars) versus contralateral (gray bars) knees across slow ($P = .038$), intermediate ($P = .11$), and fast ($P = .48$) speeds. D, Time to maximum torque in operative (black bars) versus contralateral (gray bars) knees across slow ($P = .21$), intermediate ($P = .59$), and fast ($P = .57$) speeds. Error lines represent standard deviation. Star indicates $P < .05$.

compared with the contralateral side in a 25-patient subset. Their results agree with our findings; however, they only performed isokinetic testing at 60°/s, and most importantly, only 8 of the 25 patients in their series had chronic patellar tendon ruptures, which were reconstructed whereas the remainder were acute direct repairs.[20] Given the heterogeneity of their population with the majority of their patients being acute repairs, our series likely represents a more accurate depiction of KEMR subject biomechanics.

The remaining studies assessing the biomechanics of various KEMR techniques and strategies to date have been confined to the cadaveric setting.[31,32] Mihalko et al.[31] demonstrated that patellar tendon repair augmentation with hamstring autograft reduced gap formation after numerous cycling of the cadaveric knees in comparison with traditional direct repair. Although gapping amount after cyclic loading provides some insight into dynamic integrity of reconstruction over time, their study did not assess load to failure. Karahasanoglu et al.[32] demonstrated after patellar tendon reconstruction with semitendinosus graft in a cadaveric model that graft pullout or failure to distraction forces resembled similar values in the literature to native patellar tendon load to failure. However, the study did not have a direct control group and clinical applicability is limited, given patellar tendon ruptures fail during active knee flexion under eccentric loading with ankle dorsiflexion rather than strict distraction force. Lastly, Kasten et al.[33] report similar isokinetic KEM strength data to this current study; however, they investigated acute patellar tendon repairs with either wire cerclage or suture fixation rather than KEMR.

Aside from tendon augmentation, numerous studies have assessed in vitro strength of patellar and quadriceps tendon repairs and augmentations with various suture materials,[33-36] fixation devices,[37-41] and additional synthetic augmentation modalities.[42] In the setting of an acute KEM rupture amenable to such repair techniques, the aforementioned studies provide insight into how best to repair such injuries. However, these studies offer little clinical applicability in the patient population indicated for KEMR. Unfortunately, with cadaveric studies assessing knee extensor mechanism repair and reconstruction techniques, the in vitro nature of these investigations removes tissue healing capacity and scar formation, which contribute to KEMR integrity from a biomechanical and clinical standpoint. Conversely, our study is able to account for such variables and thus provides significant insight into long-term KEMR function.

Although there is a paucity of cadaveric data, clinical outcomes studies assessing KEMR have been quite promising.[3,4,9,10] Maffulli et al.[3] demonstrated excellent clinical results in their group undergoing chronic patellar tendon reconstruction with ipsilateral hamstring tendon graft augmentation. Similar to the results of our study, patients had significant improvement in Kujala and mean modified Cincinnati score from preoperative to postoperative assessment. In addition, patients regained significant ROM and near resolution of preoperative extension lag.[3] Abdou[9] published a patient series augmenting repair of chronic patellar tendon repair with semitendinosus autograft as well as stainless-steel wire box caging with good clinical outcomes as well. Patients demonstrated an improvement in Lysholm scoring, had acceptable pain levels, and functional ROM postoperatively. However, it is unclear whether any significant changes in pain levels and ROM occurred from at follow up compared with patient preoperative status.[9] Temponi et al.[10] reported on their case series of 7 patients undergoing chronic patellar tendon reconstruction using contralateral bone—patellar tendon—bone autograft with excellent clinical outcomes as well. Improvements were noted in patient-reported and clinical outcomes from preoperative status to time of last follow-up.[10] Notably, patients demonstrated a decreased thigh girth as with Maffulli et al.'s study; however, this was a nonsignificant observation.

Aside from the aforementioned case series studies, there have been numerous case reports in the literature assessing KEMR. As in some of the patients in our series, others have also reported successful outcomes using Achilles tendon allograft-based augmentation of patellar tendon reconstruction.[16,17,43] Further reports using a combination of hamstring autografts also exist after various combinations of traumatic and chronic KEM injuries.[11,13] After reconstruction with contralateral bone—patellar tendon—bone autograft, Milankov et al.[14] assessed the patient's knee strength with an isokinetic dynamometer system performing testing similar to our study; however, they report only qualitative results suggesting knee strength improved substantially in the postoperative period.

As compared with the aforementioned studies and reports, the strengths of our investigation are the thorough biomechanical parameters with which KEMR was assessed at long-term follow-up. Given this patient population's average postoperative Tegner Activity Scale to be 3.9 in our case series with reports of patients returning to high level sports and exercise as evidenced in the literature after KEMR, it is critical to have a detailed understanding of postoperative KEM function in this group for long-term counseling on return to sports and rigorous exercise.[3,14] Here, we provide knee extensor activation speed, maximum work generated, ROM arc, and maximum torque generated across 3 different dynamic resistance settings. Although ROM arc appears to remain consistently less in across all speeds, the difference in maximum work between the operative and contralateral knee increases substantially with increased resistance, as demonstrated in Figure 2. Similarly, peak torque per body weight was only reduced between the operative and contralateral knees during the greatest resistance setting. These results suggest that while patients may not necessarily feel limited by their KEMR reconstruction in average daily activities, greater-strain athletics or rigorous exercise may exploit underlying KEM weakness.

All of our patients in this group, regardless of surgical technique, graft, or injury pattern, had to meet certain intraoperative criteria before closure: no evidence of gapping at the repair during knee passive ROM after reconstruction, normalization of patellar height after reconstruction confirmed with fluoroscopy, and normal intraoperative patellofemoral tracking. Further, all patients underwent the same postoperative rehabilitation protocol. Thus, we demonstrate if these criteria are met, patients undergoing KEMR will likely have acceptable clinical outcomes with improvements in patient reported scores.

Limitations

The major limitation of our study is the small sample size, resulting in underpowered analyses. Also, the retrospective collection of scores includes a certain degree of bias. Furthermore, our limited sample size results in a non-normal distribution of data points, which is why we reported both parametric and nonparametric paired statistical analyses for our biomechanical and patient reported outcome comparisons. Another limitation is the wide range of time points over which the data were collected, especially the final visit for testing, and the large range of time points between initial repair and subsequent revision. One would expect the patient presenting at 12.0 months to test differently than at 93 months. Lastly, another limitation of our study is the heterogeneity of our KEMR techniques, grafts, and injury patterns.

Conclusions

Patients undergoing KEMR demonstrate significant clinical improvements and are able to return to moderate level activities after surgery; however, operative knee extensor biomechanics remain with residual strength deficits when compared with the contralateral knee during dynamic isokinetic resistance testing. Although clinical results are excellent, patients should be counseled appropriately regarding possible strength loss and encouraged to further strengthen before resuming previous levels of exercise after KEMR.

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