Original Research

Quadriceps Strength in Patients With Isolated Cartilage Defects of the Knee

Results of Isokinetic Strength Measurements and Their Correlation With Clinical and Functional Results

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Background: Recent studies have found a significant deficit of maximum quadriceps strength after autologous chondrocyte implantation (ACI) of the knee. However, it is unclear whether muscular strength deficits in patients with cartilage damage exist prior to operative treatment.

Purpose: To isokinetically test maximum quadriceps muscle strength and quantify the impact of possible strength deficits on functional and clinical test results.

Study Design: Cross-sectional study; Level of evidence, 3.

Methods: To identify clinically relevant muscular strength deficits, 24 patients (5 females, 19 males; mean age, 34.5 years; body mass index, 25.9 kg/m^2) with isolated cartilage defects (mean onset, 5.05 years; SD, 7.8 years) in the knee joint underwent isokinetic strength measurements. Maximal quadriceps strength was recorded in 3 different testing modes: pure concentric contraction (flexors and extensors alternating work; con1), concentric-eccentric (only the extensors work concentrically and eccentrically; con2), and eccentric contraction in the alternating mode (ecc). Results were compared for functional performance (single-leg hop test), pain scales (visual analog scale [VAS], numeric rating scale [NRS]), self-reported questionnaires (International Knee Documentation Committee [IKDC], Knee Injury and Osteoarthritis Outcome Scale [KOOS]), and defect size (cm^2).

Results: Compared with the uninjured leg, significantly lower quadriceps strength was detected in the injured leg in all isokinetic working modes (con1 difference, 27.76 N·m [SD 17.47; $P = .003$]; con2 difference, 21.45 N·m [SD, 18.45; $P = .025$]; ecc difference, 29.48 N·m [SD, 21.51; $P = .001$]), with the largest deficits found for eccentric muscle performance. Moderate negative correlations were observed for the subjective pain scales NRS and VAS. The results of the IKDC and KOOS questionnaires showed low, nonsignificant correlations with findings in the isokinetic measurement. Moreover, defect sizes (mean, 3.13 cm^2) were of no importance regarding the prediction of the strength deficit. The quadriceps strength deficit between the injured and the uninjured leg was best predicted by the results of the single-leg hop test.

Conclusion: Patients with isolated cartilage defects of the knee joint have significant deficits in quadriceps muscle strength of the injured leg compared with the uninjured leg. The single-leg hop test may be used to predict quadriceps strength deficits. Future research should address whether preoperative strength training in patients with cartilage defects of the knee could be effective and should be taken into consideration in addition to surgical treatment.

Keywords: muscle strength; isokinetic; cartilage defect; cartilage repair; knee joint; rehabilitation

As articular cartilage possesses poor self-healing capacities, it has been a continuous medical challenge to restore damaged articular cartilage.[2] Several surgical treatment options have been established, including bone marrow stimulation techniques and autologous chondrocyte implantation (ACI).[2,6] Recently, researchers have emphasized the importance of adequate postoperative rehabilitation to successful cartilage repair. Nevertheless, clinical and scientific evidence concerning different rehabilitation protocols as well as biomechanical deficits of cartilage defects in patients are still elusive.[23]

Although the etiology of generalized osteoarthritis (OA) of the knee joint and isolated focal cartilage defects (FCDs) are not identical, OA will occur in an untreated cartilage

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defect over time. In this context, it is of particular interest that muscle dysfunction, especially muscular weakness and sensorimotor deficiency, has been implicated in the pathogenesis of OA by impairing neuromuscular protective mechanisms that prevent abnormal joint loading.[22,26,31,59] Additionally, even after successful surgical management of FCDs, functional knee performance often cannot be fully restored—quadriceps muscle weakness being one main dysfunction alongside functional instability.[37,42] In this context, it is yet unknown whether strength deficits correlate with the degree of damage and to what extent they precede surgery. As thigh muscle strength is an important factor of the day-to-day performance of the knee, it seems to be of an area of particular significance for the individual patient. Furthermore, recent studies have assessed the importance of preoperative physical condition, specifically quadriceps strength, in patients with knee injuries and have concluded that preoperative training programs should be taken into consideration as additional interventions to improve clinical outcomes.[10,15,32]

To the best of our knowledge, no study has reported maximum thigh muscle strength and related functional impairments in patients with isolated cartilage defects of the knee. The aim of the present study was therefore to isokinetically assess quadriceps muscle strength in patients with isolated FCDs prior to surgery and to relate possible muscular strength deficits to quality of life, functional performance, subjective pain, and cartilage defect size.

METHODS

This study was conducted in compliance with the European Community Good Clinical Practice (EC-GCP) and was reviewed and approved by the local university's ethics committee (vote 63/13). Between January 2012 and January 2013, all patients presenting to the University of Freiberg Hospital outpatient department for surgical cartilage repair of the knee joint were evaluated regarding eligibility for participation. After clinical and radiological assessment and verification of an isolated full-thickness cartilage defect of the knee joint on magnetic resonance imaging (MRI), the inclusion and exclusion criteria were checked. A full-thickness cartilage defect and age older than 15 years were mandatory criteria for participation. Exclusion criteria consisted of previous open knee surgery, ligament knee instability >grade I, and underlying neuromuscular diseases. Twenty-nine patients fulfilled the inclusion criteria and were asked to take part in the study. Potential subjects were informed about the scientific goal of the study and the detailed study procedure. If they were willing to participate, patients were asked for another clinical appointment within the next few days and written informed consent was obtained. Twenty-four patients agreed to take part in the study and gave written consent.

Evaluation Methods

The study consisted of 4 parts: (1) clinical examination, (2) isokinetic measurement, (3) functional performance testing (single-leg hop test), and (4) administration of validated pain scales (visual analog scale [VAS], numeric rating scale [NRS]) and self-reported disease-specific questionnaires (International Knee Documentation Committee Subjective Knee Form [IKDC][3,23] and Knee Injury and Osteoarthritis Outcome Score [KOOS][52]). Measurements were collected at a single point a few days prior to arthroscopy. The operating surgeon did not have knowledge of the results of the measurements.

To ensure standardized measurement procedures and to minimize interobserver effects, a manual with precise instructions for all measurements by the researchers (standard operating procedures [SOP]) was used. Moreover, case report forms served as protocols during the entire measurement process.

Clinical Examination. Patients' medical histories were recorded, covering information on the cause of the cartilage defect, associated injuries, medical conditions, previous surgeries, current medication, current symptoms, and pain. Leg dominance was assessed by asking individuals which leg they would use to kick a ball into a goal.[16] Before testing and measuring began, all patients were asked to indicate their current pain level using a VAS. During arthroscopy, the size and grade of the FCD was documented according to International Cartilage Repair Society (ICRS) grading.

Isokinetic Muscle Strength Testing. Patients' maximum strength in both legs was recorded using a computerized dynamometer (Con-Trex Multi Joint System; CMV AG). Patients were seated upright with 90° of hip flexion and with their arms folded across the chest. Backrest and seat position were adjusted according to the patient's anthropometric data. Patients were secured using a 5-point belt at the torso and Velcro straps at the leg (Figure 1). They were instructed to extend the leg as fast and forcefully as possible. To encourage maximal effort, verbal encouragement was given according to the SOP.[31]

Peak torque of knee extension was measured in concentric and eccentric mode at an angular velocity of 60 deg/s between 10° and 90° of knee flexion.[47] To allow for familiarization of

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Ethical approval for this study was obtained from Freiburg University.

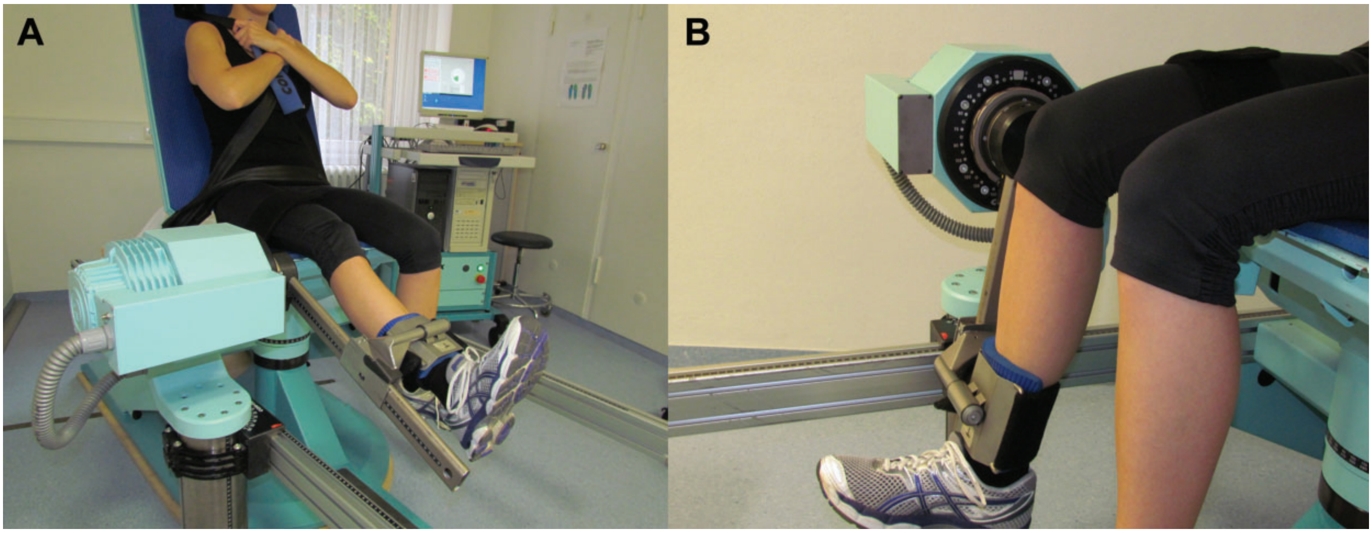

Figure 1. Isokinetic strength testing on the Con-Trex Multi Joint System. (A) Standardized positioning and trunk fixation of the patient. (B) Fixation of the lower extremity and adjustment of the dynamometer.

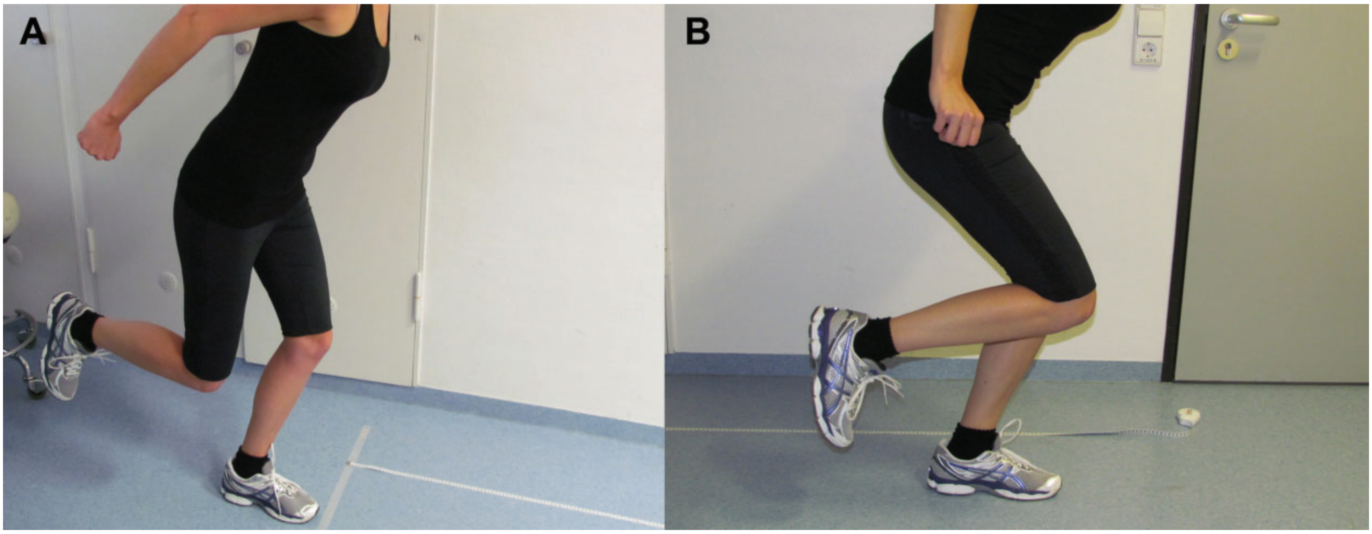

Figure 2. Single-leg hop test. (A) Position of the subject before the jump. Arms may be used moving forward. (B) After landing with the same leg, jump length is measured.

the task, the participants performed 3 submaximal efforts. Mean isokinetic peak torque (N·m) was calculated based on the highest 3 peak torques. To minimize the risk of biased results due to a possible pain-related reduction of maximum strength, the uninjured leg was tested first.[18,34] Concentric contraction was measured twice, once in a pure concentric working mode (con1: flexors and extensors work alternated) and once in a concentric-eccentric working mode (con2: only the extensors work concentrically and eccentrically). Eccentric contraction was only assessed in the alternated mode (ecc). A rest period of at least 30 seconds separated each cycle. Strength deficits were calculated as the difference between peak torque values of both legs (*uninjured – injured*) and correlated with functional performance tests and clinical results.

Functional Performance. The single-leg hop test, first described by Tegner and Lysholm,[61] has shown considerable reliability in healthy volunteers and athletes.[1,29] It is also part of the IKDC form[3] and has been used in several studies on knee injuries.[14,16,25,38,56] The single-leg hop test was performed as described by Barber et al[5]: Patients stood on 1 foot and were then asked to jump forward as far as possible. Take-off and landing were made with the same foot (Figure 2). Patients performed 3 jumps per leg, starting the measurement with the uninjured leg to minimize pain-related bias. Mean values for each leg were calculated from the 3 measurements.[44]

Self-Reported Symptoms. For the assessment of knee-related pain, patients were asked to indicate any pain in the affected knee on 2 different pain scales (VAS and NRS).

The NRS was used to quantify the general pain level of the patient and was completed once at the beginning of the questionnaire. A VAS was used to monitor the patients' pain during measurements and was completed twice, before (premeasurement) and after (postmeaurement) all measurements, respectively.

Results of the NRS take the form of labeled integer values from 1 to 10 (1 corresponding to "no pain at all" and 10 corresponding to "extremely severe pain"). In contrast, the VAS corresponds to a 10-cm line, where the ends of the line correspond to the 2 most extreme events ("no pain at all"/"extremely severe pain"). Within this range, all values between 0 (no pain) and 10 (severe pain) are possible, depending on where the patient marked the line.

Knee Scores. Functional status was evaluated using both the IKDC subjective knee assessment questionnaire and the KOOS score. The IKDC form is a reliable and valid instrument for patients with various knee injuries,[56] which allows direct comparison of the outcome between different patient groups.[27] Higher values indicate higher levels of functioning. The KOOS score has been used in numerous clinical studies on knee injuries,[9,19,52,55,57] and the literature supports both acceptable test-retest reliability and validity.[9,19,56,57] The KOOS consists of 5 subscales: (1) pain, (2) other symptoms, (3) function in activities of daily living (ADLs), (4) function in sports and recreation (sports), and (5) knee-related quality of life (QOL). The maximum score of 100 indicates that the patient has "no knee problems," whereas the minimum score of 0 indicates "severe symptoms and extreme knee problems."

Statistical Analysis

JMP 5.0.1 software (SAS Institute) was used for statistical analysis of the data. After entering the data into the database, range checks were performed to check for plausibility. Implausible values and outliers were traced back to the raw data. Means and standard deviations were calculated and analyzed for descriptive statistics.

Maximal strength was assessed as the mean value of the 3 highest out of 5 repetitions.[30,47] Mean differences between the injured and uninjured leg were tested using Student t tests for paired samples and expressed as differences as well as percentages to simplify comparison with other studies.

As the NRS score is a Likert-type scale, the mode value was assessed for analysis in correlation with biomechanical data.

Spearman rank correlation coefficients were used to assess correlation between biomechanical data from the isokinetic strength measurement and clinical results from the questionnaires (IKDC and KOOS) as well as the functional test and were interpreted as follows: $0 < |0.3|$, low; $|0.3| < |0.5|$, intermediate; and $|0.5| < |1|$, strong correlation. Significance was set to 5% ($P \leq .05$).

TABLE 1
Patient Characteristics[a]

Age, y, mean ± SD	34.5 ± 12.04
Men/women, n	19/5
Total height, m, mean ± SD	1.8 ± 0.1
Weight, kg, mean ± SD	83.85 ± 17.58
BMI, kg/m^2, mean ± SD	25.9 ± 4.96
Injured knee side, n (%)	
Left	17 (70.8)
Right	7 (29.2)
Injured and dominant, n (%)	10 (41.7)
Injured and nondominant, n (%)	12 (50)
No leg dominance determined, n (%)	2 (8.3)
Cause of cartilage damage,[b] n	
Sport	8
Accident at work	1
Activity of daily life	9
Traffic accident	2
Other	7
Grade of cartilage damage (ICRS criteria), n (%)	
III	9 (37.5)
IV	15 (62.5)
Size of cartilage lesion, cm^2, mean ± SD	3.13 ± 1.59
Defect localization, n	
Patellofemoral	12
Tibiofemoral	12
Type of surgical treatment, n	
ACI	13
Microfracture	9
No surgical treatment	2
Time between diagnosis and surgery, y, mean ± SD	1.9 ± 2.2
NRS (index knee), n (%)	
1	3 (12.5)
2	4 (16.7)
3	7 (29.2)
4	2 (8.3)
5	3 (12.5)
6	2 (8.3)
7	0 (0.0)
8	1 (4.2)
9	1 (4.2)

[a]Numbers of observations are given where no specific unit is specified. Percentages represent rounded values. ACI, autologous cartilage implantation; BMI, body mass index; ICRS, International Cartilage Repair Society; NRS, numerical rating scale for pain.

[b]Multiple answers possible.

RESULTS

Clinical Examination

The study sample consisted of 5 women and 19 men. The mean age of the 24 patients was 34.5 years (range, 15-55 years). Descriptive statistics for sample characteristics collected from questionnaires and the clinical examination are summarized in Table 1.

In 7 of 24 patients, cartilage defects affected the patient's right knee, whereas the remaining 17 subjects exhibited left-sided lesions. In 10 patients (41.7%), the injured leg corresponded to the dominant leg, whereas in 12 patients (50%) the dominant leg remained uninjured and the nondominant leg represented the affected side. Leg dominance could not be determined in 2 patients.

Mean cartilage defect size was 3.13 ± 1.59 cm^2. Nine patients were diagnosed with ICRS grade III cartilage damage, while 15 patients showed cartilage damage grade IV.[13]

TABLE 2
Isokinetic Strength Measurements and Functional Performance Test (N = 24)[a]

	Uninjured Leg	Injured Leg	Difference	% Difference	*P* Value
Isokinetic strength, N·m					
PT ext con1 (alternated)	141.79	113.42	27.76 [±17.47]	80.89	.003
PT ext con2 (ext only)	125.24	107.96	21.45 [±18.45]	85.51	.025
PT ext ecc	165.47	139.55	29.48 [±21.51]	83.21	.001
Functional performance					
Single-leg hop test, cm	125.95	103.93	22.02	84.58	.001

[a]Values represent mean performance [±SD] unless otherwise indicated. Paired *t* tests were used to compare the performance of the injured and the uninjured leg. con, concentric working mode; ecc, eccentric working mode; ext, extensors (quadriceps); PT, peak torque.

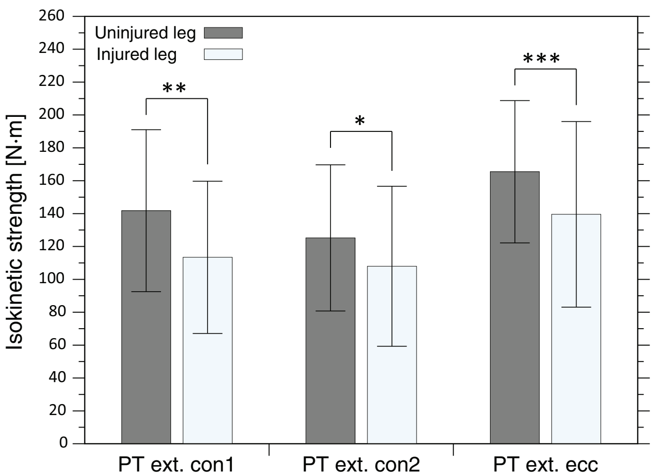

Figure 3. Results of the isokinetic quadriceps strength testing of the injured and uninjured leg (means and standard deviation) for knee extension peak torque (PT): concentric quadriceps strength in alternate (flexion-extension) mode (PT ext. con1), concentric quadriceps strength in unidirectional (extension-resistance) mode (PT ext. con2), and eccentric quadriceps strength in alternate (flexion-extension) mode (PT ext. ecc). *$P < .05$, **$P < .01$, ***$P < .001$.

Muscle Strength

Table 2 and Figure 3 show that mean isokinetic quadriceps strength was significantly lower for the injured leg when compared with the uninjured leg in all 3 tested working modes. On average, the strength of the injured leg reached 80% to 85% of the uninjured leg. Expressed in absolute terms, the mean difference in extensor muscle strength was between 21.5 and 29.5 N·m when compared with the contralateral leg. Absolute deficits were largest for eccentric muscle performance. On average, patients not only achieved greater maximum strength during the first concentric measurement (con1) compared with the second concentric measurement (con2) but also showed larger strength deficits during the first measurement in absolute and relative terms (Table 2, Figure 3). Absolute strength differences did not substantially vary according to leg dominance. Even in cases where the injured leg was the dominant extremity, strength deficits remained substantial (approximately 40 N·m).

TABLE 3
Self-Reported Symptoms
(Pain Scales and Subjective Knee Scores)

Measure	Mean	SD	Median	Minimum	Maximum	n
VAS pain						
Pretest	1.34	1.49	1.00	0.00	5.30	24
Posttest	2.81	2.03	2.28	0.00	7.20	22
IKDC total	61.41	13.95	54.59	37.90	85.06	22
KOOS						
Total	66.61	17.10	60.70	38.70	91.10	23
Symptoms	69.72	20.63	75.00	28.57	100.00	23
Pain	63.41	19.51	61.11	38.89	94.44	23
ADL	77.69	14.67	72.06	51.47	100.00	23
Sports	49.13	27.21	50.00	0.00	95.00	23
QOL	39.40	21.85	37.50	0.00	81.25	23

[a]ADL, activities of daily living; IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; QOL, quality of life; VAS, visual analog scale.

Functional Performance

The results of the single-leg hop test, presented in Table 2, showed a statistically highly significant difference between the injured and uninjured leg. The mean values of the 3 repetitions were 103.9 cm for the injured leg and 125.9 cm for the healthy leg. Jump length was reduced by 22 cm for the injured extremity on average.

Self-Reported Symptoms

Table 3 displays descriptive statistics before and after administration of the VAS pain scale and the IKDC total score, as well as the KOOS total score and its subscales.

NRS. Results of the NRS are shown in Table 1. The modal value of the NRS was 3. Considering the cumulative frequencies, 14 patients (58.3%) reported pain intensities with values of 3 or below. Only 2 patients reported a value greater than 6.

VAS. Results of the VAS (Table 3) showed lower acute pain levels compared with results of the NRS. Prior to measurement, patients reported a mean pain intensity of 1.34. Mean pain intensity ratings were significantly higher after completion of all measurements, yielding a mean VAS score of 2.81 (paired *t* test; $t = 4.70$; $P = .000$).

TABLE 4
Correlation Between Isokinetic Strength and the Horizontal Single-Leg Hop Test (Functional Performance)[a]

Working Mode	ρ (Spearman)	*P* Value
Con1	0.41	.101
Con2	0.66	.002
Ecc	0.52	.023

[a]Spearman ρ and associated *P* values based on the relationship between patients' individual strength differences in the isokinetic strength measurement and individual differences in the horizontal single-leg hop test. Con, concentric working mode; Ecc, eccentric working mode.

IKDC. The subjective part of the IKDC knee form includes questions about knee-related symptoms, functional status, and exercise. On average, patients reached a score of 61.4% (SD, 14.0%), the highest value being 85.1% and the lowest value being 37.9%.

KOOS. Patients achieved a mean KOOS sum score of 66.6 (SD, 17.1). The maximum value in the sample was 91.1 while the minimum value was 38.7. Table 3 shows the mean sum score as well as the results of the subscales: symptoms, pain, ADL, sports, and QOL. The sports and QOL subscales were rated to be most affected, yielding the lowest scores. In comparison, ADLs were rated to be least affected, reaching higher scores.

Relationship Between Muscle Strength and Functional Performance

We found a statistically significant correlation between the results of the single-leg hop test and the isokinetic strength measurement for concentric eccentric contraction, as shown in Table 4 and Figure 4. The quadriceps strength difference (*uninjured – injured*) for the second concentric measurement showed the strongest positive relationship to the results of the single-leg hop test ($R = 0.66$). Because of a single outlier point, the first plot in Figure 4 suggests a high correlation for con1, which was not supported by the statistical analysis ($R = 0.44$).

Relationship Between Muscle Strength and Self-Reported Symptoms

Moderate negative correlations were observed between the isokinetic strength measurements and both pain scales (NRS and VAS), with correlation coefficients of –0.4 and –0.6, respectively. Table 5 shows negative correlation coefficients, which indicate that stronger pain is associated with lower maximum strength. However, we also found significant relationships between reported pain and lower strength for the uninjured leg. This applies foremost to the VAS, where significance of the relationship between high pain and low maximum strength remained restricted to the uninjured leg.

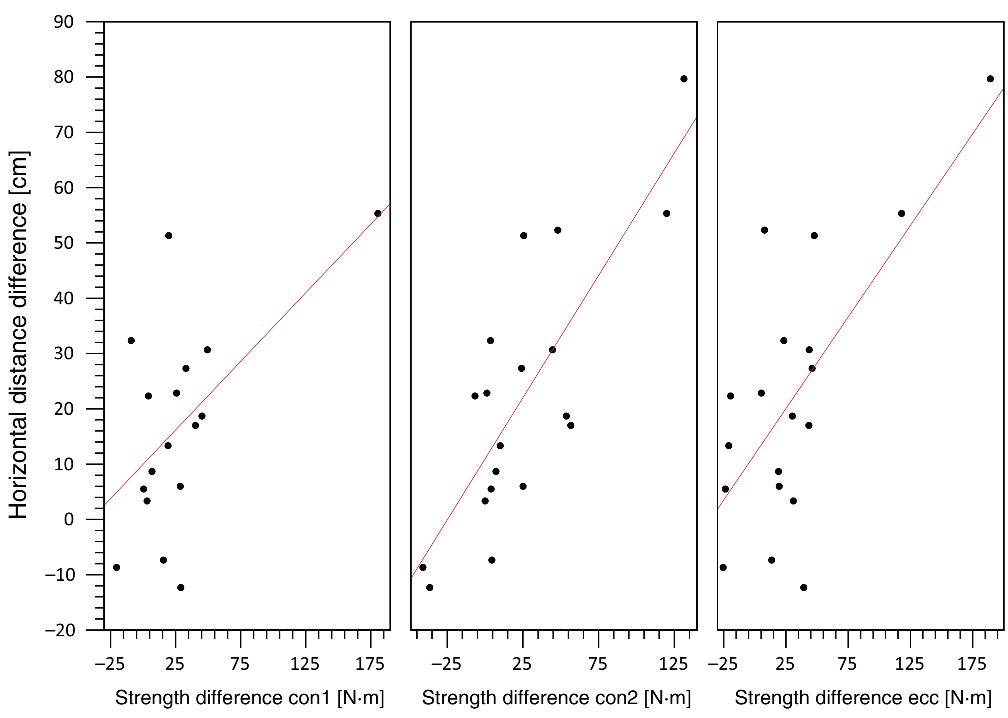

Figure 4. Correlations between isokinetic leg strength differences (*uninjured – injured leg*) and single-leg hop test jump length difference (*uninjured – injured leg*) for concentric quadriceps strength in alternate (*flexion – extension*) mode (con1), concentric quadriceps strength in unidirectional (*extension – resistance*) mode (con2), and eccentric quadriceps strength in alternate (*flexion – extension*) mode (ecc).

TABLE 5
Correlation Between Strength Measurements and Results of Pain Scales[a]

	Working Mode					
Pain Scale	Con1	Con1 Inj	Con2	Con2 Inj	Ecc	Ecc Inj
NRS						
R (Pearson)	–0.52	–0.49	–0.56	–0.30	–0.64	–0.36
P value	.011[b]	.023[b]	.005[b]	.18	.001[b]	.105
VAS						
R (Pearson)	–0.41	–0.31	–0.55	–0.08	–0.57	–0.20
P value	.049[b]	.106	.005[b]	.716	.004[b]	.363

[a]Pearson correlation coefficients and associated P values based on the relationship between patients' individual absolute strength in the isokinetic measurement and individual ratings as measured through the pain scales. Con, concentric working mode; Ecc, eccentric working mode; Inj, injury; NRS, numeric rating scale; VAS, visual analog scale.
[b]$P \leq .05$.

Table 6 shows that relationships between results from the IKDC and the KOOS questionnaire and findings from the isokinetic measurement were rather weak, yielding nonsignificant correlation coefficients between –0.01 and –0.26. We also found nonsignificant relationships between performance in the isokinetic strength measurements and defect size. The defect location (patellofemoral vs tibiofemoral) did not affect the isokinetic strength deficit.

DISCUSSION

Our primary hypothesis was supported, as preoperative maximum quadriceps strength was significantly lower in the injured leg compared with the uninjured leg in all tested working modes. Although isokinetic measurement is a frequently used tool to assess the muscle strength of the knee joint, studies that contain strength measurements prior to cartilage repair for isolated cartilage defects have, to our knowledge, not yet been published. This is the first study to report isokinetic measurement in patients with cartilage damage with a focus on preoperative strength conditions. Hence, maximum strength ratios of our sample of patients with cartilage damage could only be compared with results from studies that deal with other diseases of the knee and/or focus on postoperative strength measurements.[15,29,37,42] To collect objective information about quadriceps function in patients with cartilage knee damage, we performed biomechanical testing, recording isokinetic strength and compared the performance of the injured with the uninjured leg.[53]

At least 3 injury-related processes can explain these substantial strength differences between the injured and uninjured leg: (1) muscle atrophy, (2) changes in neuronal activity, and (3) biomechanical changes of the knee joint.[24] First, "arthrogenic muscle inhibition" represents a specific consequence of joint injuries that guarantees reflex-like protection from further damage in the early stages. Atrophy of the muscles surrounding joints usually occurs in mid- to long-term traumatic joint injuries with temporary immobilization.[40,66] Here, local pain stimuli inhibit both neurosensory and motor muscle activation, which is associated with a faster healing process. However, the same mechanism implies less muscle activation and thus prevents the complete recovery of muscular strength.[21] The atrophied and neuronally impaired tissue is not able to regenerate completely, and a partial effect of neuronal inhibition and muscle atrophy frequently persists.[24]

TABLE 6
Correlations Between Strength Measurements and Results of Knee Scores[a]

	Working Mode		
Knee Measure	Con1	Con2	Ecc
IKDC			
R (Pearson)	–0.23	–0.17	–0.26
P value	.31	.46	.25
KOOS			
Total			
R (Pearson)	–0.13	–0.18	–0.22
P value	.583	.416	.331
Symptoms			
R (Pearson)	–0.20	–0.24	–0.15
P value	.396	.288	.502
Pain			
R (Pearson)	–0.02	–0.01	–0.10
P value	.944	.953	.666
ADL			
R (Pearson)	–0.18	–0.22	–0.26
P value	.435	.323	.250
Sports			
R (Pearson)	–0.01	–0.14	–0.22
P value	.967	.536	.349
QOL			
R (Pearson)	–0.10	–0.19	–0.18
P value	.665	.403	.416
Defect size			
R (Pearson)	0.24	0.12	0.03
P value	.287	.608	.897

[a]Pearson correlation coefficients and associated P values based on the relationship between patients' individual strength differences in the isokinetic strength measurement and individual ratings as measured through knee scores, questionnaires, and defect size. ADL, activities of daily living; Con, concentric working mode; Ecc, eccentric working mode; IKDC, International Knee Documentation Committee; KOOS, Knee Injury and Osteoarthritis Outcome Score; QOL, quality of life.

Second, the extent of local intra- and extra-articular damage and the associated direct neuromuscular defect can explain reduced muscular strength. Lorentzon et al[43] attributed consecutive nonoptimal activation during voluntary movements to damaged local mechanoreceptors in fibrous and ligamentous structures of the knee joint. The lack of activation is caused by altered afferent feedback to supraspinal structures and to the corresponding motor neurons.

Quadriceps muscle weakness is considered a primary risk factor of knee joint OA.[4,49,51,59,60] The results of a wide range of rehabilitation studies emphasize the importance of thigh muscle strength alongside the general physical condition for postoperative outcomes in different knee injuries.

As one of the first research groups, Ebert et al[14] examined patients after cartilage surgery, performing strength measurements 5 years after ACI. While patients' knee flexor strength recovered completely, knee extensors of the treated side still exhibited a reduced maximum strength profile. Further long-term observations showed significant knee extensor muscle deficits in the treated leg 4 years[37] and 7 years[42] after successful cartilage transplantation. Building on these results, currently used rehabilitation protocols after ACI can be considered as insufficient to restore long-term knee strength.[14] In addition to the common early postoperative and individually adapted care and strength training, Hirschmüller et al[23] recommended extensive rehabilitative care, which should be maintained throughout the internal chondral healing process after ACI.

Moreover, the preoperative condition of the knee extensors plays a crucial role in rehabilitation. Eitzen et al[15] emphasized that preoperative muscular strength deficits are associated with deficits in postoperative functioning such as jumping, running, and climbing stairs. Observation of patients after anterior cruciate ligament (ACL) reconstruction showed that good preoperative quadriceps strength in the injured leg predicts a clinically relevant improved functioning 2 years after surgery.[15] Additionally, Tourville et al[63] recently showed that presurgical isokinetic strength loss soon after ACL injury is directly associated with OA-related outcomes at 4 years postsurgery.

Kreuz et al[38] showed a positive correlation between preoperative sports level and improvement in the long-term results after cartilage transplantation. A recent study suggested intensive preoperative training of strength and proprioception to restore side-to-side muscular symmetry in which patients optimally engage 3 months before surgery.[23] The related training protocols are believed to reduce neuromuscular malfunction and subsequent inhibition of voluntary quadriceps contraction such that postoperative quadriceps strength deficits are reduced.[15]

In our study group, isokinetic strength depended neither on the size of the lesional defect nor on the location of the defect. Compared with other study groups,[37,46,64] our patients presented a rather small mean defect size of 3.13 cm^2, which puts the nonsignificant correlation analyses into perspective. Kreuz et al[35] showed that younger adults with defects on the femoral condyles had better results concerning clinical outcome after microfracture than patients with other defect locations; however, defect size was not taken into consideration. No study has been found concerning correlation between cartilage defect size and clinical results. Considering that defect size is measured preoperatively and regularly determines medical decisions and indications, the present results appear to be decisive and should be studied in more detail.

In contrast to existing studies, we additionally assessed strength in an eccentric contraction mode, where the largest strength differences between the injured and uninjured leg were observed. The relatively greater loss of strength during eccentric movement is due to a stronger need for coordination in this working mode. Furthermore, eccentric contraction requires more complex neuromuscular activation patterns associated with more pronounced strength differences.[37]

Focusing on the 2 concentric measurement results (con1 and con2), arithmetic means showed that the second concentric measurement (con2) yields slightly lower strength values when compared with the first concentric measurement (con1). An obvious argument for the lower strength values during con2 seems to be through the fact of chronology, meaning that our patients showed lower strength values due to neuromuscular fatigue from the con1 measurement. However, according to existing literature, a between-set rest period of 30 seconds, as we used in our protocol, is considered sufficient for recovery time.[6] Requirements for coordination again provide another possible explanation for the substantial differences between the 2 isokinetic measurements. It may accordingly be reasonable to infer that the 2 concentric measurements need different patterns of muscular activation: There is evidence that the purely concentric testing mode is comparatively less complex and does not require as much coordination as the alternating testing mode.[16] In the first case, the movement resembles a simple up-and-down pressing of the lever arm, whereas the alternating testing mode consists of 2 distinct parts where concentric and eccentric movements are performed. One could argue that because of the intensified coordinative challenge, maximum concentric force development during the alternating part is prevented.

The second goal of the study was to quantify the impact of strength deficits on results from functional and clinical tests. A few studies have assessed the relationship between strength deficits and everyday function.[17,29,36,37,53,65] Isokinetic testing allows for a precise quantitative picture of muscle strength but lacks other important real-life aspects of muscle functioning, such as coordination and timing. Hence, functional and clinical test results deliver crucial complementary information for the clinical practitioner evaluating clinical outcomes.

A variety of studies tackle the question of whether the strength capability of the lower extremities should be measured by functional tests. However, besides the detection of muscular performance, as part of normal everyday movement, the application of these tests represents an assessment of neuromuscular control, speed of contraction, joint function, and range of motion.[44] Functional tests also require a range of skills such as strength, endurance, and coordination and therefore approximate the performance of multiple joints and multiple muscle groups.[17,39]

Furthermore, functional performance measures such as the single-leg hop test are easy to perform clinically and require only minimal equipment. They mimic natural movements, which are required in many ADLs and sports. The single-leg hop test is part of the common IKDC[3] form for examination of the knee and has been used in various studies of knee injuries.[15,17,20,29,44,58,62] In comparison with a series of other functional tests, Bremander et al[7] showed good test-retest reliability of the single-leg hop test. Several authors have studied the relationship between isokinetic strength measurement and performance on the single-leg hop in patients with ACL rupture.[12,28,48,58,65] The existing literature supports positive covariation between single-leg hop performance and isokinetic strength.

The results of the single-leg hop test in the present study coincide with the majority of the findings listed in the literature while demonstrating a strong positive correlation ($R > 0.5$) between the results of the isokinetic strength measurement and the results of the single-leg hop test. This indicates that strength is an important prerequisite for achieving a good hop length. The relationship between the quadriceps strength ratio and the single-leg hop test shows that decreased quadriceps strength is 1 factor contributing to patients' limited knee function. Muscular performance of the lower limb is of great importance to achieve a good jump distance. However, only about one-third of the variation in functional capacity can be explained by the variation of isokinetic strength components.[39] Compared with all other parameters assessed, the single-leg hop test shows the best predictive power with respect to the results of concentric and eccentric strength measurement. Thus, use of the single-leg hop test for the initial assessment of strength deficits in patients with cartilage defects in the knee joint represents a reasonable method in the absence of isokinetic strength measurement systems. Nevertheless, it must be emphasized that isokinetic measurement enables a quantifiable detection of maximum muscle strength with the greatest possible protection of the affected structure. In this way, pain and fatigue do not or only hardly affect the measurement.[50] A reasonable intra- and interindividual comparability is guaranteed, which is not possible with functional tests.

Manske et al[44] recommended that for the assessment of full functional and muscular deficits, both test methods should be applied.

Pain Scales

Patients' reports occupy an essential role in the evaluation of clinical therapy and rehabilitation. We raised the question of whether subjective data fit objective isokinetic measurement parameters to validate and justify their use. One key element of treatment evaluation and interpretation of study results can be seen in the direct assessment of subjective pain quantity using pain scales. The most common pain scales are the NRS and VAS. More than half of the patients (58.3%) reported a moderate subjective magnitude of pain on the NRS, which was assessed prior to strength testing, with scale scores of ≤ 3. Mean VAS score (1.34) processed before strength measurement also indicated a rather low pain level in patients. Concerns about potentially pain-triggering effects of the measurements do not seem justified when considering pain sensitivity, as measured by the absolute mean difference between pain before and after measurements (1.48).[54] However, on the basis of our results, pain-related impairment of performance in the isokinetic measurement cannot be excluded.

Statistical analyses showed moderate negative correlations between the strength capacity of the extensors and the results of the pain scales (NRS, VAS). A stronger pain sensation was therefore related to reduced maximum strength. Contrary to initial expectations, significant correlations between subjective pain and lower strength in the uninjured leg were shown. Therefore, it may be that the intensity of pain in the injured leg may also affect the degree of strength in the uninjured extremity. Presumably there is a pain-specific mechanism underlying these results. Patients with longer pain intervals and greater pain intensity avoid symptom-related movements and activities, which ultimately leads to prolonged immobilization and general inactivity. As a result of the latter, both extremities are affected and consecutive atrophy on both sides has to be expected, which explains strength deficits in the uninjured leg.

Another explanation is the cross-education phenomenon: According to study results, unilateral injury and consecutive immobilization of the affected limb may yield substantial changes in the central nervous system, which also affect the healthy side, leading to a measurable loss of strength.[8]

Self-Reported Questionnaires

Regarding the results of the present study, the sample of patient ranges is quite high among the possible outcomes of the IKDC and KOOS. This indicates a better average condition of the knee, based on symptoms and functionality, in the present sample compared with other studies.[33,37,45,64]

One additional goal of our study was to estimate the extent of isokinetic deficits based on subjective patient surveys. Statistical analyses showed a negative relationship between the IKDC and KOOS scores and isokinetically assessed strength deficits. This implies that lower mean questionnaire scores are associated with greater strength deficits. However, the coefficients did not reach a significant level. Therefore, it is not recommended to estimate strength deficit of the extensor muscles based on subjective responses in the IKDC and KOOS questionnaires.

Limitations

Our study had several limitations. First, the rather small sample size might have underestimated the significance of the documented effects. Anthropometric data (age, sex, body mass index, and defect size) showed a surprisingly heterogeneous patient group, which nevertheless was comparable to larger samples. The relatively low mean age was a result of the indication criteria for surgical treatment of cartilage damage: In general, cartilage lesions are treated surgically by regenerative processes only up to age 55 years. Another limitation of our study was the lack of a healthy control group. We used the contralateral leg to obtain a within-patient reference.[17,53] This procedure has the advantage that heterogeneous influences of maximum strength capability (eg, age, sex, weight, and/or size) are accounted for.[41] Nevertheless, we assume that strength deficits between a healthy control group and the studied sample should be larger than the within-patient differences reported here. Compared with healthy athletes tested by Müller et al[47] using the same isokinetic device, differences in maximal strength measurement up to >50 N·m occured; our patient sample reached lower values in the injured as well as in the uninjured leg in both dynamic working modes (concentric and eccentric) compared with the healthy study group.[47]

Underestimation of existing strength deficits is likely, for 2 reasons: joint damage after unilateral changes in articular cartilage metabolism is observed not only in the injured leg but also in the contralateral, uninjured knee.[11] This undermines the comparability of muscular deficits with the contralateral uninjured side. Additionally, patients consequently started all measurements with the uninjured leg. No randomization took place to avoid a pain-related bias in performance. If any cognitive training effect occurs during isokinetic measurement, this would overestimate the performance of the uninjured leg and result in smaller deficits.[17]

CONCLUSION

The results from the present study clearly indicate that objective muscular deficits occur in patients with cartilage damage of the knee. These deficits can be recorded using isokinetic devices. However, our results indicate that deficits can be captured by clinical test methods if precise isokinetic measurement is not feasible. We showed that the results of the single-leg hop test are indicative of quadriceps strength deficits. Furthermore, assessment based on self-reports such as the IKDC and KOOS questionnaires is useful for follow-up controls but cannot be recommended for use in estimating quadriceps strength deficits. Since preoperative quadriceps strength deficits may yield significant negative consequences for the long-term functional outcome after cartilage repair, we recommend preoperative treatment protocols that improve quadriceps muscle strength and muscular symmetry.

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