Original Article

A Patellofemoral Chondropathy Quantification from Vibroarthrography: A Preliminary Study

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Objective: To preliminarily investigate if the proposed parameter derived from the knee vibroarthrographic (VAG) signals, namely the VAG score, could potentially be used to quantify the patellofemoral chondropathy.

Materials and Methods: Five subjects with meniscus injury as an indication for arthroscopy were recruited for the present preliminary cross-sectional study. Prior to the arthroscopy, the Kujala scores were assessed and the knee VAG signals were recorded from all the subjects. Subjects were asked to actively perform the knee flexion-extension for three cycles in the supine position while recording the VAG signal. The proposed VAG score was defined as the power spectral density of the signal in the frequency of 450 to 1,000 Hz. Patellofemoral chondropathy was arthroscopically graded using French Society of Arthroscopy system (SFA) score and SFA category.

Results: The SFA score was significantly strongly correlated with the VAG score (r=0.87, p=0.02) but not with the Kujala score (r=–0.79, p=0.11). Likewise, the SFA category was significantly correlated with the VAG score (r=0.98, p<0.01) but not with the Kujala score (r=–0.67, p=0.22).

Conclusion: The proposed signal-based VAG score was demonstrated to be preliminarily able to better assess the patellofemoral chondropathy non-invasively, compared to the Kujala score, which is questionnaire-based.

Keywords: Chondropathy; Vibroarthrographic signal; SFA score; SFA category; Kujala score

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Patellofemoral chondropathy can be found not only in the case of solely chondromalacia patella but also concomitant with the other knee injuries like the meniscal injuries as shown in arthroscopic studies[1,2], the magnetic resonance imaging study[3], and the near-infrared spectroscopic imaging study[4]. To quantify the articular cartilage injury quickly and non-invasively, the Kujala Anterior Knee Pain Scale is often one of the top choices as it has been widely used to quantify patellofemoral disorder[5]. The scale is based on the self-reported questionnaire with acceptable reliability and validity, but the clinical outcome scale could be subjective and not directly suggest patellofemoral cartilage injury, particularly in the case of having other knee complication in addition to the chondromalacia patella.

French Society of Arthroscopy system (SFA) scoring system is a reliable score[6] used to arthroscopically quantify the articular cartilage of the knee in lateral, medial, and patellofemoral compartments[7,8]. The system consists of the SFA score and the SFA category. The SFA score, ranged from 0 as normal to 100 as full subchondral bone, included both size and depth as lesion grade of the lesions on the whole compartment. The size of each lesion grade is used to categorize the articular cartilage into the pre-defined SFA category.

The vibroarthrographic (VAG) signal has previously shown to be correlated with patellofemoral cartilage lesion[9]. The signal is basically the vibration of joint due to increased roughness-induced vibration[10]. The power spectral density of signal at the high frequency range has found to be enhanced with the increased surface roughness and correlated with the clinical severity of chondromalacia patella[11].

Therefore, the aim of the present study was to demonstrate if the proposed VAG score, derived from the measured knee VAG signal, was correlated to the SFA score and SFA category in comparison to the Kujala score. The clinical impact of this

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novel patellofemoral cartilage score would be to have an assessment tool that directly explain the patellofemoral cartilage lesions in comparison to the arthroscopy-examined SFA cartilage grading system.

Materials and Methods

Subjects and study protocol

Study participants were recruited from those with meniscus injuries who were prescribed to undergo arthroscopic surgery between December 2017 and August 2018. Exclusion criteria were trauma, patellar sublaxation, patellar dislocation or inability to flex and extend the knee comfortably. After the subjects signed the informed consents, the demographic data were collected and the patellofemoral clinical outcomes were scored with the self-reported Kujala questionnaire in Thai version[12] and the knee VAG signals were recorded afterwards, prior to the knee arthroscopy. The meniscus injury case descriptions were extracted from the intra-operative notes. The present study protocol was approved by the Institutional Review Boards of Mahidol University (COA No.MU-CIRB 2017/130.3108) and Nakhon Pathom Hospital (COA No.023/2017), Thailand.

VAG signal acquisition

The knee VAG signals of all participants were recorded by a piezoelectric accelerometer (model 352A24, PCB Piezotronics, USA) with the sensitivity of 98.3 mV/g and sampled at the rate of 10 kHz through a data acquisition system (SIRIUSm-4xACC, DEWESoft, Slovenia). The acceleration sensor was placed on the mid patella position over the hypoallergenic tape and wrapped with a self-adhesive wrap (3M Coban™) around the knee to secure the sensor. The signal was recorded when the subject was in the supine position and actively performed the knee movement, starting from full flexion to full extension and back to full flexion again continuously for three cycles within ten seconds.

Calculation of the VAG score

Baseline wander in VAG signals from the knee motion was eliminated using cascade moving average filter with hierarchical layers[13]. Short-time Fourier transform analysis was performed to obtain summing of the spectral power of the VAG signals by computing the discrete Fourier transform of each of the 256 samples per segmentation using the Hamming window of 250 samples with 256 overlap samples. The VAG score was defined as the power spectral density between 450 to 1,000 Hz, represented in the unit of dB. The calculations were done with custom programming using MATLAB 2019a (the MathWorks, MA, USA).

SFA articular cartilage grading

An arthroscopic examination of the patellofemoral cartilage was done, with a 70° arthroscope and a hook probe, prior to performing the meniscus surgery. Twelve arthroscopic pictures were taken for each knee according to ICRS articular cartilage injury mapping system including nine for patella and three for trochlea, covering the whole area of patellofemoral articular cartilage using the true 1080p HD digital camera system (Synergy HD3™, Arthrex, USA). The lesion depths were graded during the arthroscopic examination as suggested for SFA quantification[7,8], which has similar description to the Outerbridge score[14], such as grade 0 for normal, grade I for softening or swelling, grade II for superficial fissures, grade III for deep fissures, and grade IV for exposure of subchondral bone. Each knee diagram was carefully completed post-operatively from the arthroscopic pictures by an over-10-year experienced arthroscopist (Watcharaprechasakul V) who performed the arthroscopic examination and meniscus surgery. The evaluation was done by one observer as the score has been studied to be reproducible[6]. Lesion sizes were calculated in percentage of the lesion area to the whole area of either patella or trochlea using digitization of the knee diagram drawing using a custom program (MATLAB R2019a, MathWorks, USA). The cartilage SFA score and SFA category of the patellofemoral compartment for each knee was calculated to quantify the chondropathy in SFA scoring system[7,8].

Statistical analysis

Pearson correlation and linear regression analyses were done to assess the relationship of the SFA score and SFA category with the VAG score and the Kujala score, PASW Statistics, version 18.0 (SPSS Inc., Chicago, IL, USA). A p-value was calculated at the significance level of 0.05 (two-tailed).

Results

Subjects

Five subjects were included in the preliminary analysis. Most of them had medial meniscus injury (Table 1).

Arthroscopic examination and SFA chondropathy quantification

Chondropathy quantification was done after

Table 1. Demographic characteristics and meniscus injury description of the subjects

Subject	Age	Sex	BMI	Affected knee	Meniscus injury description				
					Type of tear	Medial/lateral	Position	Zone	Size (cm)
1	49	Female	27.3	Left	Vertical	Medial	Posterior horn	Red zone	2
2	37	Male	24.2	Left	Horizontal	Medial	Posterior horn	White zone	2
3	56	Female	27.3	Left	Degenerative	Medial	15% body to posterior horn	White zone	1
4	52	Female	23.1	Right	Degenerative	Medial	30% body to posterior horn	White zone	3
5	55	Female	22.1	Left	Complete	Medial	Posterior root	Root	N/A

BMI=body mass index; N/A=not available

Table 2. Calculation of SFA scores and categories for the patellofemoral compartment

Subject	Grade*	Patella (%)	Trochlea (%)	Mean value (%)	SFA score†	SFA category††
1	0	30.34	27.98	21.16	21.48	II
	I	30.42	22.02	26.22		
	II	22.19	50.00	36.09		
	III	17.05	0.00	8.53		
	IV	0.00	0.00	0.00		
2	0	55.99	69.05	62.52	16.79	III
	I	15.69	10.69	13.19		
	II	5.42	0.00	2.71		
	III	22.90	20.26	21.58		
	IV	0.00	0.00	0.00		
3	0	26.37	20.47	23.42	36.71	III
	I	17.84	0.00	8.92		
	II	34.04	20.96	27.50		
	III	21.75	58.57	40.16		
	IV	0.00	0.00	0.00		
4	0	24.01	24.30	24.15	39.40	IV
	I	18.16	0.00	9.08		
	II	44.78	35.07	39.92		
	III	13.05	0.00	6.53		
	IV	0.00	40.63	20.31		
5	0	21.14	15.14	18.14	60.76	V
	I	7.82	17.25	12.53		
	II	12.78	0.00	6.39		
	III	9.41	25.45	17.43		
	IV	48.85	42.16	45.51		

SFA=French Society of Arthroscopy system

* Cartilage grading definition: 0=normal, I=softening or swelling, II=superficial fissure, III=deep fissure and IV=exposure of subchondral bone

† SFA score = 0.14 × (mean% grade I) + 0.34 × (mean% grade II) + 0.65 × (mean% grade III) + 1.0 × (mean% grade IV)

†† SFA category description, Category 0: grade 0=100%; Category I: grade IV <2.5% and grade III <10% and grade 0 ≥85% and <100%; Category II: grade IV <2.5% and grade III <10% and grade 0 <85%; Category III: grade IV <2.5% and grade III ≥10%; Category IV: grade IV ≥2.5% and <25%; Category V: grade IV ≥25%

Table 3. Patellofemoral functional (Kujala) and cartilage scores (SFA and VAG)

Subject	SFA score	SFA category	Kujala score	VAG score
1	21.48	II	62	7.00
2	16.79	III	88	20.01
3	36.71	III	75	29.16
4	39.40	IV	46	36.62
5	60.76	V	40	54.36

SFA=French Society of Arthroscopy system; VAG=vibroarthrographic

arthroscopic patellofemoral cartilage examination. All cartilage lesion grades were found in different sizes and areas as shown in Figure 1.

The SFA scores calculated from the custom program are displayed in Table 2. Size percentage of patella and trochlea were used to determine the mean value (%) of each lesion grade to calculate the SFA score. SFA category was classified according to the description[7,8].

Statistical analysis

The SFA score, SFA category, VAG score, and Kujala score of each subject are shown in Table 3. Significant strong correlation of the VAG score was found with both SFA score (r=0.93, p=0.02) and SFA category (r=0.98, p=0.003). Negative correlation of the Kujala score was also found with both SFA score (r=–0.79, p=0.11) and SFA category (r=–0.67, p=0.22) even though the correlations were not statistically significant. Linear regression analysis is displayed in Figure 2. Body mass indexes (BMIs) were not significantly correlated with both SFA score (r=–0.58, p=0.31) and Kujala score (r=0.54, p=0.35).

Discussion

Arthroscopic finding of patellofemoral cartilage lesion in patients with meniscus injury

All the subjects had the posterior medial

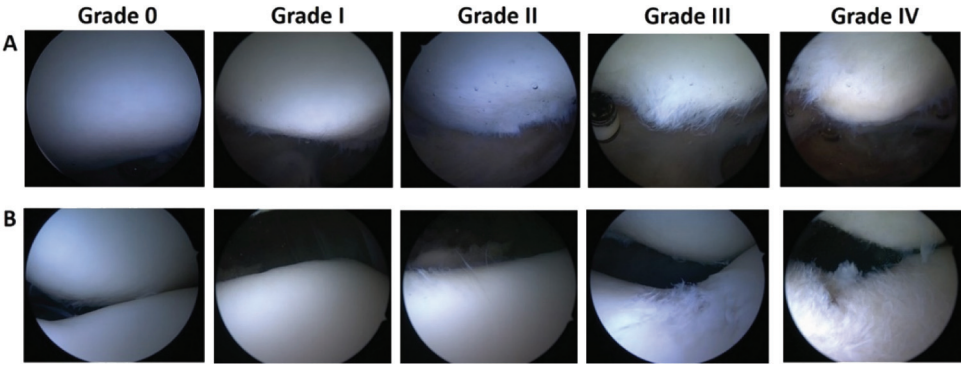

Figure 1. Sample of arthroscopic pictures for each lesion grade of the patella (A) and trochlea (B).

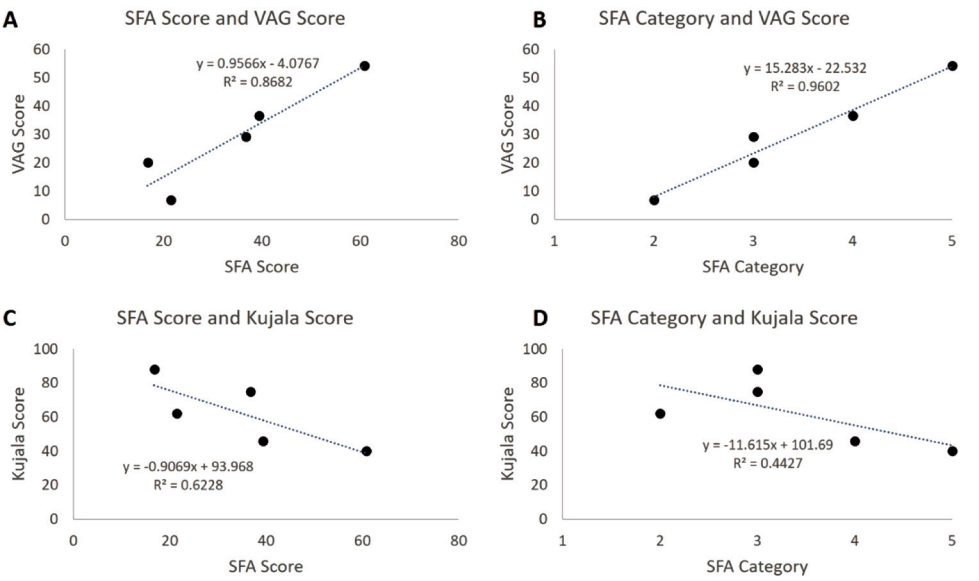

Figure 2. Linear regression between the VAG score with SFA score (A) and SFA category (B) and Kujala score with SFA score (C) and SFA category (D).

meniscus injury, which was the most common site of meniscus injury[1]. Four cases were found to affect the horn and one case affected the root. Participants were between 37 to 56 years old with normal to relatively overweight BMIs, even though the BMIs were not correlated either to the clinical outcome (Kujala score) or the chondropathy (SFA score). With the small sample size recruited in the present study, it was difficult to say whether the severity of the meniscus injury was correlated with the severity of patellofemoral cartilage injury.

SFA score and Kujala score

The Kujala score has been widely used to quantify the patellofemoral knee disorder in which some aspects of the clinical outcome could be in common with other knee injuries. In assessing the patellofemoral chondropathy, Kujala score might not directly explain the articular cartilage lesions in which it might be the reason for not seeing the good correlation between the SFA score and the Kujala score. Therefore, a new non-invasive tool to assess patellofemoral cartilage lesions is needed, particularly in patients without the anterior knee pain or with other kinds of knee injuries.

SFA score and VAG score

The proposed VAG score derived from the spectral power of the knee VAG signal was in good correlation with both SFA score and SFA category. The SFA score takes both lesions depth and size into consideration, and thus, makes it the only score to

completely quantify the chondropathy as it covers the whole articular surface. Good correlation between the VAG score to the SFA score might be due to the VAG signal been found to directly explain the articular cartilage lesions[9,11]. The VAG score also had similar intuitive quantity as the SFA score with higher score for the worse cartilage integrity, which should make it easier to adopt clinically. However, meniscus injury had also been reported to produce a distinctive signal in the time domain at specific location[15]. This proposed VAG score should potentially be able to quantify the patellofemoral chondropathy without interferences from the meniscus injury signal as the score was derived from the frequency domain analysis.

Conclusion

The present study was a preliminary study to demonstrate the possible use of VAG score as a quick non-invasive tool to assess patellofemoral chondropathy quantitatively. The VAG score was better correlated to the reliable and objective cartilage score like SFA, in comparison to the clinical Kujala score. Time to assess was less than one minute to take the VAG signal and calculate the VAG score by a custom program. Further study with more cases is highly recommended for the reliability and validity testing.

What is already known on this topic?

The knee VAG signal has been studied in assessing the patellofemoral chondral injury and other knee pathologies by analyzing various features extracted from the VAG signal.

What this study adds?

The proposed VAG score, which is a single feature derived from the signal, is possibly a quick and convenient score to be used in assessing the patellofemoral chondropathy as it was found to be correlated with the SFA score in this study.

Conflicts of interest

Authors declare no conflicts of interest.

References

1. Jones S, Caplan N, St Clair Gibson A, Kader N, Kader D. Interactions between severity and location of chondral lesions and meniscal tears found at arthroscopy. Knee Surg Sports Traumatol Arthrosc 2011;19:1699-703.
2. Hjelle K, Solheim E, Strand T, Muri R, Brittberg M. Articular cartilage defects in 1,000 knee arthroscopies. Arthroscopy 2002;18:730-4.
3. Kaplan LD, Schurhoff MR, Selesnick H, Thorpe M, Uribe JW. Magnetic resonance imaging of the knee in asymptomatic professional basketball players. Arthroscopy 2005;21:557-61.
4. Spahn G, Plettenberg H, Hoffmann M, Klemm HT, Brochhausen-Delius C, Hofmann GO. The frequency of cartilage lesions in non-injured knees with symptomatic meniscus tears: results from an arthroscopic and NIR- (near-infrared) spectroscopic investigation. Arch Orthop Trauma Surg 2017;137:837-44.
5. Kujala UM, Jaakkola LH, Koskinen SK, Taimela S, Hurme M, Nelimarkka O. Scoring of patellofemoral disorders. Arthroscopy 1993;9:159-63.
6. Lasmar NP, Lasmar RC, Vieira RB, de Oliveira JR, Scarpa AC. Assessment of the reproducibility of the Outerbridge and FSA classifications for chondral lesions of the knee. Rev Bras Ortop 2011;46:266-9.
7. Ayral X. Diagnostic and quantitative arthroscopy: quantitative arthroscopy. Baillieres Clin Rheumatol 1996;10:477-94.
8. Dougados M, Ayral X, Listrat V, Gueguen A, Bahuaud J, Beaufils P, et al. The SFA system for assessing articular cartilage lesions at arthroscopy of the knee. Arthroscopy 1994;10:69-77.
9. Befrui N, Elsner J, Flesser A, Huvanandana J, Jarrousse O, Le TN, et al. Vibroarthrography for early detection of knee osteoarthritis using normalized frequency features. Med Biol Eng Comput 2018;56:1499-514.
10. Abbott SC, Cole MD. Vibration arthrometry: a critical review. Crit Rev Biomed Eng 2013;41:223-42.
11. Bączkowicz D, Majorczyk E. Joint motion quality in chondromalacia progression assessed by vibroacoustic signal analysis. PM R 2016;8:1065-71.
12. Apivatgaroon A, Angthong C, Sanguanjit P, Chernchujit B. The validity and reliability of the Thai version of the Kujala score for patients with patellofemoral pain syndrome. Disabil Rehabil 2016;38:2161-4.
13. Cai S, Wu Y, Xiang N, Zhong Z, He J, Shi L, et al., editors. Detrending knee joint vibration signals with a cascade moving average filter. 2012 annual international conference of the IEEE Engineering in Medicine and Biology Society (EMBC 2012); San Diego, California, USA, 28 Aug - 1 Sep 2012. p. 4357-60.
14. Outerbridge RE. The etiology of chondromalacia patellae. J Bone Joint Surg Br 1961;43-b:752-7.
15. McCoy GF, McCrea JD, Beverland DE, Kernohan WG, Mollan RA. Vibration arthrography as a diagnostic aid in diseases of the knee. A preliminary report. J Bone Joint Surg Br 1987;69:288-93.