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Original Article

A New Clustering Method for Knee Movement Impairments using Partitioning Around Medoids Model

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Abstract

Background: The movement system impairment (MSI) model is a clinical model that can be used for the classification, diagnosis, and treatment of knee impairments. By using the partitioning around medoids (PAM) clustering method, patients can be easily clustered in homogeneous groups through the determination of the most discriminative variables. The present study aimed to reduce the number of clinical examination variables, determine the important variables, and simplify the MSI model using the PAM clustering method.
Methods: The present cross-sectional study was performed in Shiraz, Iran, during February-December 2018. A total of 209 patients with knee pain were recruited. Patients' knee, femoral and tibial movement impairments, and the perceived pain level were examined in quiet standing, sitting, walking, partial squatting, single-leg stance (both sides), sit-to-stand transfer, and stair ambulation. The tests were repeated after correction for impairments. Both the pain pattern and the types of impairment were subsequently used in the PAM clustering analysis.
Results: PAM clustering analysis categorized the patients in two main clusters (valgus and non-valgus) based on the presence or absence of valgus impairment. Secondary analysis of the valgus cluster identified two sub-clusters based on the presence of hypomobility. Analysis of the non-valgus cluster showed four sub-clusters with different characteristics. PAM clustering organized important variables in each analysis and showed that only 23 out of the 41 variables were essential in the sub-clustering of patients with knee pain.
Conclusion: A new direct knee examination method is introduced for the organization of important discriminative tests, which requires fewer clinical examination variables.

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Keywords ● Movement system impairment model ● Knee ● Cluster analysis ● Classification ● Syndrome

What's Known

- The movement system impairment model has certain limitations in the classification of knee impairments.
- Partitioning around medoids clustering is a method to organize homogeneous groups with similar characteristics.

What's New

- A new clinical knee examination model is introduced. The model uses the partitioning around medoids clustering method based on clinical signs and symptoms.
- The model successfully reduced the number of clinical examination variables and prioritized discriminative variables.

Introduction

Extra-articular soft tissue injuries are the most common injuries of the knee joint, which may eventually lead to knee osteoarthritis with an estimated prevalence of 24% in adults.[1, 2] Knee pain is a common musculoskeletal problem in patients referred to outpatient physical therapy centers. The prevalence of knee pain in the United States has increased by 65% over 20 years.[3] Conservative treatment of non-traumatic knee pain is usually the first line of management versus surgical treatments.[4] Over the years, various non-surgical treatments with an emphasis on correcting the impaired movement have been developed for knee pain.[5] Despite the availability of various treatments, it has been suggested that classifying patients into homogeneous groups may simplify the complexities of diagnosis and facilitate treatment options.[5-7]

Clinical methods classify patients based on their distinct signs, symptoms, treatments, or psychosocial characteristics.[8, 9] Among the most important clinical classification methods are the pathoanatomic and kinesiopathologic models.[10-12] The pathoanatomic model focuses on the effect of stresses on tissues and utilizes diagnostic labeling of the causative factors of the patient's pain (e.g., meniscal tear). However, sometimes patients are referred to a physical therapist with no definite diagnosis. Physical therapists typically treat patients based on their movement impairments rather than on the pathoanatomical source of the pain. As a result, they use the kinesiopathologic model, a movement system diagnostic classification method, as an alternative to the pathoanatomic model.[11]

Among kinesiopathologic models, the movement system impairment (MSI) model is considered the most suitable classification approach and has been reviewed clinically and kinematically during the current decade.[5, 13, 14] The MSI model of the knee has been shown to have acceptable intratester reliability.[14] This model classifies patients with knee pain into seven subgroups based on examining the knee movement, correction of faulty posture, and re-evaluation of the symptoms. The subgroups are tibiofemoral rotation syndrome, tibiofemoral hypomobility syndrome, tibiofemoral accessory hypermobility syndrome, knee extension syndrome; knee hyperextension syndrome, patellar lateral glide syndrome, and knee impairment. Previous studies have reported certain limitations in the MSI model, namely overlapping signs and symptoms,[13] time-consuming examination process,[5] challenges in determining the tibiofemoral rotation angle,[4] and the absence of differences in perceived pain levels between the usual and corrected movement conditions.[13]

Attempts have been made to validate the classification of syndromes using statistical models such as Ward's clustering method for hip disorders[15] and hierarchical clustering method for non-specific patellofemoral pain for the lower extremity examination.[16] Statistical analysis can be used to describe the characteristics of a population in an idealized model with algorithms based on similarity and differences in signs and symptoms.[17, 18] Statistical clustering is an unsupervised learning process in which the data are grouped in different clusters free from preconceptions. Unlike other clustering methods, the partitioning around medoids (PAM) model is a unique and flexible clustering method that allows the entry of various forms of variables (nominal, ordinal, or scalar) besides numeric variables.[17, 18] In the PAM model, one case is selected as a medoid, and the data with the least dissimilarities to the medoid are clustered around it. The medoids are then replaced to gain the smallest dissimilarity. This process continues until no change takes place in medoids and the determined number of clusters itself. This unique process leads to separated data groups with the least within-group dissimilarity and maximum between-group dissimilarity.[19] This highly accurate method classifies patients into clusters based on their true dissimilarities and distinguishes the important variables for clustering. Thus, classifications based on this model would be simple, most time-efficient, and require less clinical examination variables.

Studies evaluating the reliability of the MSI model have reported difficulties in classifying patients based on the signs and symptoms.[7, 14] We believe that this could be due to difficulties in the judging part of the MSI model. Another study also reported that knee examination based on the MSI model is too time-consuming (about 45 minutes).[14] To address these issues, the main objective of the present study was to use the PAM clustering method for the classification of patients based on their signs and symptoms derived from the MSI model. In addition, we aimed to identify those key tests directly related to knee examination for the sole purpose of reducing examination time.

Patients and Methods

In the present cross-sectional study, patients with knee pain were recruited from several orthopedic and rehabilitation clinics affiliated to Shiraz University of Medical Sciences (Shiraz, Iran) during February-December 2018. The participants were selected using the convenient sampling method, and the sample size was estimated in accordance with previous studies,[5, 14] and by using the statistical rules of thumb.[20] A total of 209 patients with knee pain referred for physical therapy by an orthopedic surgeon were recruited in the study. The study was approved by the local Medical Ethics Committee (number: IR.SUMS.REC.1396.S993), and written informed consent was obtained from the participants.

The inclusion criteria were aged 18-60 years and experiencing non-traumatic pain around the knee (scoring between 3 and 7 in a standing position on a numerical rating scale) for the last two months.[5, 14] The exclusion criteria were any history of surgery (bone osteotomy, bone fracture repair or surgical correction of structural deformities in the trunk or lower extremity), major general metabolic or systemic diseases, neurological diseases (radiculopathy), obvious leg length discrepancy leading to limping, pregnancy; and the use of walking aids, analgesic, and anti-inflammatory drugs up to or at the day of examination.[5, 14] The examiner was a physical therapist with 12 years of experience in treating patients using the MSI model. All procedures were conducted according to the Declaration of Helsinki.

The examination procedure began with a documentation of the patient's history (height, weight, age, sex, pain location, and intensity) followed by a physical examination. The activity level was measured using the Persian version of the Tegner questionnaire, which was previously validated with an acceptable level of reliability.[21] The questionnaire is a self-administered activity rating system (based on a scale of 0 to 10) for patients with various knee disorders. The physical postural examination included assessment of correct alignment (anterior, posterior, and side views) in standing and sitting positions as described in the MSI model.[10] The knee, femoral, and tibial movements were evaluated during different activities such as walking, half-squatting, single-leg stance (comparing both sides), and stair ambulation. A walkway and an adjustable chair were used to perform the walking and sit-to-stand transfer, respectively. Climbing was performed on stairs of 20 cm height.

The initial perceived level of pain was recorded during each movement. In case of faulty movement patterns, the therapist trained the participants on the correct pattern, requesting repetition of the movement, and report of the perceived pain level. The difference in the pain level between faulty and corrected movements was coded for each activity and rated from 0 to 7 (0: no change, 1: valgus correction, 2: varus correction, 3: hyperextension correction, 4: patellar movement correction, 5: no immediate correction available, 6: no alignment deficit, and 7: increased pain). This process was repeated in all positions. The examiner palpated each segment during movements, and if an activity was performed incorrectly (with valgus or excessive tibial external rotation), the participant was informed about the correct movement pattern. The movement was then repeated in the corrected form (if possible) and re-evaluated by the examiner. If an obvious difference was found between the previous and corrected movements, the faulty movement was recorded as the impairment. Impairments that could not be corrected immediately (hypomobility) were recorded without repetition of the movement. The deployed coding system was based on the MSI model and previous studies.[5, 14] A total of 41 scalars (pain) and nominal (alignment deficits) variables were counted during different activities. A muscle stiffness-flexibility test was performed in the supine position to determine the muscle-joint relative flexibility. It consisted of a two-joint hip flexors length test, and the result was reported positive if the tibia was abducted or rotated laterally while lowering the hip in extension. The joint integrity was measured by assessing the accessory motions of the patellofemoral and tibiofemoral joints. The McConnell patellar test[10] and patellar grind test were also performed. The foot arch was measured by determining the Feiss line and classified as high, low, or normal arch. The variables collected during examination based on the PAM clustering analysis are presented in table 1. Manual muscle testing was also performed for the muscles of the lower extremity. However, the results were not used in the PAM analysis, since muscle power is not a discriminating factor for clustering.

The extracted data from all patients were analyzed using ClusterR and VarSelLCM packages of R software (R core team, version 3.5.3, New Zealand). PAM analysis allows the management of different types of variables (nominal, ordinal, or scalar) and is robust against outlier observations.[11, 17] Moreover, it reduces the number of variables, prioritizes, and categorizes data into homogeneous clusters. The weight of each variable was defined through the discriminatory power (DP), i.e., the contribution of each variable in cluster analysis.[11, 17] After the initial PAM clustering, the analysis was repeated for each cluster to identify sub-clusters that included all variables. All other statistical analyses were performed using SPSS software, version 25.0 (IBM Inc. Chicago, IL, USA). The quality of the clusters and sub-clusters was analyzed using the silhouette coefficient internal index, ranging from 1 to -1. Values close to 1 indicated more dense clusters with more distances from other clusters (i.e., best possible categorization) and those close to -1 indicated too many or too few clusters.[22]

Table 1: The list of variables recorded during examination

Position	Symptoms	Signs
Walking	Symptom alleviation with the correction of walking	Knee valgus and varus
		Femoral abduction and adduction
		Tibial abduction and adduction
		Tibial medial and lateral rotation
		Knee hyperextension and lack of extension
Partial squat	Symptom alleviation with the correction of partial squatting	Knee valgus and varus
		Femoral abduction and adduction
		Femoral medial and lateral rotation
		Tibial abduction and adduction
		Tibial medial and lateral rotation
Sit-to-stand	Symptom alleviation with the correction of sit-to-standing	Knee valgus and varus
		Femoral abduction and adduction
		Femoral medial and lateral rotation
		Tibial abduction and adduction
		Tibial medial and lateral rotation
Single-leg stance on involved limb	Symptom alleviation with the correction of single-leg stance	Knee valgus and varus
		Femoral abduction and adduction
		Femoral medial and lateral rotation
		Tibial abduction and adduction
		Tibial medial and lateral rotation
		Knee hyperextension and lack of extension
Knee flexion in single-leg stance on uninvolved limb	Symptom alleviation with the correction of knee flexion while standing on uninvolved limb	Tibial medial and lateral rotation
Stair ambulation	Symptom alleviation with the correction of stair ambulation	Knee valgus and varus
		Femoral abduction and adduction
		Femoral medial and lateral rotation
		Tibial abduction and adduction
		Tibial medial and lateral rotation
		Knee hyperextension and lack of extension
		Tibial roll on foot in stair climb
Prone	Symptom alleviation with the correction of prone knee flexion	Tibial abduction and adduction
		Tibial medial and lateral rotation
Supine	Symptom alleviation with the correction during two-joint hip flexor length test	Relative flexibility with two-joint hip flexor length test
		Joint integrity
	McConnel and patellar grind test	Pain location
Standing	-	Foot pronation

Results

A total of 209 patients (57 men, 152 women) participated in the study of which 108 (51%) had pain of the right knee and 101 (48%) had pain of the left knee. The mean age of the patients was 43±12 years, the mean weight of 73±13 kg, and the mean height of 166±8 centimeters. Based on a visual analog scale, the pain level at the time of examination in standing position was 17±19. The mean total score of the Tegner questionnaire was 4±1. Based on all signs and symptoms, the PAM clustering analysis resulted in two main clusters and six sub-clusters.

Main Clusters

The optimum number of clusters was two with a silhouette coefficient value of 0.41. The results of the PAM clustering analysis showed that 23 out of the 41 variables were necessary for an initial clustering of patients into two main clusters (table 2). The clusters were labeled according to the most discriminative features of the diagnosed condition. The main discriminative characteristic was knee valgus, thus the corresponding clusters were labeled "Valgus" and "Non-valgus" The non-valgus cluster included characteristics of varus or no deformity. The valgus and non-valgus clusters contained 120 (57.4%) and 89 (42.6%) patients, respectively. Among all variables, the frontal plane knee deficits (valgus and varus) had the highest DP, especially in activities such as sit-to-stand transfer (DP=90.76), stair ambulation (DP=84.82), and partial squat (DP=77.10). The PAM analysis was repeated for each cluster to determine sub-clusters:

Table 2: Discriminative variables and the corresponding discriminative power and percentile of the key characteristics in each main cluster of patients with knee pain

	Variables	Discriminative power	Discriminative power (%)	Main cluster: Valgus	Main cluster: Non-valgus
1	Knee valgus and varus on sit-to-stand movement	90.76	9.14	90% increased valgus 9% no change	47% increased varus 47% no change 5% increased valgus
2	Knee valgus and varus on stair ambulation	84.82	8.55	95% increased valgus 4% no change	49% increased varus 37.1% no change 12% increased valgus
3	Knee valgus and varus on partial squat movement	77.10	7.77	87% increased valgus 10% no change 1% increased varus	47% increased varus 43% no change 8% increased valgus
4	Femoral abduction and adduction on sit-to-stand movement	75.54	7.61	81% increased adduction 17% no change	38% increased abduction 59% no change 2% increased adduction
5	Femoral abduction and adduction on partial squat movement	74.42	7.50	77% increased adduction 22% no change	41% increased abduction 52% no change 5% increased adduction
6	Femoral abduction and adduction on stair ambulation	73.96	7.45	85% increased adduction 12% no change 2% increased abduction	46.1% increased abduction 42% no change 11% increased adduction
7	Tibial abduction and adduction on stair ambulation	50.54	5.09	65% increased abduction 35% no change	6% increased abduction 68% no change 24% increased adduction
8	Femoral abduction and adduction on walking	44.14	4.45	64% increased adduction 35% no change	15% increased abduction 79% no change 4% increased adduction
9	Symptom alleviation on stair ambulation	43.73	4.41	43% Val cor 25% with Patella cor 18% no change in pain 7% with no Imm. Cor. 4% with no deficit	41% no change in pain 15% with no Imm. Cor. 14% with Var cor 11% with Patella cor 8% with Hyperext cor 7% with no Spec. Mal.
10	Femoral abduction and adduction on single-leg stance	39.03	3.93	70% increased adduction 29% no change	21% increased abduction 66% no change 12% increased adduction
11	Tibial abduction and adduction on partial squat movement	38.97	3.93	61% increased abduction 37% no change	21% increased adduction 73% no change 5% increased abduction
12	Tibial abduction and adduction on sit-to-stand movement	36.42	3.67	56% increased abduction 43% no change	19% increased adduction 75% no change 5% increased abduction
13	Symptom alleviation on partial squat movement	36.03	3.63	36% Val cor 31% no change in pain 20% with Patella cor 9% with no Imm. Cor. 1% with no Spec. Mal.	46.1% no change in pain 16% with no Imm. Cor. 15% with Var cor 10% with Patella cor 8% with no Spec. Mal. 2% with Hyperext cor
14	Symptom alleviation on single-leg stance	28.72	2.89	50% no change in pain 27% with Val cor 14% with Patella cor 5% with No Imm. Cor. 1% with No Spec. Mal.	46.1% no change in pain 21% with Var cor 15% with no Imm. Cor. 6% with Patella cor 5% with no Spec. Mal. 4% with Hyperext cor
15	Tibial abduction and adduction on single-leg stance	26.88	2.71	66% no change 33% increased abduction	16% increased adduction 82% no change 1% increased abduction
16	Symptom alleviation on sit-to-stand movement	24.47	2.47	50% no change in pain 29% with Val cor 13% with Patella cor 4% with no Imm. Cor. 2% with no Spec. Mal.	64% no change in pain 12% with Var cor 10% with No Imm. Cor. 6% with Patella cor 3% with no Spec. Mal. 3% with Hyperext cor
17	Tibial abduction and adduction on walking	23.98	2.42	75% no change 25% increased abduction	19% increases adduction 78% no change 2% increased abduction

	Variables	Discriminative power	Discriminative power (%)	Main cluster: Valgus	Main cluster: Non-valgus
18	Femoral medial and lateral rotation on stair ambulation	20.99	2.11	90% Incr Med Rot 8% no change	52% Incr Med Rot 30% no change 16% Incr Lat Rot
19	Femoral medial and lateral rotation on sit-to-stand movement	14.37	1.45	87% Incr Med Rot 12% no change	47% Incr Med Rot 47% no change 5% Incr Lat Rot
20	Femoral medial and lateral rotation on partial squat movement	14.16	1.43	82% Incr Med Rot 17% no change	48% Incr Med Rot 44% no change 6% Incr Lat Rot
21	Knee hyperextension and extension lack on single-leg stance	12.64	1.27	79% no change 13% extension lack 7% knee hyperextension	41% no change 31% knee hyperextension 26% extension lack
22	Knee hyperextension and extension lack on walking	11.17	1.13	79% no change 13% extension lack 7% knee hyperextension	41% no change 31% knee hyperextension 26% extension lack
23	Symptom alleviation on walking	10.93	1.10	75% no change in pain 13% with Val cor 7% with Patella cor 2% with No Imm. Cor.	77% no change in pain 10% with varus correct 8% with no Imm. Cor. 2% with Patella cor 1% with Hyperext cor

No change: No change in movement, Val cor: Symptoms alleviated with valgus correction, Var cor: Symptoms alleviated with varus correction, No Imm. Cor.: Movement was not correctable immediately, Hyperext cor: Symptoms alleviated with prevention of knee hyperextension, Patella cor: Symptoms alleviated with correction of patellar alignment, No Spec. Mal.: No pain difference recorded as no correction was performed, Incr Lat Rot: Increased lateral rotation, Incr Med Rot: Increased medial rotation

Sub-clusters of Valgus

The optimum number of sub-clusters of valgus was two with a silhouette coefficient of 0.26. The results of the PAM analysis showed that 12 out of the 41 variables were necessary for the sub-clustering of patients (table 3). Two sub-clusters were selected based on the presence or absence of knee hypomobility, being the most discriminative characteristic among all sub-clusters. The characteristics of each sub-cluster are listed in table 3. These sub-clusters were labeled "Valgus with hypomobility" and "Valgus", since the most discriminative feature was knee hypomobility with the highest DP, especially in a single-leg stance (DP=65.30), walking (DP=57.71), and tibiofemoral joint integrity (DP=48.48).

Valgus with Hypomobility: A total of 16 (7%) patients with a mean age of 52 years exhibited valgus combined with hypomobility. Movement pattern modification, especially in the partial squat and stair ambulation, was the major correction to alleviate the symptoms. The patients also exhibited knee valgus in the sit-to-stand transfer. The major discriminator was the lack of knee extension, especially in a single-leg stance (DP=65.30) and walking (DP=57.71).

Valgus: A total of 104 (49.7%) patients with a mean age of 41 years exhibited valgus in a sit-to-stand transfer, partial squat, and stair ambulation as major discriminators.

Sub-clusters of Non-valgus

The PAM analysis was repeated for the non-valgus cluster to identify its sub-clusters. The optimum number of sub-clusters was four with a silhouette coefficient of 0.25. The results showed that 23 out of the 41 variables were needed for the sub-clustering of patients (table 4). These sub-clusters were labeled "Hyperextension", "Hypomobility", "Varus", and "Minimal pain and dysfunction". Among all the variables, joint integrity (DP=41.49), symptoms in single-leg stance (DP=38.24), symptoms in stair ambulation (DP=36.77), and knee hyperextension and hypomobility in single-leg stance (DP=34.04) had the highest DP.

Hyperextension: A total of 10 (4%) patients with a mean age of 32 years were clustered as having hyperextension, especially in single-leg stance and walking. Although correction of faulty movement pattern may not immediately reduce the symptoms in these patients, attention to the signs of sagittal-plane knee function impairments can be a discriminator for categorization since all patients had hyperextension in walking (DP=34.01) and standing on the examined leg (DP=34.04).

Hypomobility: A total of 23 (11%) patients with a mean age of 54 years exhibited a lack of full extension, especially in single-leg stance and walking. Movement pattern modification reduced the pain, particularly in stair ambulation and single-leg stance. All patients exhibited a lack of knee extension in stair ambulation (DP=28.96). Most of the patients with hypomobility exhibited varus in movements, especially in sit-to-stand transfer (73%), partial squatting (73%), and stair ambulation (78%).

Table 3: Discriminative variables and the corresponding discriminative power and percentile of the key characteristics in valgus sub-clusters

	Variables	Discriminative power	Discriminative power (%)	Sub-cluster: Valgus with hypomobility	Sub-cluster: Valgus
1	Knee hyperextension and extension lack on single-leg stance	65.30	20.39	100% extension lack	91% no change 8% knee hyperextension
2	Knee hyperextension and extension lack on walking	57.71	38.40	100% extension lack	91% no change 8% knee hyperextension
3	Joint integrity	48.48	53.54	100% tibiofemoral hypomobility	95% no change 4% tibiofemoral hypermobility
4	Knee hyperextension and extension lack on stair ambulation	46.80	68.15	93% extension lack 6% knee hyperextension	78% no change 21% knee hyperextension
5	Symptom alleviation on stair ambulation	29.30	77.29	62% with no Imm. Cor. 31% no change in pain 6% with no Spec. Mal.	50% Val cor 29% with Patella cor 16% no change in pain 3% with No Spec. Mal.
6	Symptom alleviation on partial squat movement	26.88	85.68	68% with no Imm. Cor. 31% no change in pain	42% Val cor 31% no change in pain 24% with Patella cor 1% with No Spec. Mal.
7	Symptom alleviation on singleleg stance	11.50	89.28	43% with no Imm. Cor. 43% no change in pain 6% with Var cor 6% with No Spec. Mal.	50% no change in pain 31% Val cor 16% with Patella cor
8	Relative flexibility	9.29	92.18	100% relative tibial rotation	97% relative tibial rotation 2% no relative rotation
9	Symptom alleviation on sit-to-stand movement	9.29	95.08	62% no change in pain 31% with no Imm. Cor. 6% with no Spec. Mal.	49% no change in pain 33% Val cor 15% with Patella cor 1% with No Spec. Mal.
10	Symptom alleviation on Knee flexion in single-leg stance on uninvolved limb	7.44	97.40	56% no change in pain 43% with no Imm. Cor.	78% no change in pain 10% Val cor 7% with Patella cor 2% with No Spec. Mal.
11	Symptom alleviation on walking	5.18	99.01	81% no change in pain 18% with no Imm. Cor.	75% no change in pain 15% Val cor 8% with Patella cor
12	Symptom alleviation during two-joint hip flexor length test	3.16	100.00	100% no change in pain	62% no change in pain 31% with Patella cor 5% Val cor

No change: No change in movement, Val cor: Symptoms alleviated with valgus correction, Var cor: Symptoms alleviated with varus correction, No Imm. Cor.: Movement was not correctable immediately, Hyperext cor: Symptoms alleviated with prevention of knee hyperextension, Patella cor: Symptoms alleviated with correction of patellar alignment, No Spec. Mal.: No pain difference recorded as no correction was performed, Incr Lat Rot: Increased lateral rotation, Incr Med Rot: Increased medial rotation

Varus: A total of 26 (12.4%) patients with a mean age of 48 years exhibited knee varus as the main sign. The majority of these patients (73.1%) immediately showed reduced symptoms after movement pattern correction, especially in single-leg stance.

Minimal Pain and Dysfunction: The last sub-cluster consisted of 30 (14.3%) patients with a mean age of 35 years who had no preferred alignment fault and movement pattern correction or modified their preferred movement pattern to relieve pain symptoms. Most of them were young athletes (Tegner score of 5) scoring 8 out of 100 on a visual analog scale for average pain. The manual muscle testing of these patients showed a higher muscle strength and lower pain intensity than other patients.

A total of 23 examination variables were essential in sub-clustering knee classifications. 18 items were not considered group discriminators although they could have contributed to patient management. Irrelevant items included factors related to prone position (symptoms, tibial abduction-adduction, tibial medial-lateral rotation), tibial medial-lateral rotation (walking, partial squat, sit-to-stand transfer, single-leg stance, knee flexion while standing on the uninvolved limb, and stair ambulation); the McConnell patellar test, foot pronation, and femoral medial-lateral rotation in single-leg stance position.

Table 4: Discriminative variables and the corresponding discriminative power and percentile of the key characteristics in non-valgus sub-clusters

	Variables	Discriminative power	Discriminative power (%)	Sub-cluster: Hyperextension	Sub-cluster: Hypomobility	Sub-cluster: Varus	Sub-cluster: Self-management
1	Joint integrity	41.49	8.04	70% no change 30% tibiofemoral hypermobility	95% tibiofemoral hypomobility 4% no change	100% no change	56% tibiofemoral hypermobility 43% no change
2	Symptom alleviation on single-leg stance movement	38.24	15.46	50% no change in pain 40% Hyperext cor 10% no Spec. Mal.	60% with no Imm. Cor. 39% no change in pain	73.1% with Var cor 19% no change in pain 7% with Patella cor	73% no change in pain 13% with Patella cor 13% with no Spec. Mal.
3	Symptom alleviation on stair ambulation	36.77	22.59	60% with Hyperext cor 40% no change in pain	60% with no Imm. Cor. 39% no change in pain	50% with Var cor 46% no change in pain 3% with Patella cor	40% no change in pain 30% with Patella cor 23% with No Spec. Mal. 6% with Hyperext cor
4	Knee hyperextension and extension lack on single-leg stance	34.04	29.19	100% knee hyper-extension	91% extension lack 8% no change	65% no change 34% knee hyperextension	66% no change 30% knee hyperextension 3% extension lack
5	Knee hyperextension and extension lack on walking	34.01	35.78	100% knee hyper-extension	91% extension lack 8%% no change	65% no change 34% knee hyperextension	66% no change 30% knee hyperextension 3% extension lack
6	Symptom alleviation on partial squat movement	29.26	41.46	80% no change in pain 10% with Hyperext cor 10% with no Spec. Mal.	65% with no Imm. Cor. 34% no change in pain	53% with Var cor 42% no change in pain 3% with Patella cor	46% no change in pain 26% with Patella cor 23% with No Spec. Mal. 3% with hyper-extension prevention
7	Knee hyperextension and extension lack on stair ambulation	28.96	47.07	90% knee hyper-extension 10% no change	100% knee extension lack	65% no change 30% knee hyper-extension 3% knee extension lack	63%% no change 33% knee hyper-extension 3% knee extension lag
8	Knee valgus and varus on sit-to-stand movement	28.77	52.65	100% no change	73% increased varus 17% no change 8% increased valgus	88% increased varus 7% no change 3% increased valgus	86% no change 6% increased varus 6% increased valgus
9	Knee valgus and varus on stair ambulation	27.28	57.94	100% no change	78% increased varus 17% no change 4% increased valgus	92% increased varus 3% no change 3% increased valgus	56% no change 30% increased valgus 13% increased varus
10	Knee valgus and varus on partial squat movement	26.87	63.15	100% no change	73% increased varus 13% no change 13%increased valgus	80% increased varus 15% no change 3% increased valgus	76% no change 13% increased varus 10% increased valgus
11	Symptom alleviation on sit-to-stand movement	26.65	68.32	70% no change in pain 20% with Hyperext cor 10% with No Spec. Mal.	60% no change in pain 39% with No Imm. Cor.	53% no change in pain 42% with Var cor 3% with Patella cor	73% no change in pain 16% with Patella cor 6% with No Spec. Mal. 3% with Hyperext cor
12	Femoral abduction and adduction on stair ambulation	20.52	72.30	100% no change	69% increased abduction 26.1% no change 4% increased adduction	80% increased abduction 11% no change 7% increased adduction	63% no change 23% increased adduction 13% increased abduction

	Variables	Discriminative power	Discriminative power (%)	Sub-cluster: Hyperextension	Sub-cluster: Hypomobility	Sub-cluster: Varus	Sub-cluster: Self-management
13	Femoral abduction and adduction on sit-to-stand movement	19.97	76.17	100% no change	52% increased abduction 43% no change 4% increased adduction	76% increased abduction 19% no change 3% increased adduction	93% no change 6% increased abduction
14	Femoral abduction and adduction on partial squat movement	17.15	79.49	100% no change	60% increased abduction 26.1% no change 13% increased adduction	73.1% increased abduction 26% no change	80% no change 13% increased abduction 6% increased adduction
15	Symptom alleviation on walking	15.68	82.53	90% no change in pain 10% with Hyperext cor	65% no change in pain 34% with no Imm. Cor.	61% no change in pain 34% with Var cor 3% with Patella cor	96% no change in pain 3% with Patella cor
16	Femoral medial and lateral rotation on stair ambulation	13.64	85.18	90%No change 10% Incr Lat Rot	60% Incr Med Rot 21% Incr Lat Rot	73.1%Incr Med Rot 23.1% Incr Lat Rot 3% no change	46%Incr Med Rot 43% no change 10% Incr Lat Rot
17	Femoral medial and lateral rotation on partial squat	13.26	87.75	100% no change	60% Incr Med Rot 34% no change 4% Incr Lar Rot	65% Incr Med Rot 19% Incr Lat Rot 15% no change	60% no change 40% Incr Med Rot
18	Femoral medial and lateral rotation on sit-to-stand	10.64	89.81	100% no change	52% Incr Med Rot 39%no change 8% Incr Lat Rot	73.1% Incr Med Rot 15% no change 11% Incr Lat Rot	63% no change 36% Incr Med Rot
19	Tibial abduction and adduction on stair ambulation	7.66	91.30	100% no change	56% no change 39% increased adduction 4% increased abduction	53% no change 46% increased adduction	80% no change 16% increased abduction 3% increased adduction
20	Tibial roll on foot in stair climb	7.35	92.72	100% did not roll	65% did not roll 34% rolled	61% did not roll 38% rolled	80% rolled 20% did not roll
21	Tibial abduction and adduction on partial squat	6.34	93.95	100% no change	56% no change 39% increased adduction 4% increased abduction	53% no change 38% increased adduction 7% increased abduction	3%abd, 96% no def
22	Femoral medial and lateral rotation on single leg stance	5.98	95.11	100% no change	73% Incr Med Rot 17% no change 3% Incr Lat Rot	76% Incr Med Rot 19% no change 3% Incr Lat Rot	66% Incr Med Rot 30% no change 3% Incr Lat Rot
23	Symptom alleviation during two-joint hip flexor length test	5.35	96.15	100% no change	100% no change	76% no change 11% Var Cor 11% Patella Cor	60% no change 40% patellar cor

No change: No change in movement, Val cor: Symptoms alleviated with valgus correction, Var cor: Symptoms alleviated with varus correction, No Imm. Cor.: Movement was not correctable immediately, Hyperext cor: Symptoms alleviated with prevention of knee hyperextension, Patella cor: Symptoms alleviated with correction of patellar alignment, No Spec. Mal.: No pain difference recorded as no correction was performed, Incr Lat Rot: Increased lateral rotation, Incr Med Rot: Increased medial rotation

Discussion

In the present study, we found that 23 out of the 41 clinical examination variables were adequate to categorize the patients in appropriate clusters and sub-clusters. We identified two main clusters (valgus and non-valgus) and six sub-clusters (valgus, valgus with hypomobility, hyperextension, hypomobility, varus, and minimal pain and dysfunction). The results showed that patients with knee impairment can be classified efficiently with a fewer number of examination variables than the MSI model. These variables were prioritized according to importance and DP in each step. The PAM analysis was also used as a novel method for knee examination to allocate patients to different sub-clusters.

A comparison of PAM sub-clusters with the MSI model showed that both models used similar impairments (valgus, varus, hypomobility, and hyperextension) as classification criteria. Patients with knee extension syndrome, as classified in the MSI model, were not entered into the study due to the reported low presence.[5, 14] In line with the MSI model, patients in the sub-cluster "minimal pain and dysfunction" mostly exhibited the characteristics of patients with patellofemoral pain and knee joint hypermobility. These patients did not express pain during routine tests, making it necessary to perform more specific high loading or neuromuscular tests to determine the characteristics of this cluster. Patients with no specific alignment deficits have been labeled as neuromuscular or muscular deficits, one of the subcategories of patellofemoral pain.[23] Patellofemoral dysfunctions were not classified as a separate cluster for two reasons. First, tests such as stair climbing were not effective in discriminating the pain source of the patellofemoral or tibiofemoral joint.[24] Nonetheless, they were among the most important discriminative variables in our study. Second, pain variables were not that essential in diagnostic tests for the patellofemoral joint impairment.[24] Keays and colleagues categorized patients with patellofemoral pain into four main categories. Among all, the patellar osteoarthritis group was only distinguished by the use of X-ray imaging.[25] In the current study, patellar deficiency associated with knee impairments was assigned to the main sub-clusters.

The majority of our patients had dynamic knee valgus as the dominant movement pattern (valgus cluster). This was in line with previous studies reporting a high frequency of valgus movement in patients with knee pain.[14, 25] The main clusters identified in the current study were somehow similar to previous studies.[5, 14, 25]

Signs can be a key factor in classifying patients when symptoms are not conclusive. We found that signs were more important in primary clustering and valgus sub-clustering of patients since, they were more obvious and with higher DP than symptoms. However, symptoms had a higher diagnostic value in patients with a dominant movement pattern other than valgus. Kajbafvala and colleagues also reported similar findings.[5] They used factor analysis to validate four syndromes of the knee classification system in which only one factor included symptoms and the other three included signs only. Salsich and colleagues found that despite the correction of tibiofemoral alignment, the patient's pain did not decrease significantly.[13] Another study on the validation of the knee MSI model reported that the category "patellar lateral glide syndrome" was the only factor in which pain was important.[5] This syndrome was not identified in the PAM sub-clustering, since the examination variables related to the patella (pain location, McConnell patellar and symptom alleviation with patellar correction) did not have a DP higher than other variables. On the other hand, deficient patella rarely occurs in isolation and is usually a secondary diagnosis based on a primary diagnosis of tibiofemoral rotation or knee hyperextension.[11, 13] Additional tests such as X-ray or trunk evaluation could be useful to attain a more uniform group.[25, 26]

In the present study, we also identified a pattern for knee examination based on the most important variables. Physical therapists should pay attention to the presence of valgus in activities, since it is the most observed faulty movement pattern among patients. It is very common to diagnose this pattern in patients during sit-to-rise transfer, stair ambulation, or partial squat. After the diagnosis of knee valgus in conjunction with hypomobility, the patient may be treated differently from those without such impairment. Hypomobility can be easily detected when a patient stands on the impaired leg or walks. Back again to the first step, if the patient shows a varus pattern in movement or has no frontal plane deficits, therapists should pay attention to the presence of deformities in the sagittal plane such as hypomobility or hyperextension. In this step, therapists should primarily examine the joint, pay attention to the pain pattern, and observe the faulty movements especially in walking and standing on the impaired leg. If therapists need a complete and accurate assessment, all the 23 variables should be examined. The identification of the applicable patient's cluster is determined by the skills of the physical therapist on examination, palpation, and interpretation of the findings.

The present study had some limitations. First, patients with severe symptoms (numerical rating scale above 7 in standing position or failure to perform the test because of severe pain) were not included due to the inability to perform all the tests, especially those with high loading activities. Second, clustering analysis could not classify those patients showing high tolerance to tests, since they could not fully reveal deficits in the signs and symptoms of a test. Usually, activities with high physical demand (single-leg hop test and single-leg squat test) are performed for accurate classification.[14] Another limitation of the study was that we applied tests that can generally be used for all patients with knee pain. Hence, specific tests such as single-leg squat, jump, and hop tests were not performed on patients with a low level of impairments.

Conclusion

A new direct knee examination method is introduced that organizes important discriminative tests and requires fewer clinical examination variables. By examining the essential variables determined in each step, one can easily classify patients with knee impairments using the proposed knee examination approach. Future studies should focus on comparing the result of the current study with the syndromes described in the MSI model. To the best of our knowledge, no studies have been performed on the efficiency of the MSI model on patients with knee pain. Since disabled patients with acute traumatic or disability-related pain were excluded, future studies should consider the inclusion of such patients.

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