Diagnosis of Periprosthetic Joint Infection in Medicare Patients

Multicriteria Decision Analysis

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Abstract

Background In the setting of finite healthcare resources, developing cost-efficient strategies for periprosthetic joint infection (PJI) diagnosis is paramount. The current levels of knowledge allow for PJI diagnostic recommendations based on scientific evidence but do not consider the benefits, opportunities, costs, and risks of the different diagnostic alternatives.

Questions/purposes We determined the best diagnostic strategy for knee and hip PJI in the ambulatory setting for Medicare patients, utilizing benefits, opportunities, costs, and risks evaluation through multicriteria decision analysis (MCDA).

Methods The PJI diagnostic definition supported by the Musculoskeletal Infection Society was employed for the MCDA. Using a preclinical model, we evaluated three

diagnostic strategies that can be conducted in a Medicare patient seen in the outpatient clinical setting complaining of a painful TKA or THA. Strategies were (1) screening with serum markers (erythrocyte sedimentation rate [ESR]/C-reactive protein [CRP]) followed by arthrocentesis in positive cases, (2) immediate arthrocentesis, and (3) serum markers requested simultaneously with arthrocentesis. MCDA was conducted through the analytic hierarchy process, comparing the diagnostic strategies in terms of benefits, opportunities, costs, and risks.

Results Strategy 1 was the best alternative to diagnose knee PJI among Medicare patients (normalized value: 0.490), followed by Strategy 3 (normalized value: 0.403) and then Strategy 2 (normalized value: 0.106). The same ranking of alternatives was observed for the hip PJI model (normalized value: 0.487, 0.405, and 0.107, respectively). The sensitivity analysis found this sequence to be robust with respect to benefits, opportunities, and risks. However, if during the decision-making process, cost savings was given a priority of higher than 54%, the ranking for the preferred diagnostic strategy changed.

Conclusions After considering the benefits, opportunities, costs, and risks of the different available alternatives, our preclinical model supports the American Academy of Orthopaedic Surgeons recommendations regarding the use of serum markers (ESR/CRP) before arthrocentesis as the best diagnostic strategy for PJI among Medicare patients.

Level of Evidence Level II, economic and decision analysis. See Instructions to Authors for a complete description of levels of evidence.

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Introduction

Numerous tests and algorithms have been proposed to guide the workup of hip and knee periprosthetic joint infection (PJI)

Table 1. Musculoskeletal Infection Society PJI diagnostic criteria [21]

Based on the proposed criteria, a definite PJI exists when:

One of the following major criteria is present

- (1) There is a sinus tract communicating with the prosthesis
- (2) A pathogen is isolated by culture from 2 or more separate tissue or fluid samples obtained from the affected prosthetic joint

OR

Four of the following minor criteria are present

- (1) Elevated serum ESR and serum CRP concentration
- (2) Elevated synovial WBC count
- (3) Elevated synovial PMN%
- (4) Presence of purulence in the affected joint
- (5) Isolation of a microorganism in 1 culture of periprosthetic tissue or fluid
- (6) > 5 neutrophils/high-power field in 5 high-power fields observed from histologic analysis of periprosthetic tissue at $\times 400$ magnification

PJI = periprosthetic joint infection; ESR = erythrocyte sedimentation rate; CRP = C-reactive protein; WBC = white blood cell; PMN% = polymorphonuclear percentage.

[6, 15, 16, 18]. The American Academy of Orthopaedic Surgeons (AAOS) published a clinical guideline in 2010 to assist in the evaluation of patients for PJI [6, 17] and subsequently the Musculoskeletal Infection Society (MSIS) developed a consensus definition for PJI diagnosis in 2011 (Table 1) [21]. A key characteristic of the MSIS PJI definition is its multidimensional quality, whereby a definitive diagnosis is dependent on the presence of major and/or minor criteria.

Insofar as healthcare resources are limited, the exploration and development of accurate, safe, and cost-efficient strategies for diagnostic and therapeutic interventions are paramount. However, current levels of knowledge in PJI-related research do not allow for diagnostic recommendations incorporating consideration of the benefits, opportunities, costs, and risks presented by the different diagnostic strategies and tests. This is particularly important in Medicare patients because the high frequency with which patients in this population undergo arthroplasty makes PJI a critically important—and expensive—complication to study, even though the prevalence of PJI in this group seems to be comparable to the prevalence in other groups [13, 16].

We therefore used the multidimensional MSIS criteria to determine the best diagnostic strategy for knee and hip PJI, considering the benefits, opportunities, costs, and risks of the available alternatives for a Medicare patient in the ambulatory setting.

Materials and Methods

Decision making is an essential part of clinical practice. Evidence-based medical knowledge, as well as

socioeconomic, cultural, legal, and psychologic factors, should be taken into account in the solution of decision problems whenever possible [10]. The identification of the best diagnostic strategy for PJI is a multidimensional decision-making problem. When considering whether a patient has PJI and when deciding what tests to use to get the answer, surgeons generally will consider the alternatives in light of benefits, opportunities, costs, and risks. For this reason, we decided to use multicriteria decision analysis (MCDA), which is a systematic and comprehensive decision-making method that allows the inclusion of quantitative and qualitative variables [4]. MCDA allows this process, normally conducted by surgeons using intuition, in a more rigorous, mathematical way, to see whether our intuitive solutions can be supported by the available evidence. Dolan [8] defined MCDA as “a method that guides the user through an evaluation of potential decision options using explicit profiles of their advantages and disadvantages across a range of distinct dimensions.” MCDA bestows priority among different options by referencing a specific set of objectives the decision maker has identified. The identification of an objective and the criteria defining the objective (including an estimation of the relative weights of each criterion) make the decision-making process open, explicit, and reproducible. The latter are advantages of MCDA over informal judgment, which necessarily is the more common approach in clinical practice.

Decision-Making Model and Clinical Scenario

To create a clinically applicable decision-making scenario, we initiated our analytic model with the following clinical situation: a Medicare patient is seen in the outpatient clinical setting complaining of a painful TKA or THA. After thorough evaluation, including detailed history, physical examination, and radiographic imaging, the clinician is unable to explain the etiology of the patient’s symptoms (ie, findings such as the presence of a sinus tract in overt PJI or evidence of catastrophic implant failure, etc, are not seen) and proceeds to attempt to rule out PJI. The clinician must evaluate: What is the best strategy to diagnose PJI using the MSIS criteria, considering benefits, opportunities, costs, and risks of the different available diagnostic alternatives?

The MSIS criteria [21], as well as their categorization into major and minor, generate an appropriate framework for the utilization of MCDA and a structured decision-making process. Various methods for MCDA execution are available, and each may incur different levels of complexity. For this study, MCDA was conducted using the analytic hierarchy process, which has been previously used for benefits, opportunities, costs, and risks analysis [31].

Analytic Hierarchy Process

The analytic hierarchy process is the most frequently used method of MCDA for medical decision support [9]. It allows the decision maker to design a hierarchical structure and evaluate the trade-offs between decision criteria and alternatives, thus facilitating improved clinical and management decisions [27]. The basic structure of analytic hierarchy process is depicted (Fig. 1). Dolan et al. [9] summarized it in five steps: (1) create a decision model by defining the decision goal, the options, and the criteria that will be used to determine how well the options meet the goal; (2) judge how well the options satisfy each criterion by making a series of pairwise comparisons among them using a 9-point scale ranging from equally good to extremely better or by incorporating the direct weight of the priorities (the different priorities must sum to 1.00) (we used both methods); (3) determine the relative priorities of the criteria in meeting the decision goal by making a series of pairwise comparisons among them using a 9-point scale ranging from equally important to extremely more important or incorporating the direct weight of the priorities (the different priorities must sum to 1.00); (4) combine the option judgments and the criteria priorities to create a numeric ratio scale that indicates how well the options meet the goal; and (5) if desired, perform sensitivity analysis to explore the effects of changing the option judgments, criteria priorities, or both.

The measurement utilized to compare the different options is called the total score. The total score is calculated by multiplying each option's score by the global priority for each criterion, summing over all criteria, and then normalizing the results [8]. It represents the priority of each alternative with respect to the goal, as it was

conceived by the decision maker. To validate the comparisons, Saaty [22] established the consistency ratio. It provides information about logical consistency among pairwise comparison judgments. It serves to measure how consistent the judgments have been relative to large samples of purely random judgments. A perfectly consistent set of pairwise comparisons has a consistency ratio of 0.0 (no logical inconsistency). A consistency ratio of less than 0.1 is generally considered acceptable [8]. If the consistency ratio exceeds 0.1, the judgments could be untrustworthy because they suggest randomness. Further mathematical explanation about consistency ratio can be found in Saaty's article [22]. One of us (CDL) conducted the analysis using SuperDecisions™ Software (Creative Decisions Foundation, Pittsburgh, PA, USA), with separate models for hip and knee PJI.

Three diagnostic strategies including seven different tests were chosen to be included in the analytic hierarchy process (Table 2). The three strategies were chosen because they are potentially able to accomplish major and minor MSIS diagnostic criteria, including (1) screening with serum markers (erythrocyte sedimentation rate [ESR] and C-reactive protein [CRP]) followed by arthrocentesis in positive cases, (2) immediate arthrocentesis, and (3) serum markers requested simultaneously with arthrocentesis. The presence of a sinus tract, a major diagnostic criterion, was excluded from the analysis as it is an independent indicator of PJI without necessitating further testing (evident during physical examination). Frozen section/biopsy, a minor diagnostic criterion, was excluded from the analysis, as such samples are typically retrieved intraoperatively and therefore do not represent a clinically significant entity at the ambulatory setting that we stated as the study scenario.

Fig. 1 A flowchart illustrates the basic structure of analytic hierarchy process. Alternatives represent nondominated/efficient strategies identified by the first phase of MCDA. Criteria are weighted assigned

values given a desired goal. Priority among different options is assigned by referencing a specific set of objectives the decision maker has identified.

Table 2. Strategies and associated costs for the diagnosis of PJI in knees and hips

Strategy	Knees				Hips					
	Visit	Sequence	Purpose	CPT® code	Costs (USD)	Visit	Sequence	Purpose	CPT® code	Costs (USD)
Screening with ESR/CRP and arthrodesis in positive cases	1	Consultation	First evaluation	99212	75	1	Consultation	First evaluation	99212	75
	1	Blood test (ESR/CRP)	Screening		96	1	Blood test (ESR/CRP)	Screening		96
	2	Consultation	Evaluation	99212	75	2	Consultation	Evaluation	99212	75
	2	Arthrocentesis	Rule out infection	20610	175	2	Arthrocentesis under fluoroscopy	Rule out infection	77002	200
	3	Consultation	Establish diagnosis	99212	75	3	Consultation	Establish diagnosis	99212	75
		Requested tests: cell count and differential, aerobic culture, anaerobic culture, fungal culture			495		Requested tests: cell count and differential, aerobic culture, anaerobic culture, fungal culture			495
Simultaneous serum markers and arthrodesis		Total			991		Total			1016
	1	Consultation	First evaluation	99212	75	1	Consultation	First evaluation	99212	75
	1	Blood test (ESR/CRP)	Screening		96	1	Blood test (ESR/CRP)	Screening		96
	1	Arthrocentesis	Rule out infection	20610	175	1	Arthrocentesis under fluoroscopy	Rule out infection	77002	200
	2	Consultation	Establish diagnosis	99212	75	2	Consultation	Establish diagnosis	99212	75
		Requested tests: cell count and differential, aerobic culture, anaerobic culture, fungal culture			495		Requested tests: cell count and differential, aerobic culture, anaerobic culture, fungal culture			495
Immediate arthrodesis		Total			916		Total			941
	1	Consultation	First evaluation	99212	75	1	Consultation	First evaluation	99212	75
	1	Arthrocentesis	Rule out infection	20610	175	1	Arthrocentesis under fluoroscopy	Rule out infection	77002	200
	2	Consultation	Establish diagnosis	99212	75	2	Consultation	Establish diagnosis	99212	75
		Requested tests: cell count and differential, aerobic culture, anaerobic culture, fungal culture			495		Requested tests: cell count and differential, aerobic culture, anaerobic culture, fungal culture			495
		Total			820		Total			845

PJI = periprosthetic joint infection; CPT® = Current Procedural Terminology; ESR = erythrocyte sedimentation rate; CRP = C-reactive protein.

Fig. 2 The analytic hierarchy process benefits, opportunities, costs, and risks flowchart for diagnosis of PJI incorporates the nondominated diagnostic strategies from the balance sheet with criteria of benefits, opportunities, costs, and risks and respective criteria subnets

for the goal of best diagnostic strategy. WBC = white blood cells; PMN = polymorphonuclear cells; FN = false negatives; FP = false positives; ** Major MSIS diagnostic criterion; * Minor MSIS diagnostic criterion.

Our analytic hierarchy process was established as depicted (Fig. 2). The goal level was represented by the best diagnostic strategy for PJI diagnosis. The criteria level was composed of four criteria, namely benefits, opportunities, costs, and risks. For each criterion, a subnet was created according to the software developers' recommendation, some of them presenting subcriteria (Table 3). The alternatives level comprised the three diagnostic strategies previously mentioned.

The four subnets are shown for the hip PJI model (Table 4) and the knee PJI model (Table 5). In the subnet for benefits, benefits were considered the ability that a particular alternative had to meet the PJI diagnostic criteria supported by the MSIS. To diagnose PJI, either one major or four minor criteria were required. Priority values were assigned to each criterion by relative importance in establishing a diagnosis. A major criterion was allocated a priority value four times higher than a minor criterion. The subnet for opportunities was constructed using two criteria:

(1) ability to avoid unnecessary joint aspirations (invasive diagnostic method) and (2) ability to expedite the diagnosis. As these data are not available in the literature, a pairwise comparison was employed on the basis of a qualitative assessment we performed. In the subnet for costs, costs in USD were calculated using the information provided in Table 2. These values were then converted to priority values using normalization according to the software developer's instructions. In the subnet for risks, we considered risks as the probability to make a wrong diagnosis if a particular strategy (alternative) is chosen. We calculated the wrong diagnosis probability by summing the rate of false positives plus the rate of false negatives presented by each one of the diagnostic alternatives. The source of information for false-negative and false-positive rate was extracted from Alijanipour et al. [1] for screening strategy in knees and hips, Barrack et al. [3] for knee arthrocentesis, and Williams et al. [32] for hip arthrocentesis. Since this value has not been described for one of the

alternatives (simultaneous serum markers and joint aspiration), we decided to calculate an average of the values observed on the other two alternatives (since they are intimately related), for both the knee and hip models.

The final goal or total score (best diagnostic strategy) was calculated by combining the different subnets' priority results, providing a benefits, opportunities, costs, and risks summary score. The additive negative (subtractive)

formula was chosen as recommended by the software creators [23], as well as by Wijnmalen [31]. The formula considers costs and risks as negative additive factors (negative features) affecting benefits and opportunities (positive features). It leaves the most costly and risky alternatives with the highest priorities, as they come up from the subnets, but subtracts from the benefits and opportunities. It can end up giving negative results. If resource allocation is the objective, alternatives with negative results probably should not receive any investment. The formula is summarized as follows: weight (benefits) * priority (benefits) + weight (costs) * (−priority (costs)) + weight (opportunities) * priority (opportunities) + weight (risks) * (−priority (risks)).

A sensitivity analysis was also performed to evaluate the robustness of the decision accomplished [11]. Sensitivity analysis allows the adjustment of values for benefits, opportunities, costs, and risks to determine whether there are critical values for each above or below which the model would recommend a different approach.

Results

The results obtained showed that the screening strategy with serum markers followed by arthrocentesis in positive cases (Strategy 1) was the best alternative to diagnose knee PJI among Medicare patients (normalized value: 0.490), followed by serum markers requested simultaneously with

Table 3. Local and global priority of the different variables

Merits	Criteria	Local priorities	Global priorities
Benefits (0.400)	MSIS diagnostic criteria (1.000)		
	2 positive cultures	0.444	0.178
	1 positive culture	0.111	0.044
	Serum ESR/CRP	0.111	0.044
	PMN%	0.111	0.044
	WBC count	0.111	0.044
	Purulence	0.111	0.044
Costs (0.200)	USD	1	0.200
Opportunities (0.200)	Faster diagnosis	0.5	0.100
	Unnecessary aspirations	0.5	0.100
Risks (0.200)	Rate of FN + rate of FP	1	0.200

MSIS = Musculoskeletal Infection Society; ESR = erythrocyte sedimentation rate; CRP = C-reactive protein; PMN% polymorphonuclear percentage; WBC = white blood cell; FN = false negatives; FP = false positives.

Table 4. Priority values used during the analytic hierarchy process model for hip PJI diagnosis.

Merits	Criteria	Priority value		
		Screening	Simultaneous	Direct arthrocentesis
Benefits (0.40)*	MSIS diagnostic criteria			
	2 positive cultures (0.444) [†]	0.333	0.333	0.333
	1 positive culture (0.111) [†]	0.333	0.333	0.333
	Serum ESR/CRP (0.111) [†]			
	Purulence (0.111) [†]	0.333	0.333	0.333
	WBC count (0.111) [†]	0.333	0.333	0.333
	PMN% (0.111) [†]	0.333	0.333	0.333
	Total priority value for subnet analysis	0.352	0.352	0.296
Opportunities (0.20)*	Faster diagnosis (0.5) [†]	0.072	0.649	0.279
	Unnecessary joint aspirations (0.5) [†]	0.818	0.091	0.091
	Total priority value for subnet analysis	0.445	0.370	0.185
Risks (0.20)*	Rate of FN + rate of FP (1.00) [†]	0.292	0.334	0.374
	Total priority value for subnet analysis	0.292	0.334	0.374
Costs (0.20)*	USD (1.00) [†]	0.363	0.336	0.302
	Total priority value for subnet analysis	0.363	0.336	0.302

* Priority with respect to the final goal; [†]priority with respect to the goal in the subnet; PJI = periprosthetic joint infection; MSIS = Musculoskeletal Infection Society; ESR = erythrocyte sedimentation rate; CRP = C-reactive protein; WBC = white blood cell; PMN% = polymorphonuclear percentage; FN = false negatives; FP = false positives.

Table 5. Priority values used during the analytic hierarchy process model for knee PJI diagnosis.

Merits	Criteria	Priority value		
		Screening	Simultaneous	Direct arthrocentesis
Benefits (0.40)*	MSIS diagnostic criteria			
	2 positive cultures (0.444) [†]	0.333	0.333	0.333
	1 positive culture (0.111) [†]	0.333	0.333	0.333
	Serum ESR/CRP (0.111) [†]			
	Purulence (0.111) [†]	0.333	0.333	0.333
	WBC count (0.111) [†]	0.333	0.333	0.333
	PMN% (0.111) [†]	0.333	0.333	0.333
	Total priority value for subnet analysis	0.352	0.352	0.296
Opportunities (0.20)*	Faster diagnosis (0.5) [†]	0.072	0.649	0.279
	Unnecessary joint aspirations (0.5) [†]	0.818	0.091	0.091
	Total priority value for subnet analysis	0.445	0.370	0.185
Risks (0.20)*	Rate of FN + rate of FP (1.00) [†]	0.284	0.334	0.382
	Total priority value for subnet analysis	0.284	0.334	0.382
Costs (0.20)*	USD (1.00) [†]	0.363	0.336	0.301
	Total priority value for subnet analysis	0.363	0.336	0.301

* Priority with respect to the final goal; [†]priority with respect to the goal in the subnet; PJI = periprosthetic joint infection; MSIS = Musculoskeletal Infection Society; ESR = erythrocyte sedimentation rate; CRP = C-reactive protein; WBC = white blood cell; PMN% = polymorphonuclear percentage; FN = false negatives; FP = false positives.

arthrocentesis (Strategy 3; normalized value: 0.403) and then immediate arthrocentesis (Strategy 2; normalized value: 0.106). The same sequence of priorities was observed for the hip PJI model: screening strategy with serum markers followed by arthrocentesis in positive cases (normalized value: 0.487), serum markers requested simultaneously with arthrocentesis (normalized value: 0.405), and immediate arthrocentesis (normalized value: 0.107).

The main analytic hierarchy process model, as well as the subnets, had a consistency ratio of less than 0.1, suggesting that the model had acceptable logical consistency.

The sensitivity analysis performed for both the hip and knee PJI models showed that, regardless of the importance allocated to the criteria benefits, opportunities, or risks during decision making, the ranking of the best diagnostic alternative was not affected. However, if during the decision-making process, cost savings was given a priority higher than 0.543 (hip model) or 0.555 (knee model), the ranking for the preferred diagnostic strategy changed, and the alternative of requesting serum markers simultaneously with arthrocentesis became superior. Furthermore, if the priority of costs was allocated a value higher than 0.715 in the knee model or higher than 0.721 in the hip model, the best alternative was immediate arthrocentesis. This means that, if a clinician investigating a probable knee PJI considers that the variable costs has a priority higher than 55.5% during his/her process of decision making, he/she should request serum markers simultaneously with

arthrocentesis. If he/she considers that the variable costs accounts for more than 71.5% of the priority during his/her process of decision making, the best alternative in that particular case scenario is to directly perform an arthrocentesis. In every other case scenario, screening strategy with serum markers followed by arthrocentesis in positive cases is the best diagnostic strategy.

Discussion

Our aim was to create a structured and reproducible strategy for the diagnosis of knee and hip PJI while optimizing resources and decreasing variability inherent to a clinician's personal judgment. In our opinion, when a clear clinical or laboratory feature is identified as a target (in this case represented by the MSIS criteria), strategies that can delay the diagnosis, increase expense, or rely on variable clinical acumen are unwarranted. For the diagnosis of knee and hip PJI, in almost all situations, the strategy of screening with serum markers followed by arthrocentesis in positive cases was the best diagnostic strategy from the perspective of a benefits, opportunities, costs, and risks analysis.

The limitations of this study are related to (1) the PJI diagnostic criteria used, (2) the method, (3) the limited number of decision makers during the creation of the model, and (4) the preclinical nature of our data. For the diagnostic criteria, it is unknown whether all providers

involved in the treatment of PJI are using the MSIS definition [21], including different medical societies and physicians across the country. We believe that this definition is the best available tool because it creates a tangible target to follow during the diagnostic workup, and so we chose it for this model. In regard to the method used to create the prioritization of diagnostic strategies, the analytic hierarchy process is not the only method of MCDA and the use of different methods can modify the presented results. Concerning the limited number of decision makers, we chose analytic hierarchy process for its adaptability to different decision makers' requirements (flexibility), ease of use, and strength of measurement [9]. Our intention is to promote the replication of this study by other researchers around the world to generate their own priorities according to local available resources and patient populations while targeting the same MSIS diagnostic criteria [21]. The variables included in our decision-making model may be further complemented, eg, the patient's willingness to undergo a screening strategy involving blood analysis alone versus a strategy (arthrocentesis) that may expedite diagnosis but involves a certain level of invasiveness, possible discomfort, and the risk of pathogen inoculation. We believe the analytic hierarchy process permits the ability to increase the number of variables included and to modify their priority during the analysis, the latter being dependent on the individualized priorities of the decision maker. It is probable the inclusion of the newly presented diagnostic tests (which are currently not part of the MSIS criteria, such as leukocyte esterase [19, 30], synovial CRP [20], or others [5]) would modify the presented results. We decided to not include them because they are not formally accepted as MSIS diagnostic criteria. With respect to the preclinical nature of our data, we believe that the utility with which diagnostic information is maximized and resources are efficiently allocated with the utilization of MCDA for PJI diagnosis should be demonstrated in a prospectively conducted clinical trial.

An additional important limitation of our model is uncertainty. The sources of uncertainty in analytic hierarchy process models are multiple and have been extensively discussed in the literature [25], including some modifications proposed to resolve this problem [2]. Zahedi [33, 34] divided the judgmental uncertainty into two forms: external and internal sources. The former refers to the environment for collecting performance data of the criteria. The latter is caused by the decision maker because of limited or insufficient information. In our models, the external and internal sources of uncertainty are multiple, mainly due to the lack of data regarding some criteria, especially in the opportunities criterion. We resolved this by extrapolating information from hard data similar in nature, as we did with false-negative and false-positive rates in Strategy 3. In

consequence, these data might not be completely accurate. As a method to assess the uncertainty of our models, we evaluated rank reversal, in which the ranking of alternatives is reversed after adding or excluding an alternative [24, 28]. Rank reversal is intimately related to uncertainty, so we considered it to address this shortcoming. In both analytic hierarchy process models, rank reversal was not observed.

Our findings based on MSIS criteria and Medicare costs are in accordance with the AAOS PJI diagnostic guidelines [7]. As the AAOS guidelines were published before the MSIS criteria, we believed an assessment of the AAOS recommendations from the standpoint of the MSIS criteria was necessary. In addition, the AAOS guidelines considered scientific evidence as the sole criteria to build recommendations and did not include costs or other important features that are essential for decision making. Thus, because of these reasons, we strongly believe that our present investigation was required.

To obtain our goal, we chose an analytical method that allowed the prioritization of the available alternatives in an organized manner. The latter has been used successfully in the field of economic and environmental sciences and is rapidly gaining popularity in health-related sciences. An important advantage of the analytic hierarchy process is that it measures the degree to which judgments are inconsistent and establishes an acceptable tolerance level for the degree of inconsistency. Other advantages and the disadvantages of the method have been broadly described previously [12, 14]. Several authors have discussed the use and application of the analytic hierarchy process in health and medical decision making. Although other methods of cost-efficiency/cost-effectiveness analysis are available and have been used in the setting of the orthopaedic research [26, 29], we believed that benefits, opportunities, costs, and risks analysis using analytic hierarchy process was more appropriate for the inclusion of qualitative measurements, such as in our study. Furthermore, we expect that our paper will serve to introduce a formalized and accessible method of decision making to the orthopaedic community.

The minimal difference observed between the screening strategy with serum markers followed by arthrocentesis in positive cases versus serum markers requested simultaneously with arthrocentesis for both hip and knee PJI can make interpretation of the results difficult. This variance may be subjected to further analysis if other factors are involved in decision making (ie, a patient's willingness to undergo invasive testing, etc). Analytic hierarchy process is a dynamic method and allows the introduction of additional variables for decision making, a fact that may result in a magnification of the differences that we observed. Another important issue is the consequential unnecessary monetary expenditures that may occur if arthrocentesis is

used but not required. The reader must consider that our analysis refers to a specific patient population (as stated in the decision-making question) and does not include, for instance, an analysis of cost reduction in a nationwide sample of patients.

The sensitivity analysis of our model for both hip and knee PJI regarding benefits, opportunities, and risks was robust, showing no changes in the ranking of alternatives. On the other hand, both models were sensitive to the variable costs. Nonetheless, the ranking of preferred diagnostic alternative is changed only in those scenarios where the priority allocated to cost reduction during decision making is greater than 50%. As clinicians, we believe that the allocation of such an elevated priority for monetary variables during diagnostic decision making is almost never observed. For this reason, we consider our model robust in this dimension as well. Additionally, it is important to notice that our sensitivity analysis was performed only at the criteria (merits) level. Probably the modification at a subnet level could possibly influence the results.

In conclusion, the categorical PJI diagnostic criteria issued by the MSIS allow the use of MCDA to prioritize different diagnostic strategies. After considering the benefits, opportunities, costs, and risks of the different available alternatives, our preclinical model supports the AAOS recommendations regarding the use of serum markers (ESR/CRP) before arthrodesis as the best diagnostic strategy for PJI among Medicare patients.

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