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A shared decision-making tool to support the decision of patients with Lumbar Disc Herniation on whether to undergo surgery: a pilot study

Uma ferramenta compartilhada para apoiar a decisão dos pacientes com Hérnia Discal Lombar sobre se devem ser submetidos à cirurgia: um estudo piloto

Una herramienta de toma de decisiones compartida para apoyar la decisión de los pacientes con Hernia Discal Lumbar sobre si someterse o no a cirugía: un estudio piloto

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Abstract
This study aims to develop a decision support tool for patients and surgeons dealing with the uncertainty of surgical outcomes and the expectations of both parties for treating symptomatic lumbar disc herniation (LDH). The study uses a mixed-methods approach with Markov Chains (MC) and Analytic Hierarchy Process (AHP) to predict future health states after surgery for LDH, based on patient-reported outcomes measures (PROMs) and custom weights to each individual PROM and elicited priorities. A case-based analysis of two patients is presented to demonstrate the utility of the model in providing a likely trajectory that priority PROMs will follow over time. The study was conducted under the STROBE guidelines as a post hoc analysis of a large spine outcomes research study conducted in southern Brazil. Data were collected from patients operated between 2006 and 2017 to assess pain, disability, mood, and general health status from the preoperative time point to 1 year after surgery using patient-reported outcome questionnaires. The output of the algorithm represented the chances of surgery fulfilling the expectations of Patients A and B. The results presented by the tool suggest that Patient A will have a considerably higher probability of satisfaction and/or not meeting expectations with surgery than Patient B. The study demonstrates the feasibility and utility of a data-driven decision support tool that takes into account patient preferences and beliefs in generating high-quality decision-making and more utility for long-term outcomes in treating symptomatic lumbar disc herniation.
Keywords: Spine; Surgery; Markov chains.

Resumo
Este estudo visa desenvolver uma ferramenta de apoio à decisão para pacientes e cirurgiões que lidam com a incerteza dos resultados cirúrgicos e as expectativas de ambas as partes no tratamento da hérnia discal lombar sintomática (LDH). O estudo utiliza uma abordagem de métodos mistos com Markov Chains (MC) e Processo de Hierarquia Analítica (AHP) para prever estados de saúde futuros após a cirurgia para LDH, com base em medidas de resultados relatados pelo paciente (PROMs) e pesos personalizados para cada PROM individual e prioridades elucidadas. Uma análise baseada em casos de dois pacientes é apresentada para demonstrar a utilidade do modelo em fornecer uma trajetória provável que as PROMs prioritárias seguirão ao longo do tempo. O estudo foi conduzido sob as diretrizes da STROBE como uma análise pós hoc de um grande estudo de pesquisa de resultados da coluna vertebral realizado no

sul do Brasil. Foram coletados dados de pacientes operados entre 2006 e 2017 para avaliar a dor, incapacidade, humor e estado geral de saúde desde o momento pré-operatório até 1 ano após a cirurgia, utilizando questionários de resultados relatados pelos pacientes. Os resultados apresentados pela ferramenta sugerem que o paciente A terá uma probabilidade consideravelmente maior de satisfação e/ou de não atender às expectativas com a cirurgia do que o paciente B. O estudo demonstra a viabilidade e a utilidade de uma ferramenta de apoio à decisão baseada em dados que leva em conta as preferências e crenças dos pacientes na geração de decisões de alta qualidade e mais utilidade para resultados a longo prazo no tratamento da hérnia de disco lombar sintomática.
Palavras-chave: Coluna vertebral; Cirurgia; Cadeias de Markov.

Resumen
Este estudio pretende desarrollar una herramienta de apoyo a la toma de decisiones para pacientes y cirujanos que se enfrentan a la incertidumbre de los resultados quirúrgicos y las expectativas de ambas partes para el tratamiento de la hernia discal lumbar sintomática (HDL). El estudio utiliza un enfoque de métodos mixtos con cadenas de Markov (MC) y el proceso de jerarquía analítica (AHP) para predecir los futuros estados de salud después de la cirugía de LDH, sobre la base de medidas de resultados informados por los pacientes (PROM) y pesos personalizados para cada PROM individual y prioridades obtenidas. Se presenta un análisis basado en casos de dos pacientes para demostrar la utilidad del modelo a la hora de proporcionar una trayectoria probable que las PROM prioritarias seguirán con el tiempo. El estudio se realizó según las directrices STROBE como análisis post hoc de un gran estudio de investigación de resultados de columna vertebral realizado en el sur de Brasil. Se recopilaron datos de pacientes operados entre 2006 y 2017 para evaluar el dolor, la discapacidad, el estado de ánimo y el estado de salud general desde el punto de tiempo preoperatorio hasta 1 año después de la cirugía mediante cuestionarios de resultados informados por el paciente. La salida del algoritmo representó las probabilidades de que la cirugía cumpliera las expectativas de los pacientes A y B. Los resultados presentados por la herramienta sugieren que el paciente A tendrá una probabilidad considerablemente mayor de satisfacción y/o de no cumplir las expectativas con la cirugía que el paciente B. El estudio demuestra la viabilidad y utilidad de una herramienta de apoyo a la toma de decisiones basada en datos que tiene en cuenta las preferencias y creencias del paciente para generar una toma de decisiones de alta calidad y más utilidad para los resultados a largo plazo en el tratamiento de la hernia discal lumbar sintomática.
Palabras clave: Columna vertebral; Cirugía; Cadenas de Markov.

1. Introduction

Lumbar disc herniation (LDH) is a significant perpetrator of disease burden worldwide (Berger et al., 2017; Hirshman et al., 2018). It is the most common cause of lumbosacral radiculopathy, presenting a lifetime prevalence of around 3 to 5 percent in adult life (Berger et al., 2017; Tarulli & Raynor, 2007). Despite its impact, LDH usually follows a natural history presenting a 63% incidence of regression (Liao et al., 2020). When these rates are accounted for with nonoperative treatment, approximately, 80% of cases are solved (Singer et al., 2005; McCulloch, 1996; Morgante et al., 1996).

Major trials such as SPORT indicated that surgical intervention provides timely relief of symptoms and slight changes in secondary outcomes (e.g., sciatica bothersomeness, satisfaction with symptoms, and self-rated improvement). At the same time, nonoperative treatment can also avoid the progression of disability equaling surgery on primary outcomes of treatment (e.g., motor function) (Mundell et al., 2021; Neckelmann et al., 2002; Tosteson et al., 2006). Cost-effectiveness and utility analyses also suggested that the value generated by the procedure depends on the specificity of the sample for whom the therapy will be indicated (Falavigna et al., 2011; Deyo et al., 1996; Saaty, 1987).

Although, given the variability of symptoms as well as of values and expectations of each patient in clinical practice, it is challenging for surgeons to objectively estimate the benefit (e.g., grade of pain relief, ability to work, and self-efficacy) and satisfaction that a patient will obtain from surgery, at the time they deal with the uncertainty regarding the potential natural resolution (Parisien et al., 2016; Tversky & Kahneman, 1974). In addition, very few patients achieve complete resolution of pain, which often leads to further dissatisfaction with treatment (Elwy et al., 2011; O'Neill et al., 2003). In both of these cases - i.e., favorable and unfavorable outcomes - the use of a shared decision-making (SDM) model seems beneficial in order to support the determination of the best treatment for each individual patient. In SDM, before reaching a decision together, clinicians share their knowledge about treatment options, including benefits, harms, and uncertainties, while patients share information about their goals, concerns, and preferences (Falavigna et al., 2012; Eden et al., 2017). Although most healthcare professionals intend to share the decision-making process with the patient, several factors have been identified as barriers to its implementation (Clabeaux et al., 2002). However, patient participation is also desired during decision-making since major individual differences are usually present between subjects (Clabeaux et al., 2002; Lam & Loke, 2017). In a review including seven quantitative studies it was found that the choice to undergo surgery could rely on factors such as the patient's level of pain, psychosocial health, and their level of functional disability (Clabeaux et al., 2002; Lam & Loke, 2017). One of the concerns from the patients on whether or not to opt for surgery was assumptions regarding the benefits and harms of different treatment modalities (Clabeaux et al., 2002; Lam & Loke, 2017).

The Analytic Hierarchical Process (AHP) is a decision-making method to systematically prioritize alternatives when multiple criteria must be considered. AHP was designed for use in complex situations where uncertainty exists, several decision-makers are involved, and multiple - subjective and objective - considerations are essential. These aspects make of the AHP as an attractive approach for decision-making in healthcare. Meanwhile, Markov Chains (MC) models are useful for modeling prognosis or long-term outcomes. Since the introduction of Markov models in medical decision-making, 40 years ago, Markov models have been applied increasingly (Sonnenberg & Beck, 1993; Hirshman et al., 2018). In spine surgery, it was used on multiple occasions, such as to assess the cost-effectiveness of LDH surgery after accounting for its effect on worker productivity (Koenig et al., 2014).

In this study, we present a probabilistic prognostic model constructed on MC and AHP to support the decision-making process of spine surgery for LDH while accounting for personal values and expectations of individual patients.

2. Methodology

This is a post-hoc analysis of a large spine outcomes research study conducted in southern Brazil. From a prospectively collected database, we extracted data from patients operated from December 2006 to May 2017. This research was conducted under the STROBE guidelines and was approved by the University of Caxias do Sul Ethics Committee; before enrolling in the study, the patients provided consent to participate. All analyses were conducted in Microsoft® Office Excel 360.

Inclusion criteria

Presence of LDH on MRI with associated clinical correlation, symptoms refractory to 4 to 8 weeks of conservative treatment or the presence of progressive motor impairment, and willingness and capacity to participate in the study with follow-up.

Exclusion criteria

Patients were excluded if there was a lack of concordance between the symptoms and lumbar spine MRI, previous lumbar spine surgery, any preexisting spinal pathology, and lumbar instability.

All patients were evaluated preoperatively, perioperatively, and then at 1, 6 and 12 months postoperatively through patient-reported outcome measures (PROMs).

Mathematical and Operational Process Background

Analytic Hierarchy Process (AHP)

The AHP is a method to prioritize alternatives when multiple criteria must be considered, structuring problems in the form of a hierarchy or a set of integrated levels, such as the goal, the criteria, and the alternatives. It is an important asset to support medical decision-making since the values and preferences may vary substantially among individuals. For instance, reducing pain can be more meaningful than returning to work or daily functioning for a given patient, while, for another, returning to work quickly is a priority and eliminating pain is not of the highest importance.

AHP is based on three fundamental axioms: (1) there is a finite set A of alternatives and a set C of criteria upon which the alternatives in A can be compared; (2) Two alternatives from set A can be compared with respect to C, a criterion in set C, such that either one is preferable to the other, denoted >c, or they are equally preferable, denoted =c'. (3) The relative intensity of preference for one alternative (Ai) compared with another alternative, (Aj) in set A relative to a criterion C, in set C, can be assigned a positive real number Pc(A¡}Aj).

This approach requires that a series of ratings or intensities be provided for each criterion, sometimes identical to a general Likert scale or a visual analog scale. These intensities must be pairwise compared for each criterion, and then alternatives are evaluated by selecting the appropriate intensity for each criterion. Then, a priority score for each treatment is calculated based on an additive value function.

Another highlight of the AHP method is that it also accounts for the degree to which human judgments are inconsistent and establishes an acceptable tolerance level for the degree of the respective inconsistency. Consistency in the AHP methodology refers to the property of transitivity. For example, if A is twice as preferable as B, and B is three times preferable than C, then, to be consistent, A must be six times more preferable than C. To standardize the measurement of consistency in matrices of different sizes, Saaty (1987), has defined a measure called the consistency ratio (CR). By convention, a consistency ratio of 0.1 or less is considered acceptable.

The weights and scores, called priorities, were derived from the pairwise comparison matrix, where the decision-maker compares two dimensions at the same hierarchy level.

After the normalization of |A|, priority weights were calculated computing the geometric mean and assigning the same weight to all individuals in the group.

MC models

A MC is a process that consists of a finite number of states and some known probabilities at a given period. With this method, a sequence of observations can be modeled as a discrete-time stochastic process, which assumes that the prospective values can be predicted using the current one, independently of previous data. In this type of model, it is assumed that only the probability distribution given in the present state determines the probabilistic outcome of the future state - also known as the memoryless feature of MC. For example, if the status of a process is known at times X_1, X_2...X_n, then it can be said that only the latest information - i.e., the state of the process at the X_n time - is sufficient to predict the future progression of the process ($X_n + 1$).

This approach has an interesting clinical correlation: while clinicians often have knowledge of prior medical history, cumulative treatment burden, physiological trends, and past responsiveness to therapy, often during a critical illness clinicians make treatment decisions based on the current physiological state.

Patient-Reported Outcome Measures (PROMs)

We assessed patients' pain, disability, mood, and overall health from the preoperative time-point to 30-days and 1-year follow-up evaluations after surgery using PROM questionnaires. To prevent bias, an independent investigator who was not involved with the patient's clinical care administered the questionnaires.

The Numerical Rating Scale (NRS) ranging from 0 (no pain) to 10 (complete pain) was used to assess the intensity of pain in both sciatic leg pain and low back pain components. The Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36) was used to evaluate the healthcare-related quality of life. The SF-36 instrument was translated and validated for Brazilian Portuguese in 1999 by Ciconelli et al (Vos et al., 2020). Depression and anxiety components were assessed using the Hospital Anxiety and Depression Scale (HAD) (Falavigna et al., 2012; Quaresma et al., 1999). The Fear Avoidance and Beliefs questionnaire present 16 questions, which estimate the expectations of a patient in two subdomains; the first 5 questions are related to physical activity (FABq-Physical), and the other 5 questions to work (FABq-Work) (Roberts et al., 2010; Costa et al., 2008). We also used PROLO, which consists of a 10-point Likert-type scale with final weight subdivided equally into economic and functional components.

At the last evaluation, the patients were asked about their satisfaction with the procedure: “Would you have the same treatment to achieve the same result again?” Patients who answered “definitely yes” or “probably yes” were considered satisfied with the procedure. Dissatisfaction was noted if they answered, “do not know,” “probably would not,” or “definitely would not.”

PROMs that were previously validated in Brazil had their reported cutoffs used to set the range for the categorization of health states to be considered by our algorithm (Falavigna et al., 2011). The NRS for pain (leg and back components) and PROLO were modeled as continuous variables. Subsequentially, we calculated the probabilities of transitioning health states of each individual patient according to the PROMs utilized following multiple time horizons: (1) preoperatory; (2) 30-days; and (3) 1 year after surgery.

The Decision-Making Model

Part I

In order to address the significance of each PROM for individuals and allow them to be properly accounted into the AHP model, a six-question questionnaire was applied in the first interview asking about the different health domains comprised by the PROMs mentioned in the prior section, according to the AHP guideline proposed by Saaty (Saaty, 1987). This questionnaire was designed to elicit (quantify) patients' priorities regarding the potential outcomes on a nine-point scale. The questionnaire was developed according to the AHP process (Saaty, 1987); the health domains to which the priorities were elicited are presented in Table 1. After completing the questionnaire, a matrix is computed to output the right principal eigenvector. Conceptually, this is equivalent to taking the average of both the direct comparisons that were made and the indirect comparisons they imply. The result is a normalized, ratio-level scale that reflects the judgments made through pairwise analysis between the alternatives. Following the pairwise comparisons performed, the AHP process at this time yields the abovementioned CR, which, by convention, should be greater than 0.1.

Table 1 - Eliciting individual priority questionnaires utilized to address the importance given by the patients to each health domain through the respective Patient Reported Outcomes Instruments.

How relevant is it to you…	Corresponding Instrument
The relief of your pain?	NRS for pain (Back and Leg)
Improvement in quality of life?	SF-36 (PCS, MCS)
Improvement in the ability for daily functioning?	ODI, PROLO
A decrease in symptoms of depression?	HAD-D / BDI
A decrease in symptoms of Anxiety	HAD-A
To be globally satisfied with the surgery?	Reported satisfaction (Likert-type question)

MCS = Mental Component Summary; NRS-BP and LP = Numerical Rating Scale for pain, back and leg components, respectively; PCS = Physical Component Summary; BDI = Beck Depression Inventory; ODI = Oswestry Disability Scale; FABq-WC and PC = Fear and Avoidance Beliefs Work and Physical components. Source: Authors (2022).

Part II

According to the values and cutoffs validated for the respective outcome measures, points in the scales were aggregated in bands to categorize the different states a patient could go through after surgery within a given measuring instrument. Those interval bands of values have their thresholds and ranges defined according to previous literature when available. When cutoffs were not previously reported, the values were divided into quartiles in which the lower-bond quartile is the worst potential state for a given outcome and the upper quartile is the healthiest state measured by the instrument. Likert-type scores were accounted as continuous variables. As an example of health states and patients' transitioning process between them, the change of a patient in the preoperative period from a Beck Depression Inventory scoring 35 (severe depression) to a score of 26 (moderate depression) in 30 days after surgery would configure the referred change of health-states in this time-horizon. Further description of the values adopted for each band is available as Supplemental Material. Based on our sample, we calculated the probability of a patient transiting toward the potential states in the time-horizon of 30 days and 1 year after surgery. Traditionally, these approaches were conceived for population-level analysis rather than individual-level analysis. Transition probabilities are aggregated across all patients. By stratifying groups based on specific characteristics across the decision flow, we will partially address this issue, also controlling for potential confounding. For each patient, the following stratifications were recorded and accounted for, respectively, as a node of the final decision flow: (1) sex, (2) beliefs and expectations on work – as per component assessed in FAbq -, and (3) beliefs and expectations related to physical activities – as per the respective component in the FABq.

Part III

To assess the potential benefit from surgery considering patients' priorities and expectations, the MC transition matrix computed the probabilities of health-state transition (i.e., probability of improvement, probability of decrease, and the probability of no change from the prior state) for each individual PROM in the period of 30 days and 1 year, and weighted according to the vectors computed by AHP. As a result, a unitless value was assigned to each variable ranging from -1 to 1 (indicating the extremes of decrease and improvement, respectively), according to the equation below, where X is a PROM score, and P is the respective probability of the potential future states.

$$\mathrm{X} = 1 * \text{Probability of improvement} - 0.5 * \text{Probability no change} - 1 * \text{Probability of worsening}$$

After this stage, multiplying the results of the AHP and MC transition matrices, we obtained a probabilistic instrument that simulates the chances of a patient has to commute to other states independent of all his/her previous history and to use the insights provided to improve patient's and surgeon's decision-making from a novel patient-centered perspective regarding the treatment of LDH.

Case-based Analyses

To evaluate the feasibility and utility of the model and evaluate whether it provides reasonable results, two patients whose criteria were sufficient to indicate surgery prospectively responded to the full-length questionnaires (i.e., the ones regarding the PROMs and the one for priorities elicitation) and are presented here as a case-based analysis of the model's applicability. The results for patients A and B regarding the probability of having their expectations met according to individual priorities elicited by the questionnaires are illustrated in Table 2a and 2b.

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Table 2a - Raw scores obtained from validation with Patients A and B.

Instrument	Case A	Case B
NRS-BP	5	2
NRS-LP	9	2
SF-36	40	70
SF-36 CM	50	75
SF-36 CF	30	60
ODI	70	30
HAD-D	15	5
HAD-A	14	4
BDI	45	12
FABq-Work	30	12
FABq-Physical	6	4

Table 2b - Questionnaire utilized to elicit report of priorities according to the AHP method.

How relevant is it to you…	Case A	Case B
The relief of your pain?	7	3
Improvement in quality of life?	8	7
Improvement in the ability for daily functioning?	8	4
A decrease in symptoms of depression?	4	5
A decrease in symptoms of Anxiety	3	5
To be globally satisfied with the surgery?	9	5

MCS = Mental Component Summary; VAS-BP and LP = Visual Analog Scale Back and Leg Pain components, respectively; PCS = Physical Component Summary; BDI = Beck Depression Inventory; ODI = Oswestry Disability Scale; FAB-WC and PC = Fear and Avoidance Beliefs Work and Physical components. Source: Authors (2022).

3. Results and Discussion

Sample Characteristics

The demographics and clinical characteristics of the 240 patients included in the study are summarized in Table 3. Regarding intraoperative complications, incidental durotomy occurred in 3 patients (1.2%), nerve lesions occurred in 2 (0.8%) patients, and cerebrospinal fluid leakage was also observed in 2 (0.8%) during the intraoperative time. Postoperative complications occurred in 20 patients (8.7%): recurrent disc herniation (n = 4, 1.7%), superficial infection (n = 1, 0.4%), motor deficit (n = 1, 0.4%) seroma (n = 3, 1.2%), suture granuloma (n = 2, 0.8%), and trochanteric bursitis (n = 2, 0.8%). Table 4 compares baseline and post-operative at 1-year scores of the PROMs utilized in our decision-making support tool. Satisfaction with treatment was observed in 87.5% (n = 211) and 91.2% (n = 220) of patients at 30 days and one year after surgery, respectively.

Table 3 - Summary of demographic and clinical characteristics of the patient sample.

No. of patients	240
Female sex	116 (48.30)
Age in years, mean (SD)	46.50 (12.80)
Duration of symptoms in days, median (IQR)	84.80 (30.00)
Duration of hospitalization in hours, median (IQR)	21 (12.00)
Duration of surgery in mins, mean (SD)	54 (24.00)
Time to return to work in days, median (IQR)	20 (20)
Preoperative Motor Impairment	158 (65.80)
Preoperative sensitive Impairment	189 (78.80)
Preoperative reflex deficit	116 (48.30)
IQR: Interquartile range. SD: Standard Deviation.	

Source: Authors (2022).

Case-Based Analyses

Both patients A and B present with LDH associated with neurological impairment and sciatica, a motive usually taken to prescribe surgical treatment. Respectively, Patient A is a male who reports a positive view of physical activities although he relates potential fear and avoidance beliefs towards his work. In addition, he elicited higher priorities in solving the impact of LDH on his quality of life (assigning a priority of 8) and wants to end up feeling overall satisfaction (with a priority score assigned as 9).

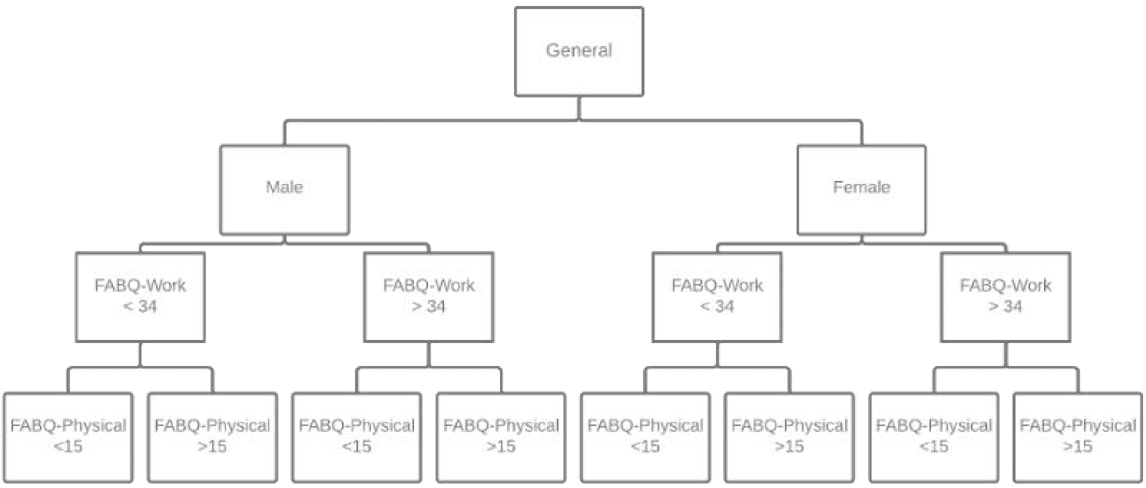
Table 4 - Patient reported outcomes registered both preoperatively and during the 6-month follow-up.

Outcome Measure	**Average Score (95% CI)**	
	Baseline	**1 year after surgery**
ODI	54.4 (51.9-56.8)	35.90 (34.70 – 37.10)
NRS-BP	3.67 (3.34 - 4.01)	1.08 (0.89 - 1.26)
NRS-LP	8.66 (8.48 - 8.84)	1.16 (1.00 - 1.32)
HAD-DC	6.89 (6.46 – 7.32)	4.96 (4.75 – 5.17)
HAD-AC	7.40 (6.92 – 7.88)	3.48 (3.05 – 3.91)
SF-36	40.70 (38.80 – 42.60)	64.50 (62.30 – 66.80)
PCS	33.50 (31.8 – 35.30)	62.80 (60.20 – 65.30)
MCS	47.90 (45.40 – 50.30)	65.90 (63.30 – 68.40)
BDI	10.50 (7.42)	5.08 (4.36 – 5.81)
FABq-WC	17.5 (16.8 – 18.30)	12.20 (11.30 – 13.00)
FABq-PC	23.60 (22.00 – 25.10)	16.10 (14.70 – 17.50)

MCS = Mental Component Summary; VAS-BP and LP = Visual Analog Scale Back and Leg Pain components, respectively; PCS = Physical Component Summary; BDI = Beck Depression Inventory; ODI = Oswestry Disability Scale; FABq-WC and PC = Fear and Avoidance Beliefs Work and Physical components. Source: Authors (2022).

The high score of the patient related to his work allocated him to the respective branch of our decision tree followed by patients with the impact of work on their problem and a positive score regarding physical activities. Meanwhile, Patient B is also a man but was framed as having positive beliefs about both his work and his ability to do physical activities, according to the two FABq components, despite the current burden from LBP. However, per ranking analyses, the mental burden is a much more significant complaint to him than Patient A. As a result of the baseline data assessed regarding gender, FABq-Work and FABq-Physical he was allocated to the pertinent stratification group. According to the decision tree, the allocation of both patients in their respective paths through its branches is illustrated in the Figure 1 below.

Figure 1 - Decision tree representation.



Source: Authors (2022).

Table 5 demonstrates the probabilities arising from the MC's matrix of health states' transition from the current state of cases A and B, respectively, within 30-days and 1 year after surgery. For instance, Patient A has a 46% probability of increasing his scores on quality of life (i.e., per the SF-36) transitioning to other states in 30 days after surgery followed by an ascendant trend in this probability to 72% after 1 year (Table 5).

Table 5 - Probabilities of transitioning health-states regarding Patients A and B**.**

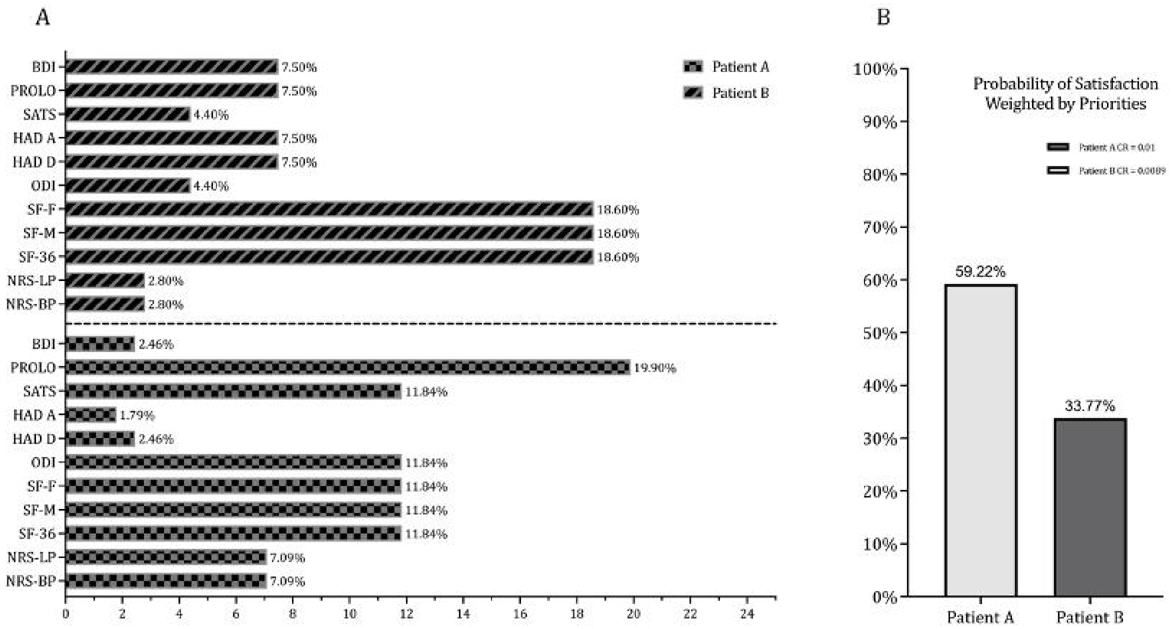
			NRS-BP	NRS-LP	SF-36	SF-36 CM	SF-36 CF	ODI	HAD-D	HAD-A	BDI
Probalities 30-days after surgery	**Improvement**	Case A	100%	100%	46%	43%	40%	94%	67%	67%	100%
		Case B	88%	0%	11%	19%	20%	19%	0%	0%	0%
	No change	Case A	0%	0%	54%	57%	56%	0%	33%	33%	0%
		Case B	13%	0%	58%	58%	60%	52%	81%	67%	84%
	Worsening	Case A	0%	0%	0%	0%	4%	6%	0%	0%	0%
		Case B	0%	100%	23%	23%	20%	29%	19%	33%	16%
Probalities 1 year after surgery	**Improvement**	Case A	100%	100%	72%	73%	83%	100%	89%	100%	100%
		Case B	88%	100%	42%	42%	40%	5%	0%	0%	0%
	No change	Case A	0%	0%	28%	27%	13%	0%	11%	0%	0%
		Case B	13%	0%	23%	23%	60%	57%	85%	81%	84%
	Worsening	Case A	0%	0%	0%	0%	4%	0%	0%	0%	0%
		Case B	0%	0%	35%	35%	0%	38%	15%	19%	16%

NRS-BP and LP = Numerical Rating Scale for pain, Back and Leg components, respectively; SF-36 = Short Form 36; PC = Physical Component; MC = Mental Component; BDI = Beck Depression Inventory; ODI = Oswestry Disability Scale; FABq-WC and PC = Fear and Avoidance Beliefs Work and Physical components. Source: Authors (2022).

The individual values for the priorities came from the scores the patients gave in the AHP questionnaire for elicitation of preferences (Tables 1 and 4), in which Patient A scored 8 for SF-36. In contrast, Patient B scored 7 even though the scoring in this same criterion was higher for Patient B. Due to the pairwise comparisons with other metrics, the result culminated in individual weights presenting the patient's perceptual priority. Finally, when crossing values from the MC transition matrix and the weights from the AHP for those patients, the tool resulted in a percentage value representing the chances of spine surgery meeting their individual expectations.

Figure 2A shows the values derived from the reported priorities accounting for the PROMs and the Consistency Ratio obtained by the AHP method for cases A and B. For example, referring to the SF-36, Patient A had 12% priority for this metric compared to another while Patient B had 19% priority assigned to this domain. Figure 2B illustrates the related output for each of the patients. The results presented by the decision-aid tool suggest that Patient A (82.61%) will be considerably more likely to feel dissatisfaction and/or unmet expectations with surgery than Patient B (35.04%).

Figure 2 - (A) values derived from the reported priorities and **(B)** shows the related output for each of the patients.



Source: Authors (2022).

In order to enhance reproducibility and transparency the full model as well as a calculator that can be imputed with values from new patients is available as Supplemental Materials 1 and 2, respectively. The calculator allows the input of personalized values for the same parameters presented in Table 4, obtained from the patient-reported questionnaires discussed in this article.

Discussion

We developed and studied the feasibility and utility of a tool to help spine surgeons and patients to optimize shared decision-making in the context of symptomatic LDH. The proposed tool for decision support provides the probability of an individual with symptomatic LDH achieving the most relevant outcome from surgery according to his own priorities and values within the period of 30 days or 1 year. The algorithm was based on both predictive and multicriteria analytic components. The predictive feature relies on a MC transition matrix to compute the probability of a patient commuting across different health states according to baseline values of PROMs (e.g., NRS for low back pain) in the considered time-horizon. The multicriteria analyses were performed using an AHP approach that, once having elicited the priorities of the patients within six health domains (i.e., pain, quality of life, daily functioning, anxious and/or depressive mood, and global satisfaction) can provide personalized weights and hierarchy for the patient's priorities. To our knowledge, this is the first study to present a decision-making support tool for both patients and surgeons to deal together with the uncertainty of surgical outcomes and both parties' expectations.

MCs are prevalent modeling methods in healthcare. Their most common application is in cost-effectiveness or cost-utility analyses (Steffensen et al., 2019; Sonnenberg & Beck, 1993). MCs are powerful tools that enable physicians to critically analyze clinical and surgical interventions to optimize the quality-of-life measurements and the lifelong costs incurred in treating specific conditions (Hirshman et al., 2018). Also, they are often used for predictive tasks. For example, Tighe and colleagues proposed MCs as a feasible method for describing probabilistic postoperative pain trajectories, pointing toward the possibility of using MC-based decision processes to model sequential interactions between pain intensity ratings and postoperative analgesic interventions (Tighe et al., 2016). In spine care, Koenig et al. utilized MCs to determine the effect of surgical treatment of LDH on workers' earnings and missed workdays (Koenig et al., 2014).

AHP applications, even though not as widely disseminated as MCs, have presented several practical applications over the years in medicine and healthcare, having increased their growth in applications as the patient becomes more central in decision-making (Liberatore & Nydick, 2008; Mirarchi et al., 2013). In a related study, Hummel et al. applied AHP methodology to compare specialists' and patients' preferences in multiple spinal cord injury rehabilitation centers regarding two treatments for patients with C6-level tetraplegia (Hummel et al., 2005). Their results showed that patients' preferences usually differ from those of the rehabilitation team; patients gave more weight to the burden of treatment and less weight to functional improvement, diverging from the specialists (Hummel et al., 2005).

Previous qualitative research identified that the decision to undergo surgery was not necessarily based on their understanding of the risks and benefits associated with the procedure but due to the debilitating pain and quality of life decrease at the time of the decision (Rubash et al., 2018; Cenic et al., 2019). In studies on symptomatic patients related to benign prostate disease and osteoarthritis, the grade of symptoms' bothersomeness had a more significant effect on predicting surgery than objective scores in a well-informed sample (Bedair et al., 2021). In addition, patients who did not match their goals are more likely to regret surgery and not present significant changes in outcomes (Cenic et al., 2019). Therefore, it is essential for spine surgeons to consider patients' knowledge, perceptions, beliefs, and expectations as necessary as objective symptoms or functional status when deciding on herniated disc treatment (Qureshi et al., 2015; Cenic et al., 2019). However, the purpose of shared-decision making is not to increase or decrease surgery rates but to ensure that the right patient is matched with the proper treatment. A high-quality decision requires proper knowledge and alignment between the treatment received and the patients' aims.

Strengths and Limitations

In spite of the novelty and patient-centered aspect developed by our model, it still presents several limitations. First, there are important patient-level aspects that we did consider in favor of the emphasis on PROMs (e.g., age and sex). Second, existing comorbidities were not taken into consideration, as they are probably more commonly found in elderly patients and are a possible reason for elderly patients having lower PROM scores. Furthermore, it would have been advantageous to use the available clinical examination data, since lower limb and back pain in elderly patients with disc herniation may also be associated with other diagnoses, such as spinal stenosis, hip arthrosis, discitis, rheumatoid arthritis, mechanical low back pain, degenerative disc disease, ankylosing spondylitis, vertebral fracture, and arterial circulation insufficiency, which may explain the lower PROM score in elderly patients. It would also have been advantageous to compare the results of the questionnaires with other general departments and in specialized spine units; taking into account, for example, the different perceptions of the patient pre and post surgery, contemplating both their ages and gender and the surgical techniques used. In addition, we can mention the fact that the mathematical models become very complicated when more states and more interactions between states are added. In time-dependent probabilities, as in the case of surgical recovery and postoperative symptomatic follow-up, this complexity becomes particularly problematic, given the various specificities and characteristics of each patient. Therefore, if we add more and more information and conditions, the transition matrix gets too large, leading to a more complicated model and, consequently, more difficult to manage. Moreover, the attempt to approach sensitivity analysis with case-based analysis was flawed because we were unable to assess changes in model outcomes as a result of varying model parameters within the range of values.

4. Conclusion

Among all the advancements in spine care over the last few years, the recognition of the importance and incorporation of patients' interpretation of their care are arguably among the most important. The use of prospective clinical registries based on patient-reported outcome measures is an important component of medical care because it has the potential to narrow the gap between the clinician's and patient's view of clinical reality and help tailor treatment plans to meet the patient's preferences and needs. Thus, by means of algorithms based on probabilistic stochastic components (Markov Chains) and multiple criteria (Analytic Hierarchy Process), the proposed decision support tool is able to provide the probability that an individual with symptomatic lumbar disc herniation will be satisfied with the surgical outcome in a given period of time, taking into account the patient's priorities and expectations regarding the disease and the procedure. To date, we believe this is the first study to present a decision support tool for patients and surgeons dealing with the uncertainty of surgical outcomes and the expectations of both parties.

Therefore, in this study, we demonstrated the utility and feasibility of applying a decision-support tool on both sides of the patient-doctor binomial providing a probable trajectory that priority PROMs will follow over time. It also takes personalized weights to each patient’s outcomes and elicits priorities having as output the chance of satisfaction with surgery in each time horizon. A data-driven decision-support tool that accounts for patient preferences and beliefs would be a valuable addition to generating high-quality decision-making and more utility for long-term outcomes.

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