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ORIGINAL ARTICLE

Development of a multi-criteria decision-making–based assessment model for dental material selection: Engine-driven nickel-titanium instruments case study

Nurcan Deniz[1] · **Ekim Onur Orhan**[2,3]

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Abstract

Objectives The aims of this study are (i) to propose specific selection criteria related to NiTi instruments for dental practitioners and (ii) to objectively assess the NiTi instruments.

Materials and methods The steps of the methodology are as follows: Step 1: "Delphi method" was employed to reach a consensus on criteria defined according to the literature review and a group of panelists. Step 2: "Smart pairwise comparisons" were employed to rank the proposed criteria. Step 3: "Borda voting" was employed to determine the weights of the proposed criteria. Step 4: To determine assessment scores, "Simple Additive Weighting" was employed. Step 5: Reliability and validity checks were made by "simulation."

Results Specific criteria classified under dimensions were proposed and weighted for the NiTi instrument assessment. In this context, an assessment model was proposed and validated.

Conclusions The proposed assessment model for NiTi instruments could aid to make the decision-making process as systematic, transparent, and reproducible as possible not only for dental practitioners but also for healthcare professionals. Also, this proposed model can represent a reference framework for further MCDM studies which can rank or classify materials in medical science.

Clinical relevance The model proposed in this study can be used to aid decision-making in clinical practice by means assessing the NiTi instrumentation system alternatives for practitioners.

Keywords Medical material selection · Multi-criteria decision-making · Endodontics · Assessment model · Nickel-titanium instruments · Delphi method

Introduction

Nickel-titanium (NiTi) instruments are frequently used in daily endodontic practice for shaping the root canal system [1]. Overall endodontic instruments tend to straighten within a curved root canal during its rotational movement, resulting in lateral stress on the root canal walls [2]. Thus, the principal requirement of the instruments is high flexibility in order to minimize the lateral stress and to achieve the centered shaping [3]. Since the elastic deformation limits of nitinol alloys are higher than the stainless steel, their metallurgical character is a significant advantage for the complex nature of root canal anatomy [1–3]. Root canal shaping with engine-driven NiTi instruments has been reported to cause significantly lesser canal transportation or other shaping errors than conventional hand instruments [4–6]. In concordance, this endodontic shaping concept has transformed from hand instrumentation to engine-driven NiTi instruments in dental education over years [7, 8].

Currently, it is known that 256 different alternatives of engine-driven NiTi instruments exist [9]. Overall, hundreds of manufacturers claim that their products are designed for optimal shaping in the majority of cases. Inherently, the

✉ Nurcan Deniz
nurcanatikdeniz@gmail.com; ndeniz@ogu.edu.tr

1 Department of Business Administration, Faculty of Economics and Administrative Sciences, Eskişehir Osmangazi University, 26040 Eskişehir, Turkey

2 Department of Endodontics, Faculty of Dentistry, Eskişehir Osmangazi University, 26040 Eskişehir, Turkey

3 Translational Medicine Research and Clinical Center, Eskisehir Osmangazi University, 26040 Eskisehir, Turkey

great number of NiTi instruments becomes not only hard to review but also this might be led to confusion in the assessment of the alternatives for practitioners [10].

The metallurgical properties and operating performances of the NiTi instruments are well understood [11–15]. However, the shaping systems still maintain their complexity in endodontic practice [10]. For instance, each system could be used per manufacturer instructions or together with different systems independently [12]. Especially, the combination of different NiTi instrument systems usage with a solid base of anatomic and biologic knowledge can lead to a predictable higher quality of root canal treatment on a broader basis by specialists [12]. Instrument alternatives do not be a problem for specialists due to clinical experience, and intuitive decisions seem sufficient in meeting accepted standards of treatment for specialists [16]. On the other hand, Dahlström et al. [10] have determined six different categories of issues that the general dentists regarded as problematic for root canal treatment. In one of these categories, "equipment/materials complexity," NiTi instruments have been demonstrated as an issue for general dentists [10]. In addition, switching to different instrumentation systems for practitioners is challenging due to the necessity of adapting to the new situation [10].

Recently, Hülsmann et al. [17] have been emphasized that the scientific value of studies on NiTi instrument durability is controversial. Therefore, the consequences of many of these reports have been described as “useless for the general dental practitioner as well as for the endodontic specialist when they are seeking information on a specific instrument system” [18]. To make a sustainable decision about a material, each corresponding criterion under the “economic,” “environmental,” “social,” and “experience-based” dimensions should be assessed together by the decision-maker [19]. However, essential criteria concerning the assessment of NiTi instruments have not been defined in the literature yet.

Multi-criteria decision-making (MCDM) approach is used to produce clear, analytic, objective, and unbiased decisions in the complex nature of decision-making problems [20]. More specifically, various decision-support tools and techniques in the MCDM umbrella can be adapted for systematic material selection problems in medicine and dentistry for criteria determination, ranking the alternatives, showing the best options, etc. [21, 22]. In this context, recently, Büyüközkan and Göçer [22] have proposed an MCDM method to treat the uncertainty in the decision-making process in the wearable monitoring devices for cardiac patients. Similarly, Aherwar et al. have used MCDM techniques to select novel-developed implant materials [23]. Also, MCDM techniques have been applied for the selection of biomaterials used by the prosthesis and implant manufacturers in a previous study [24]. Validation checks have shown that the proposed decision-making model and the rankings generated have been sufficiently stable in the previous study [22].

The main goals of this study are to present the complexity of the NiTi instrument assessment problem, to raise interest among practitioners in dentistry and to assess NiTi instruments under various evaluation criteria. With this motivation, the aims of this study are (i) to propose specific criteria related to NiTi instruments for dental practitioners and (ii) to objectively assess the NiTi instruments.

Materials and methods

Theory

To assess NiTi instruments, an MCDM-based conceptual framework methodology was proposed. It is assumed that the readers in healthcare have limited information about MCDM techniques. Thus, specific nomenclature needs to be clarified to increase the readability. MCDM is a sub-discipline of operations research that explicitly evaluates multiple conflicting criteria in decision-making both in daily life and in settings such as business, government, and medicine. An “alternative” represents the option in a decision-making process. For the performance assessment of an alternative, relevant “criteria” are used. The criteria are not equally important in the decision-making process. Thus, to express this relative importance, the “weight” of each criterion is necessary to be determined [25]. “Delphi method” was used to reach a consensus between a panel of experts. “Borda count” is a voting system completed “smart pairwise comparison” to determine the weight of each criterion. “Simple Additive Weighting” (SAW) is a scoring method based on the multi-attribute decision technique and weighted average. The steps of the proposed methodology are shown in Figure 1.

Step 1: Criteria determination with Delphi method

In the first step, specific criteria pool regarding the endodontic NiTi instruments was generated. In this step, the Delphi method (Rand Corp., Santa Monica, CA) was employed to reach a consensus between panelists. The relevant literature review was conducted in April 2020 in the database PubMed using the search terms “nitinol”[All Fields] OR “nickel-titanium”[All Fields] OR “nickel titanium”[All Fields] AND “Endodontics”[All Fields] to determine the criteria.

Qualified academicians who meet the inclusion criteria were included in the Delphi analysis as “panelists.” Panelists in this study were anonymous and blind. The included panelists have (1) no conflict of interest or financial interest with NiTi instrument manufacturers; (2) a publication that includes any NiTi instrumentation system; (3) a publication

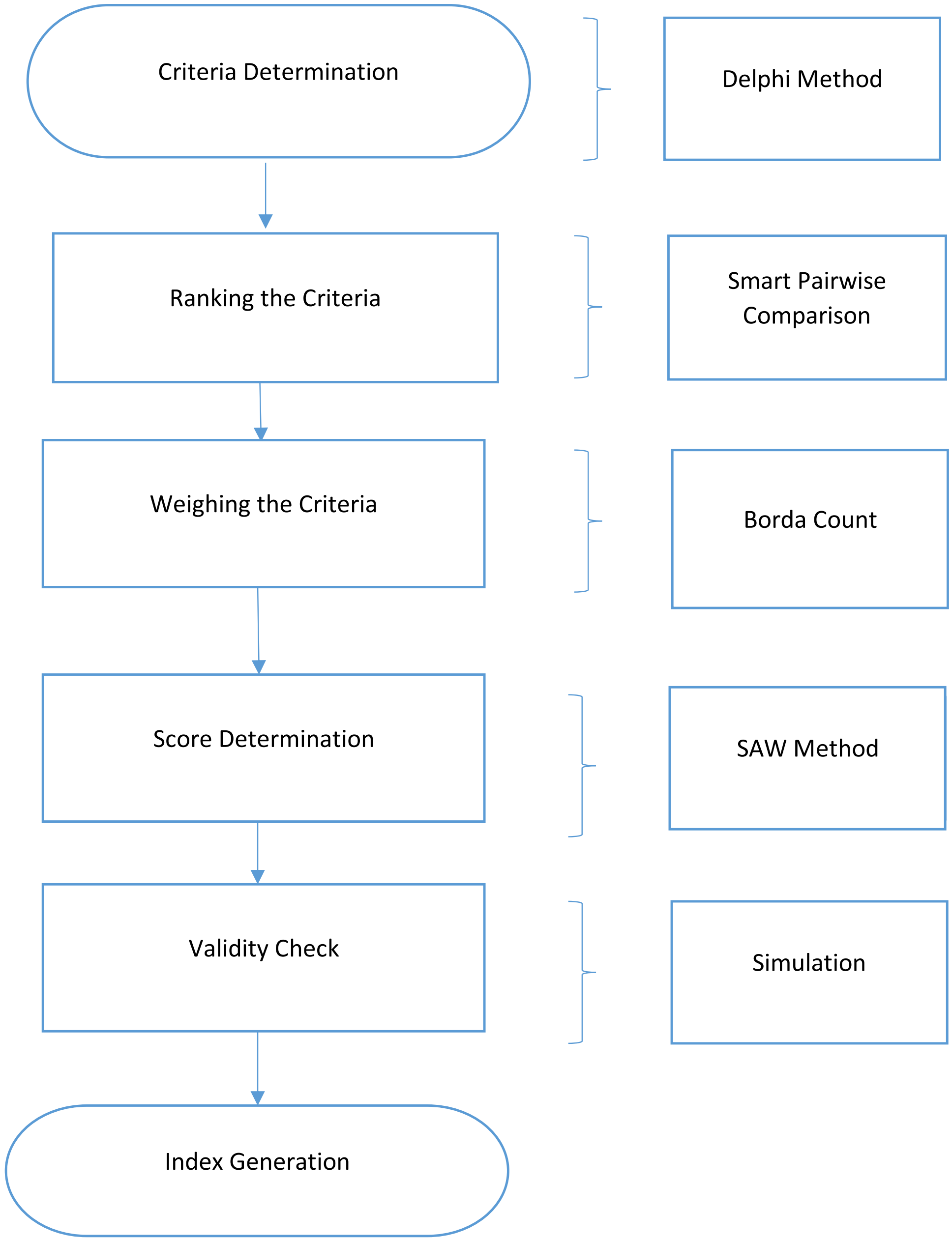

Fig. 1 The flowchart of proposed methodology

that includes at least one keyword used in the literature research; (4) a return from the entire Delphi rounds; (5) over 15 years overall professional experience; and (6) position academic career in an institute or university.

The Delphi method was employed to reach consensus in an iterative questionnaire exercise with controlled feedback from a group of panelists [26]. Accordingly, two questionnaire rounds were performed via e-mail communication. In the first questionnaire round, a linear numerical scale (the Likert scale) combined with an open-ended question was used. Likert scale is a type of psychometric response scale in which responders specify their level of agreement to a statement typically in 5 points. In the second round, the mean and standard deviations of each item were sent to the panelists to follow the results of prior consensus. In this round, panelists were able to alter their former decisions.

To determine the consensus on items, the "Content Validity Ratio" (CVR) was used in this round. CVR value was calculated via Equation (1).

$$CVR = \frac{N_{PE} - (\frac{N}{2})}{N/2} \quad (1)$$

In Equation (1), the N_{PE} represents the number of panelists who found an item essential (having a score of 4 or 5 for an item on the 5-Likert scale) where N represents the number of panelists. If all panelists indicate that the same item is essential, *CVR* gets a "+1 value" as maxima, whereas if all panelists indicate that the same item is non-essential, *CVR* gets a "−1 value" as minima. The threshold value of the *CVR* is "0.29." Hereby, if the *CVR* value of criterion is less than "0.29," it needs to be excluded from the proposed criteria pool after the consensus [27].

Step 2: Criteria ranking with smart pairwise comparisons

To determine the importance of the proposed criteria, binary comparisons were made by the panelists. To eliminate a potential inconsistency problem related to an excessive number of pairwise comparisons and to reduce the comparison numbers, a smart algorithm was developed as defined by the previous studies [28, 29]. The smart algorithm constructed in software (Excel, Microsoft Corp., Redmond WA, USA) realizes pairwise comparisons by using the memory of the previous answers (Figure 2). To show how to fill the template, a brief manual was also sent to blind panelists.

The smart algorithm was launched with two fixed questions. The first question of the pairwise comparison (Q1) was "Which dimension is more important? A or B?" and the second question (Q2) was "C or D?". Following the two answers, new pairwise comparison questions connected to the prior answers were arisen automatically. The latter questions were variable and individual for panelists. When the answers to all questions were completed for each panelist, the individual rankings appeared automatically. The individual rankings show the opinion regarding the importance level of the dimensions from highest to lowest. Then, each panelist assigned an importance score between "0 and 100" to the rankings for all dimensions (Figure 2). Finally, entire scores of each dimension were converted to "1" for normalization.

Step 3: Weight determination with Borda count

Borda count was used as an aggregation method for combining panelists' preferences for group decision-making. In the proposed method, lowest-ranked preference receives 1 point, and the penultimate ranking receives 2 points and proceeds [30].

Step 4: Assessment score generation with SAW

To determine a score of each alternative, SAW method was employed [31]. The total assessment score of each alternative is obtained via Equation (2), and if there are alternatives, they need to be ranked in a descending order. k denotes criteria number, w denotes weights, and c denotes criteria values in this equation [32].

$$Score = w_1c_1 + w_2c_2 + \ldots \ldots . + w_kc_k \quad (2)$$

Step 5: Simulation of the assessment model

At the end of the proposed methodology, reliability and validity checks of the assessment model were carried out with a simulation created by the RAND function (Excel v16.20; Microsoft Corp., Redmond WA, USA).

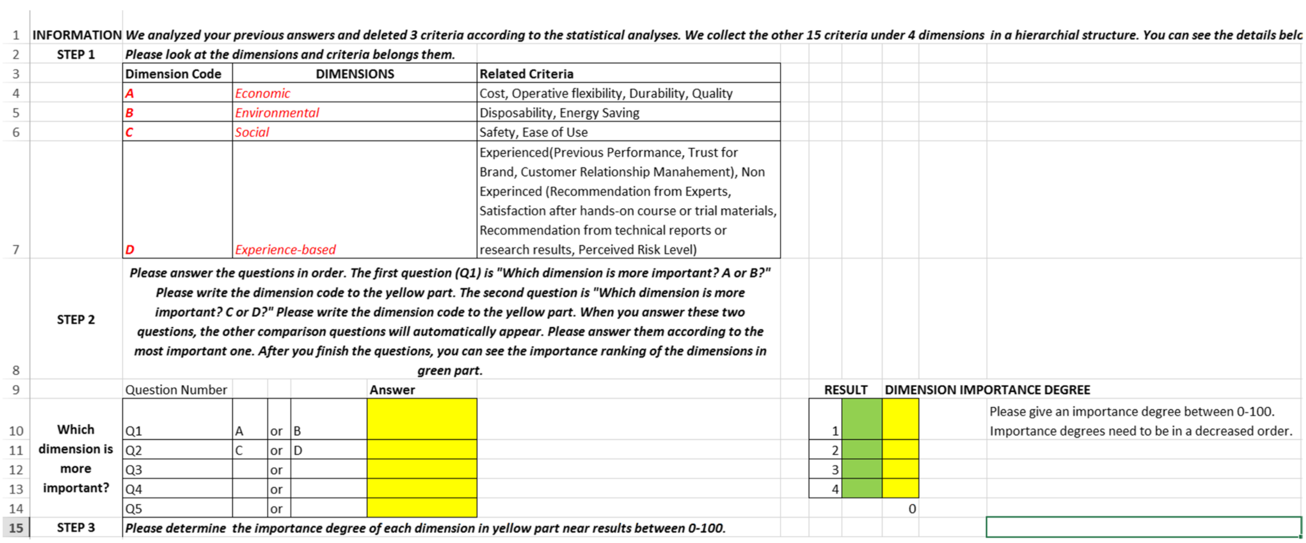

Fig. 2 A screenshot from smart pairwise comparison template

Results

Step 1: Criteria determination with Delphi evaluation

The literature search resulted in 33 review articles, of which 29 were considered relevant according to their titles and abstracts. These articles were examined for the Delphi rounds.

Seven panelists were included in this study from Cyprus, Slovenia, South Korea, and Turkey. The expertise levels of the panelists were between 15 and 25 years. The consensus was provided after two rounds of the Delphi method.

Eighteen criteria were derived from dental science, supply chain management, and consumer behavior for criteria pool. The first half of the criteria was derived from the examined review articles. Criteria no.14 and no.16 were derived from a previous study [33]. The rest of the criteria, derived from supplier selection, marketing, or consumer behavior literature, consists of universal nomenclatures that affect purchasing The eighteen criteria are as follows:

Cost The panelists had a consensus on the "cost" of NiTi instruments and therefore preferred to minimize it. The criterion was designated in three intervals as "1–19 €," "20–39 €," and "+40 €."

Operative flexibility Some NiTi instrumentation systems are designed to be motioned with unique parameters. Solely, these unique kinematic parameters are installed within their unique electric motor sources. A practitioner cannot operate such types of NiTi instruments without their designated motor sources. Thus, such NiTi instrument systems should be considered with their motor source together in decision-making. NiTi instruments were classified according to requiring a specific endo motor source or to be capable of using with a universal endo motor source either. The panelists had mostly consensus on the "operative flexibility," and therefore, NiTi instruments operated with universal kinematic settings were mostly preferred.

Disposability NiTi instrument systems are presented as either "single-use" or "reusable" per their manufacturer instructions. However, there is still no consensus on the number of reusing NiTi instruments. In fact, a NiTi instrument has many drawbacks due to its repetitive use as gradually decreasing its efficiency and fatigue resistance. The panelists had mostly consensus on the "disposability," and therefore, single-use NiTi instruments were mostly preferred.

Energy-saving NiTi instrument systems are classified as either "pre-sterilized" or "non-sterile" per their manufacturers within their blisters or packages. The pre-sterilized instrument is ready to use; therefore, it saves energy, natural sources, and time consumption. On the contrary, a non-sterile instrument has to be cleaned and sterilized before its usage. The panelists had a consensus on the "energy-saving," and therefore, pre-sterilized NiTi instruments were preferred.

Safety NiTi instrument systems are classified as the medical device "Class I" according to directive 93/42/EEC, and international standards about these instruments have been designated by ISO and ADA/ANSI [34, 35]. However, there is still plenty of uncertified NiTi instrument available in global markets. Consequently, to cite the safe medical product manufactured under the associated regulations [34, 35], the "C/E" expression was used. The panelists had a consensus on the "safety," and therefore, globally certificated NiTi instruments were preferred.

Ease of use Conventional root canal shaping systems are designed to use together with more than three different sizes of instruments for shaping canals to the desired geometry. To able to reach the identical shaping goals by reducing the number of the instrument decreases the complexity of the treatment procedure and saves time consumption. "Easy" represents a system with a single instrument, "medium" represents a system with a double or triple instrument, and "difficult" represents a system with more than three different sizes of instruments in the proposed criterion. The panelists had mostly consensus on the instruments with "ease of use," and therefore, single-file shaping systems were mostly preferred.

Durability A NiTi instrument has unique durability characteristics due to the metallurgical and manufacturing processes [36–38]. The manufacturing subject arose in the "safety" criterion. The metallurgical classification of NiTi instruments was made as follows: "Superelastic (SE) NiTi (Conventional) instruments, Electropolished SE NiTi instruments, M-wire® NiTi instruments, R-phase of NiTi instruments, T-wire® heat-treated NiTi instruments, C-wire® heat-treated NiTi instruments, Blue-wire® heat-treated NiTi instruments, Gold-wire® heat-treated NiTi instruments, Controlled memory (CM)-wire® heat-treated NiTi instruments, Electrical discharge machining of CM-wire®, and Max-Wire® heat-treated NiTi instruments." The panelists had mostly consensus on the "durability" of the NiTi alloy alternatives. Literature-based durability data of different alloys were ranked by criteria weights.

Quality Regarding Dickson's 23 main supplier selection criteria, "quality" is one of the most important criteria [39]. The panelists had a consensus on the "quality." Globally patented markings (® or ©), trademarks icons (™), European Conformity (CE) markings, or American National Standards Institute/American Dental Association (ANSI/ADA) certifications of NiTi instruments were considered as high-quality.

Delivery conditions "Delivery conditions" is significant in the main supplier selection criteria [39]. Decision-makers consider delivery conditions as "on-time" or "with delay" to compare suppliers [39]. The proposed criterion was assessed with a 5-Likert scale ("5" represents the highest level, "1" represents the lowest).

Previous performance "Previous performance" is significant in the main supplier selection criteria [39]. The former experience of a decision-maker affects the latter decisions for the same product [39]. The proposed criterion was assessed with a 5-Likert scale.

Designs of NiTi instruments were listed to the panel: "S-shape (two-blade), complex shape (two- and tri-blades) with constant tapered"; "triangular shape (triple blade), constant tapered"; "concave triangular shape (triple-blade), progressively tapered"; and "triple U shape (having radial lands), constant tapered." The "design of NiTi instrument" (outer geometry; core diameter, taper, flute design, and the cross-sectional geometry) is known to impact on cutting efficiency and centering ability of instruments. However, this non-measurable term (instrument design) was proposed to include in the "previous performance" criterion under the dimension of "experience-based practitioners."

Trust for a brand "Trust for a brand" is one of the significant criteria in supplier-buyer transaction performance [40]. The source of confidence relies on the previous purchasing experience of a decision-maker [40]. The proposed criterion was assessed with a 5-Likert scale.

Customer relationship management "Customer relationship management" is a significant criterion in supplier-buyer transaction performance [40]. Warranty policy of product and problem-solving performance of suppliers could be considered under this criterion [41]. The proposed criterion was assessed with a 5-Likert scale.

Recommendation from experts In consumer behavior, information seeking is one of the important issues in purchasing decisions. The information comes out professionally either from internal sources (previous experience of the product) [42] or from external sources (with the recommendation from experts or colleagues) [33]. The proposed criterion was assessed with a 5-Likert scale.

Satisfaction after hands-on courses This specific criterion was generated since the hands-on courses in any professional learning organization could affect the decision-making in dentistry [33]. The proposed criterion was assessed with a 5-Likert scale.

Recommendation from technical reports or research results The majority of the relevant studies on NiTi instruments are in vitro comparisons and preclinical observations [17]. In addition, the individual mechanical properties or shaping abilities of numerous NiTi instrument brands have been informed by comparative studies. The proposed criterion was assessed with a 5-Likert scale. The drawbacks concerning the limitation to the in vitro study designs were mentioned in the introduction section.

Brand image The main purpose of marketing is to influence consumers' perceptions and establish the brand image in consumers' minds. The brand image can build brand equity, and it draws significant attention from academics and practitioners due to play an important role in marketing activities. Accordingly, there is a strong correlation between brand image, customer satisfaction, and customer loyalty [43]. The proposed criterion was assessed with a 5-Likert scale.

Perceived risk level Risk perception and the decision-making of purchasing have a relationship [44]. The proposed criterion was assessed with a 5-Likert scale.

In the first Delphi round, panelist no.2 sent a feedback to the open-ended question as "free product samples could affect the decision-making." Consequently, the title of criterion no.15 was revised as "Satisfaction after hands-on courses or trial materials." The first round of Delphi results are listed in Table 1. The Delphi iteration process was terminated at the second round since there was no alteration to the former decisions. The eighteen criteria were decreased to fifteen since the *CVR* values of these 3 criteria (no.8 "design," no.10 "delivery," and no.17 "brand image") were less than 0.29.

The proposed 15 criteria were classified under 4 dimensions in a hierarchical structure (Table 2). The first three dimensions ("economic," "environmental," and "social") were determined as brand independent according to the triple bottom line approach recommended by Luthra et al. [45]. "Cost," "operative flexibility," "durability," and "quality" were classified under the economic dimension. "Disposability" and "energy-saving" were classified under the "environmental" dimension. "Safety" and "ease of use" were classified under the "social" dimension.

The "Experience-based" dimension was generated as a brand-dependent dimension having two sub-dimensions depending on the former experience of the decision-maker. If the decision-maker has former experience about the

Table 1 The first-round results of Delphi method

#	Criterion	Mean	Standard deviation	N_{PE}	*CVR*
1	Cost	3.86	0.69	5	0.43
2	Operative flexibility	4.00	0.82	5	0.43
3	Disposability	3.71	0.95	5	0.43
4	Energy saving	3.86	1.07	5	0.43
5	Safety	4.86	0.38	7	1.00
6	Ease of use	4.14	0.69	6	0.71
7	Durability	4.14	0.69	6	0.71
8	Design	3.00	1.15	3	-0.14
9	Quality	4.43	0.79	6	0.71
10	Delivery	3.57	0.53	4	0.14
11	Previous performance	4.00	0.58	6	0.71
12	Trust for brand	3.57	0.79	5	0.43
13	Customer relationship management	3.43	1.40	5	0.43
14	Recommendation from experts	4.00	0.58	6	0.71
15	Satisfaction after hands-on courses or trial materials	4.43	0.79	6	0.71
16	Recommendation from technical reports or research results	4.43	0.79	6	0.71
17	Brand image	3.29	0.76	3	-0.14
18	Perceived Risk level	4.00	1.00	6	0.71

N_{PE} number of experts found the item essential, *CVR* Content Validity Ratio

Table 2 The hierarchical structure of dimensions

Code	Dimensions	Sub-Dimension	Related Criteria
A	**Economic**		Cost, Operative flexibility, Durability, Quality
B	**Environmental**		Disposability, Energy Saving
C	**Social**		Safety, Ease of Use
D	**Experience-based**	Experienced	Previous Performance, Trust for Brand, Customer Relationship Management
		Non-Experienced	Recommendation from Experts, Satisfaction after hands-on course or trial materials, Recommendation from technical reports or research results, Perceived Risk Level

instrument type/brand assessed, the "experienced" division becomes valid. Therefore, three specific criteria need to assess as follows: "previous performance," "trust for the brand," and "customer relationship management." On the other hand, if the decision-maker does not have any former experience about the type/brand assessed, the "non-experienced" division becomes valid. Therefore, four specific criteria need to assess as follows: "recommendation from experts," "results of technical reports or researches," "satisfaction after the hands-on course or trial materials," and "perceived risk level."

Step 2: Importance determination with smart pairwise comparison results

Panelists made pairwise comparisons using a smart template structured in MS Excel. As an example, the comparison of panelist no.1 is given in Figure 3.

Step 3: Weight determination with Borda Count

The sum of each dimension multiplying with Borda rank weight is equal to the group score. Group scores

INFORMATION	***We analyzed your previous answers and deleted 3 criteria according to the statistical analyses. We collect the other 15 criteria under 4 dimensions in a hierarchical structure. You can see the details below.***											
STEP 1	***Please look at the dimensions and criteria belongs them.***											
	Dimension Code	**DIMENSIONS**	**Related Criteria**									
	A	*Economic*	Cost, Operative flexibility, Durability, Quality									
	B	*Environmental*	Disposability, Energy Saving									
	C	*Social*	Safety, Ease of Use									
	D	*Experience-based*	Experienced (Previous Performance, Trust for Brand, Customer Relationship Management), Non Experienced (Recommendation from Experts, Satisfaction after hands-on course or trial materials, Recommendation from technical reports or research results, Perceived Risk Level)									
STEP 2	***Please answer the questions in order. The first question (Q1) is "Which dimension is more important? A or B?" Please write the dimension code to the yellow part. The second question is "Which dimension is more important? C or D?" Please write the dimension code to the yellow part. When you answer these two questions, the other comparison questions will automatically appear. Please answer them according to the most important one. After you finish the questions, you can see the importance ranking of the dimensions in green part.***											
	Question Number				**Answer**			**RESULT**		**DIMENSION IMPORTANCE DEGREE**		
Which dimension is more important?	Q1	A	or	B	A			1	A	80	0.35	Please give an importance degree between 0-100. Importance degrees need to be in a decreased order.
	Q2	C	or	D	D			2	D	60	0.26	
	Q3	A	or	D	A			3	C	50	0.22	
	Q4	B	or	C	C			4	B	40	0.17	
	Q5	D	or	C	D					230	1	
STEP 3	***Please determine the importance degree of each dimension in yellow part near results between 0-100.***											

Fig. 3 A screenshot from the pairwise comparison results of panelist no.1

of each dimension are given in Table 3. The normalized weights are determined by dividing all the scores by the total score. The same procedure was employed for each criterion.

In the proposed methodology, each dimensional weight was determined by multiplying the normalized weight of each criterion and normalized dimensional group score. As an example, the criteria weights of the "economic" dimension are given in Table 4. According to the results, "disposability" became the least important criterion with 0.04-dimensional weight, and "safety" became the most important criterion with 0.21-dimensional weight.

Table 3 The ranking and weights of dimensions. The numbers are shown with only two decimal digits as "x.xx"

Borda Rank Weight	Expert 1		Expert 2		Expert 3		Expert 4		Expert 5		Expert 6		Expert 7		Group Score		Normalized Weight
4	**A**	0.35	**D**	0.27	**B**	0.29	**A**	0.37	**C**	0.38	**C**	0.27	**C**	0.38	**A**	6.61	0.34
3	**D**	0.26	**A**	0.26	**D**	0.27	**C**	0.26	**A**	0.27	**A**	0.26	**A**	0.29	**B**	2.72	0.14
2	**C**	0.22	**C**	0.24	**A**	0.27	**D**	0.22	**D**	0.19	**B**	0.24	**B**	0.19	**C**	6.03	0.31
1	**B**	0.17	**B**	0.23	**C**	0.18	**B**	0.15	**B**	0.15	**D**	0.23	**D**	0.14	**D**	3.88	0.20
															TOTAL	**19.24**	**1.00**

Table 4 The weights of the economic dimension

Group score		Normalized weight	Dimensional weight
Criterion #1 Cost	4.51	0.24	0.08
Criterion #2 Operative flexibility	4.17	0.22	0.08
Criterion #3 Durability	6.08	0.32	0.11
Criterion #4 Quality	4.04	0.21	0.07
Total	**18.79**	**1.00**	**0.34**

Table 5 The simulation database

	Random number	Level number	Related level
Experience	0.099	2	1
1	0.147	3	1
2	0.811	2	2
3	0.437	11	5
4	0.023	2	1
5	0.914	2	2
6	0.357	2	1
7	0.324	2	1
8	0.440	3	2
9	0.542	5	3
10	0.264	5	2
11	0.631	5	4

Step 4: Assessment model generation and validity check

To check the validity of the proposed methodology, a virtual NiTi instrument was generated with random numbers (RN). The virtual instrument assignments are given in Table 5. The first RN identifies the experience level of a decision-maker on a virtual instrument. If the RN is less than 0.5, the "experienced" division is appropriate; else, the "non-experienced" division is appropriate. In this context, the experience level of the virtual instrument was assigned as "0.099"; thus, the "experienced" division was employed to further assignments.

The level numbers and the related levels for each criterion are shown in the second and third columns in Table 5, respectively. As an example, the level number of the first criterion (cost) is "3" due to having three levels as "1–19 €," "20–39 €," and "+40 €". In addition, the relationship between the three levels of the cost is determined as 1 or equally weighted. Accordingly, the "related level" of the cost criterion is 1. In the virtual NiTi instrument, the assigned RN value to the cost is "0.147" (RN≤0.33 or RN≤1/3). This means the cost of the instrument is assumed between "1 and 19 €."

The overall assessments of the virtual NiTi instrument were made as follows: Cost is between "1 and 19 €," operated by a universal motor source, the alloy made by T-wire®, having a quality certification, safe, reusable after sterilization, having a pre-sterile package, ease of use level is medium, the previous performance level is medium, trust for the brand level is high, and customer relationship management level is low.

Step 5: Simulation of the assessment model

The total score emerges automatically when a NiTi instrument is assessed. As the final step of the study, the assessment score was generated for the virtual NiTi instrument. The overall assessments of the virtual NiTi instrument are given in Figure 4. The total score is evaluated according to the scale shown in Table 6. The total score of the virtual NiTi instrument was calculated as 0.84 or "the highest."

Also, a well-known NiTi instrument system starter kit (ProTaper Universal; Dentsply Sirona, Tulsa Dental Specialities, Johnson City, TN, USA) has been assessed with the proposed model. Regarding the original example, the overall assessments of the original NiTi instruments were made as follows: Cost is between "20 and 39 € (about 30 €)," operated by a "universal motor source," the alloy made by "SE NiTi", having a "quality certification," "safe," "reusable" after sterilization, having "non-sterile package," "ease of use level is hard," the "previous performance level is medium," "trust for the brand level is high," and "customer relationship management level is high". The total score of the ProTaper Universal Starter Kit was calculated as 0.759 or "the highest." The screenshot of the practical example is shown in Figure 5.

Discussion

A conceptual framework based on MCDM was developed for the "medical material selection problem" in this study. As a case study, the endodontic NiTi instrument decision-making problem was processed because of the gap in this field. Specific criteria for assessing NiTi instruments were proposed according to the literature review-based Delphi technique. The panelists reached consensus about the proposed criteria and weights of them obtained with binary comparison and Borda count-based group decision-making. The proposed criteria were classified under four dimensions in a hierarchical manner, and an assessment score was obtained using the SAW method. Undoubtedly, readers in healthcare might not be familiar with the MCDM-based frameworks [46]. Therefore, the proposed methodology of this study is also addressed in the discussion part to increase clarity.

Dimension	C	Criteria	Level	Level Weight		Criteria Weight	Score	
ECONOMIC	1	Cost	1-19 €	1.00	1			
			20-39 €	0.67				
			40 €	0.33		0.08	1	
	2	Operative Flexibility	Specific motor (complex kinematic)	0.50				
			Universal motor (simple kinematic)	1.00	1	0.08	1	
	3	Durability	Super Elastic NiTi wire (Conventional)	0.25				
			Electropolished SE NiTi instruments	0.50				
			M-wire	0.50				
			NiTi alloy in R-phase	0.50				
			T-wire Heat-treated NiTi alloy	0.75	1			
			C-wire Heat-treated NiTi alloy	0.75				
			Blue Heat-treated NiTi alloy	0.75				
			Gold Heat-treated NiTi alloy	0.75				
			Controlled memory (CM) alloy	0.75				
			Electrical discharge machining with CM alloy	1.00				
			MaxWire	1.00		0.11	0.75	
	4	Quality	Certificated	1.00	1			
			Non-Certificated	0.30		0.07	1	
ENVIRONMENTAL	5	Disposability	Single use	0.40				
			Reusable	0.60	1	0.04	0.6	
	6	Energy saving	Pre-sterilized	1.00	1			
			Non-sterile	0.90		0.1	1	
SOCIAL	7	Safety	C/E	1.00	1			
			Non-certificated	0.30		0.21	1	
	8	Ease of use	Easy (Single file instrument systems)	1.00				
			Medium (Double-triple file instrument systems)	0.67	1			
			Hard (Multiple file instrument systems)	0.33		0.1	0.67	
EXPERIENCE-BASED	9	Previous Performance	Highest	1.00				
			High	0.80				
			Medium	0.60	1			
			Low	0.40				
			Lowest	0.20		0.08	0.6	
	10	Trust for Brand	Highest	1.00				
			High	0.80	1			
			Medium	0.60		0.07	0.8	
			Low	0.40				
			Lowest	0.20				
	11	Customer Relationship Management	Highest	1.00				
			High	0.80				
			Medium	0.60				
			Low	0.40	1			
			Lowest	0.20		0.05	0.4	
		TOTAL SCORE					0.84	Highest

Fig. 4 A screenshot from the validity check result of a virtual product

The present study was performed to realize special aims. In this case study, the first aim was to propose the relevant evaluation criteria for NiTi instrument selection according to the literature review and consensus of panelists in the context of sustainability and reproducibility. Therefore, the Delphi method was proposed to employ in the first step of the methodology. The Delphi method consists of an iterative questionnaire exercise with controlled feedback from a group of panelists to reach consensus. The included panelists must be anonymous and blind experts in the same field. A panelist is defined as "any individual with relevant knowledge and experience of a particular topic," and the size of the panel needs to be a minimum of "four participants," but the qualities of the expert panel are more important rather than its count [47]. Following the panel invitation, the Delphi method requires a minimum of two questionnaire rounds consisting of open- or close-ended questions (three rounds, if round one is open-ended) [47]. The initial round mostly aims a qualitatively sorting, categorizing, and searching for common themes of criteria as qualitatively, whereas the subsequent round aims to quantitatively rank the criteria in terms of their significance [47]. For this purpose, linear numerical scales such as the "Likert scale" are often used in this round. The Delphi rounds continue iteratively with statistical feedbacks until a consensus is reached on related criteria [47]. In addition, the questionnaires of rounds could be applied via electronic mail online [27]. Various techniques are used to make the consensus on criteria. The *CVR* proposed by Lawshe [48] is the commonly used value for removing or retaining a criterion.

The second aim was to provide a simple and comprehensive multi-dimensional decision framework for NiTi instrument assessments. For this purpose, the Delphi method is suitable to be employed standalone or in combination with other MCDM techniques [49]. The pairwise comparisons among criteria are commonly used to determine the importance of the criteria [28, 29]. To reduce the comparison count and not to cause inconsistency with the previous answers, a smart algorithm was developed in the "pairwise comparison step" of this study [28, 29]. Borda count was proposed to combine with the methodology steps of this study as the aggregation purpose for combining panelists' preferences in group decision-making [49]. In addition, the SAW method was proposed to employ for the determination of the overall assessment score and validation checks in these steps [31]. In the proposed assessment model, the proposed criteria scores were multiplied with the corresponding criteria weights individually, and the scores were summed in the SAW [50].

As the major finding of the study, the proposed assessment model for NiTi instruments can act as a decision-making support tool for practitioners to give more systematic, transparent, and reproducible decisions in multi-dimensional and multi-criteria conditions. In addition, this proposed methodology or MCDM framework could be adapted to any kind of medical material selection problem.. In addition, this model can easily be adapted to any kind of medical material selection problem.

Conventionally, the decision-making about an instrument is related to the professional experience of a practitioner or the professional interactions from colleagues and experts in the same field [51]. However, to make transparent decisions, a systematic multi-dimensional and multi-criteria construct of benefit assessment is needed [46]. Currently, the importance and popularity of the framework of MCDM increase not only for systematic material selection but also for aiding and supporting healthcare decision-making. Several applications of MCDM are available in the literature about these related subjects [23, 34]. The fuzzy analytical hierarchy process (FAHP) method of MCDM has been used for a more objective and systematic choice among infectious medical waste disposal firms [41]. Diaby and Goeree [25] have shown the usage of MCDM models for decision-making in the reimbursement process in healthcare. Mobinizadeh et al. [52] have proposed a model for priority setting of health technology assessment using MCDM techniques. One of the MCDM technique "Technique for Order of Preference by Similarity to Ideal Solution" (TOPSIS) has been used for choosing among sugar analyzing devices and aiding diabetic patients [53]. The intuitionistic fuzzy Choquet integral has been used for choosing a smart medical device, and the generated model has been validated as comparing with several MCDM techniques [22]. Likewise, some MCDM techniques have also been used for "diagnosis and treatment" purposes of professional practice in healthcare [20]. In addition, some MCDM applications have been utilized for the systematic selection of paramedical materials in previous studies [21, 54, 55].

Table 6 Assessment scores *versus* categories

Assessment scores	Categories
0.74 - 1.00	Highest
0.67 - 0.73	High
0.51 - 0.67	Medium
0.34 - 0.50	Low
0 - 0.33	Lowest

Dimension	C	Criteria	Level	Level Weight		Criteria Weight	Score	
ECONOMIC	1	Cost	1-19 €	1.00				
			20-39 €	0.67	1			
			40 €	0.33		0.08	0.67	
	2	Operative Flexibility	Specific motor (complex kinematic)	0.50				
			Universal motor (simple kinematic)	1.00	1	0.08	1	
	3	Durability	Super Elastic NiTi wire (Conventional)	0.25	1			
			Electropolished SE NiTi instruments	0.50				
			M-wire	0.50				
			NiTi alloy in R-phase	0.50				
			T-wire Heat-treated NiTi alloy	0.75				
			C-wire Heat-treated NiTi alloy	0.75				
			Blue Heat-treated NiTi alloy	0.75				
			Gold Heat-treated NiTi alloy	0.75				
			Controlled memory (CM) alloy	0.75				
			Electrical discharge machining with CM alloy	1.00				
			MaxWire	1.00		0.11	0.25	
	4	Quality	Certificated	1.00	1			
			Non-Certificated	0.30		0.07	1	
ENVIRONMENTAL	5	Disposability	Single use	1.00				
			Reusable	0.67	1	0.04	0.67	
	6	Energy saving	Pre-sterilized	1.00				
			Non-sterile	0.90	1	0.1	0.9	
SOCIAL	7	Safety	C/E	1.00	1			
			Non-certificated	0.30		0.21	1	
	8	Ease of use	Easy (Single file instrument systems)	1.00				
			Medium (Double-triple file instrument systems)	0.67				
			Hard (Multiple file instrument systems)	0.33	1	0.1	0.33	
EXPERIENCE-BASED	9	Previous Performance	Highest	1.00				
			High	0.80				
			Medium	0.60	1			
			Low	0.40				
			Lowest	0.20		0.08	0.6	
	10	Trust for Brand	Highest	1.00	1			
			High	0.80				
			Medium	0.60		0.07	1	
			Low	0.40				
			Lowest	0.20				
	11	Customer Relationship Management	Highest	1.00	1			
			High	0.80				
			Medium	0.60				
			Low	0.40				
			Lowest	0.20		0.05	1	
		TOTAL SCORE					0.759	Highest

Fig. 5 The screenshot of the practical example of an original product

An assessment model for NiTi instruments was developed in this study. The proposed model should be only used to assess original NiTi instruments alternatives. Besides over 250 different types of original NiTi instrument alternatives, some counterfeit instruments are also available in market [56, 57]. In the literature, there are two reports available about the counterfeit NiTi instruments used for root canal shaping [56, 57]. The first comparison has been made between the ProTaper Universal (Dentsply-Sirona, Ballaigues, Switzerland) instruments and counterfeits [56]. The latter comparison has been made between the Reciproc Original (VDW, Munich, Germany) instruments and counterfeits [57]. Particularly, the evidence-based reports have recommended that "identification strategies for these counterfeit instruments should be developed for practitioners, thereby preventing their inadvertent use." [56, 57]. Overall, the original instruments outperform counterfeit instruments [56, 57]. Furthermore, the manufacturing conditions or metallurgical properties of a counterfeit NiTi instrument are unpredictable and unknown. In fact, counterfeit instruments represent the "pseudo character" of their corresponding original product. Thus, the proposed model cannot produce a desired real "total score" with pseudodata of any counterfeit instruments. As a consequence, the counterfeit instruments were considered as the "limitation of this study" by the authors.

It should be noted that the importance level of the proposed criteria could alter depending on panelists or dimensional modifications. The proposed criteria and criteria weights are able to be modified in further studies due to refinement or updating purposes [27]. In addition, the first proposed criteria for the NiTi instruments could be a reference to further studies in dentistry.

The outcomes of this study could have geographical limitations due to the distribution of the selected panelists, and therefore, the proposed NiTi assessment model in this study may not be applied universally. Hypothetically, this could be considered as a limitation of our study. Considering a re-evaluation of related literature updates or a broader selection of panelists could alter establishing criteria in the selection of these instrumentations. Furthermore, establishing a stringent interactive via the web-based or conventional questionnaire alternatives towards experts may aid to improve this NiTi instrument assessment model. Consequently, further studies are needed to improve the proposed NiTi assessment model and transforming it into a useful decision-making tool universally.

Within the limitations of the study, the following conclusions can be drawn:

The proposed assessment model for NiTi instruments could aid to make the decision-making process as systematic, transparent, and reproducible as possible not only for dental practitioners but also for healthcare professionals. Also, this proposed model can represent a reference framework for further MCDM studies which can rank or classify materials in medical science.

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Declarations

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