How Do ***MD***'s ***M***ake ***D***ecisions?

A thesis submitted to McGill University in partial fulfillment of the requirements of the degree of a

MASTERS OF SCIENCE

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Abstract (English)

Adverse medical events are one of the leading causes of death in developed countries, and have increasingly been attributed to cognitive errors of physicians rather than solely their skillset. A vast array of treatment algorithms have been developed, but the analysis of the medical decision-making process per se is still lacking. The objective of the current thesis research is to gain insight into *how* physicians arrive to their decisions in order to better understand the processes that could lead to cognitive errors.

Despite the increased awareness that appropriate decision-making processes are critical to avoid adverse events, there have been limited studies investigating or tracing cognitive processes due to the difficulty of evaluating and quantifying cognitive errors.

In this thesis project a novel computerized software (*MDcisions™*) was developed to trace the process of decision making by physicians exposed to a series of clinical scenarios, designed to expose information-acquisition patterns, information processing, decision rules, and heuristics. Specifically, the program records the sequence in which each subject selects, views, ranks, and assigns weights to information provided concerning the presented medical scenario, as well as the time taken to perform each described action.

Knowledge gained from this research will enable better understanding of the thinking pattern and the processes of decision making by different physicians. This new understanding might lead to interventions and education programs to decrease cognitive errors and biases, in order to target adverse events in medicine.

Abstract (French)

Les événements médicaux indésirables sont l'une des principales causes de décès dans les pays développés et sont de plus en plus attribués aux erreurs cognitives des médecins plutôt qu'à leur compétence. Une vaste gamme d'algorithmes de traitement a été développée, mais l'analyse du processus décisionnel médical en tant que tel est toujours manquante. L'objectif de la recherche de thèse actuelle est de comprendre comment les médecins arrivent à leurs décisions afin de mieux comprendre les processus qui pourraient conduire à des erreurs cognitives.

Malgré la prise de conscience accrue que les processus de prise de décision appropriés sont essentiels pour éviter les événements indésirables, il ya eu peu d'études d'investigation ou de traçage des processus cognitifs en raison de la difficulté d'évaluer et de quantifier les erreurs cognitives.

Dans ce projet de thèse, un nouveau logiciel informatisé (MDcisionsTM) a été développé pour retracer le processus décisionnel des médecins exposés à une série de scénarios cliniques conçus pour exposer les modes d'acquisition de l'information, le traitement de l'information, les règles de décision et les heuristiques. Plus précisément, le programme enregistre la séquence dans laquelle chaque sujet sélectionne, visualise, classe et attribue des pondérations aux informations fournies concernant le scénario médical présenté, ainsi que le temps nécessaire pour exécuter chaque action décrite.

Les connaissances acquises grâce à cette recherche permettront de mieux comprendre le mode de pensée et les processus de prise de décision par les différents médecins. Cette nouvelle compréhension pourrait conduire à des interventions et des programmes d'éducation visant à réduire les erreurs cognitives et les biais, afin de cibler les événements indésirables en médecine.

Chapter 1: Introduction/Background

Adverse events are defined as "unintended injuries or complications resulting in death, disability, or prolonged hospital stay that arise from health care management" (1) , and are one of the leading causes of mortality, that affect developed countries (2). In the United States, adverse events are responsible for approximately 251,000 deaths annually and have recently been recognized as the third leading cause of mortality (2). In Canada, 7.5% of patients admitted every year to hospitals suffer from an adverse event, leading to 24,000 deaths annually (1, 3). Other countries like Australia report adverse event rates as high as 16.6% (4-6). However, given that adverse events are self-reported and that medical errors are generally underreported, it is likely that the statistics underestimate the real impact of these procedural errors (5, 7, 8).

Adverse events are increasingly linked to cognitive errors, indicating a type of medical error involving a flawed decision making process, rather than a lack of knowledge (9). The ability of physicians to make appropriate decisions becomes even more critical in acute settings and is especially pertinent to surgical specialties, because nearly half of all adverse events in hospitalized patients occur in the operating room and half of those are attributable to the surgeon's decisions (3). In a survey, experienced surgeons viewed cognitive skills as a valuable and desirable quality to have in surgical trainees, even when compared to technical skills, and ranked one's decision-making ability as the most important character trait in surgery (10, 11). Some surgeons believe that a successful and skilfully performed operation is mostly attributable to successful decision-making processes, while only 25% is attributable to dexterity (12). Despite these investigations, tracing of cognitive processes have remained limited. The lack of insight into these critical errors may be because “cognitive errors are considerably less tangible than procedural errors [and are] unable to be witnessed or recorded and usually occur [subconsciously]” (13).

Traditionally, it is expected that physicians use a rational model of decision-making, which entails a careful examination of all possible alternatives including their risks and benefits. However, the complexity, urgency, and uncertainty of particular clinical situations at times compel doctors to use heuristics (cognitive shortcuts) to facilitate rapid decisions, thus bypassing some rational thought processes (14). Often, these cognitive shortcuts can lead the user to a quick and acceptable solution. However, when relied on too heavily or in the wrong circumstances, they *can* lead to cognitive errors and poor decisions (15, 16). One poor decision at the root of a thought process can have ill effects on all its consequential decisions.

Though studies have recorded biases and heuristics among health care professionals, (13, 16-19) they did not trace the decision-making process per se (20). Inspired by the ‘Decision Board’ in the field of diplomacy initiated by Prof. Alex Mintz (21-24), we developed a medical matrix (MDcisions™) to trace decision-making processes in health care. The current research aims to use this novel multi-method decision making analysis amongst physicians, combining elements of structural and process-tracing techniques to understand and evaluate how a physician makes a decision. Many medical algorithms are shaped in the form of decision trees to compare between options until a superior one is isolated. In contrast, we aim to look at the decision process, representing the roots of the decision tree, specifically the decision process in the mind of the physician.

Chapter 2: Literature review

2A. Decision-making in medicine

The term “decision analysis”, coined in 1964, by Stanford professor Howard, came to define the process by which we study decision-making in all aspects of life (25). Despite the exponential growth in the field of decision making in business, it has not been adequately explored in the medical literature. There have been medical catalogues describing cognitive heuristics and errors, (13, 16-19), but to date, we are not aware of studies examining the decision-making process as proposed in this thesis.

Improving decision-making is becoming increasingly important in medicine and there has been a growing awareness that ‘errors in thinking’ often result in adverse events leading to interest in this field (20). Research that focused on analyzing the past three decades of articles examining biases and heuristics in medical decision-making have concluded that biases and heuristics have been under-investigated with regards to medical personnel compared with patients (20). Heuristics (cognitive shortcuts) have been quoted as the most prominent theory of how perception influences decision-making (26). The use of heuristics and the emphasis on an approach that is mainly based on experience may not align well with evidence-based practices in the medical field.

Research in internal medicine found that medical errors, mainly diagnostic errors linked to flawed clinical reasoning, pose an important healthcare burden and a challenge for physicians and policy makers worldwide (27). There have been analytic reviews studying cases where diagnosis were wrong or missing due to faulty cognitive processes. “Physicians in general underappreciate the likelihood that their diagnoses are wrong and that this tendency to overconfidence is related to both intrinsic and systemically reinforced factors" (28). There have also been studies using standardized tests for diagnostic errors. One method of testing diagnostic accuracy is to control for variations in case presentation by using standardized cases that can enable comparisons of performance across physicians. One such approach is to incorporate what are termed *standardized patients* (SPs). Usually, SPs are lay individuals trained to portray a specific case or are individuals with certain clinical conditions trained to be study subjects (29, 30). Diagnostic errors have been detected in a significant proportion of physicians when tested with SPs or standardized case scenarios (29, 31). Studies using standardized cases have found that not only is there variation between providers who analyze the same case (32, 33) but that physicians can even disagree with themselves when presented again with a case they have previously diagnosed (34).

Much of the research in medicine with regards to decision making utilizes and discusses evidence-based medicine practices, assuming doctors make rational decisions based on the available data in the literature. However, medical decision-making for patients often does not fit the guideline template and requires individualized patient care, which makes it particularly prone to error due to the complexity, urgency, and uncertainty of any given situation (35). Heuristics (cognitive shortcuts) have been quoted as the most prominent theory of how perception influences decision-making (26). The use of heuristics and the emphasis on an approach that is mainly based on experience may not align well with evidence-based practices in the medical field.

Medical education theory recently described means for minimizing and avoiding diagnostic error via cognitive strategies (36), entitled metacognition (awareness and understanding of one's own thought process). Clinicians can develop cognitive strategies to minimize latent errors in diagnosis. This metacognitive approach can be taught to practicing clinicians and to those in training in order to avoid adverse outcomes associated with delayed or missed diagnoses and with the clinical management of specific cases (36).

In the medical decision-making literature, there have been studies on the correlation between stress and decision-making (37, 38), shared decision-making between patient and physician (39, 40), and decision-making with the intent of improving clinical outcome (41, 42). Others have created crisis simulations to evaluate the physician's performance and leadership under realistic scenarios (43-45). Descriptive survey-based studies in medicine, addressing what physicians believe to be important in a trainee, highlighted decision-making as a trait required for competency as a physician, where cognitive skills are as important (if not more important) than technical skills (10, 46, 47). In experiments to assess decision-making tools for surgeries, Sarker and colleagues recorded real-time laparoscopic operations and evaluated the choices made by surgeons and then compared these choices to standardized guidelines and expert opinion through hierarchical task analysis (47-50). Studies have also evaluated the importance of simulation for training which yielded positive results (51, 52).

There is a lack of evidence to support routine application of strategies to increase the awareness of non-rational decision factors (13, 18, 53). Nevertheless, without self-awareness of how humans make decisions, modifying decision behavior is likely to be difficult. Strategies for improving such self-awareness might begin with educating physicians with respect to the diversity of decision factors currently used in medicine. Explicit teaching about mechanisms of cognition and the consequences of common cognitive errors could then be prioritized from the beginning of medical school as a preventive tool. Long-term strategies to rapidly recognize and recover from these errors could likewise be taught in medical school, throughout residency, and in continuing medical education (13, 18, 53). Evidence to support unequivocally the routine application of decision-making strategies has been developed in other fields, such as diplomacy.

2b. The Psychology behind the Decision matrix

The "Decision Board" is a computerized platform that allows analysis of sophisticated sequential and interactive decision problems (54). Its capability to trace and record the actual path of the decision-making process for multiple scenarios, mimicking real-life constraints. An example of the Decision Board is demonstrated as part of the online simulation and can be accessed at car simulation on mdcisions.com. A Decision Board is comprised of the following 5 components (21) and we will use the decision to purchase a car as an example:

1) **Alternatives:** Choices available to the decision maker in this scenario (e.g. different types of cars like coupes, sedans)
2) **Dimensions:** criteria that the decision maker takes into account when evaluating the alternatives (e.g. cost, family demographics, style, and safety)
3) **Implications:** consequences of an alternative choice for a given dimension. In our example sedan (the alternative) are less stylish (the dimension) than coupes.
4) **Ratings:** assigning a value (on scale of 0-10) of the information provided to them (e.g. subjective attractiveness of the implication). In our example the recently married

person may rate a minivan highest because he plans starting a family with a rating of 10 as opposed to style that would be subjectively less important therefore less attractive)

5) **Weights:** level of relative importance (rated on a scale of 0-10) for each dimension. In our example, if style is not important to the decision maker, they would weigh it least relative to other dimensions such as cost, safety, and family friendliness).

Studies of this nature utilizing a Decision Board have been successfully implemented in the fields of diplomacy, politics, military decisions, and psychology (21-23, 55-58). It is well known that people perceive the same information in different ways, which in turn, influence how information is processed and decisions are made (54). A review of the literature for decision-making analysis has found that the decision-making process could be characterized and understood as influenced by the following factors: search patterns, decision rules, cognitive shortcuts (heuristics) and biases (54).

I. **A search pattern** describes the way information is gathered and processed by the individual (21). In real-life scenarios, search patterns could be expected to differ based on many factors including, such as the decision maker's experience. There are several search patterns described in the literature relevant to this thesis and these search patterns are not mutually exclusive.

Holistic vs Non-holistic:

- **Holistic**: A comprehensive search where the person analyzes the risks and benefits of each alternative (choice) for a decision to be made. This can be exhaustive and time consuming. (59)

- **Non-holistic:** A less comprehensive search where the person looks only at certain information in order to find a satisfactory solution. These searches are often a result of cognitive shortcuts because not all available information is evaluated. There is a tendency for individuals to search for evidence that supports their preconceptions. (59)

Alternative vs Dimension-based:

- **Alternative-based:** evaluating the implications of each choice (alternative) e.g. examining all the information about Sedan followed by all the information of coupe when making a decision (11).
- **Dimension-based:** evaluating the implications of each criteria (dimension) e.g. comparing cost of the various cars (11).

Poliheuristic based: In diplomacy, the Decision Board is based on the Poliheuristic (PH) choice theory developed in 1993, which uses a two-stage decision process (22, 58).

- **1st stage (cognitive):** the decision maker utilizes cognitive shortcuts to narrow down a number of alternatives, thus limiting the set of choices. (22)
- **2nd stage (rational):** Following the first stage, the decision maker closely evaluates the remaining choices in a holistic, alternative based manner. (22)

II. Decision rules:

Search patterns can enable us to determine the decision rules that the decision maker utilizes to narrow the alternatives to their final decision. Decision rules are a set of models that describe how a decision maker reaches a decision (65 – 67). They include the following:

Non-compensatory decision rules: the unattractive implications are ignored, the decision is based on the most important reason(s), and no trade-offs are made. (60)

Dominance rule: Alternative A is selected given that it is more attractive than Alternative B in terms of at least one dimension but not less attractive on any other dimensions (i.e. better in at least one dimension, and better or at least equal in other dimensions). Dominance is sometimes due to the decision maker's subjectivity.

Conjunctive: Exclude alternatives if they do not meet the minimum requirement for a particular dimension. (21)

Disjunctive: Choosing alternatives if at least one or more implications are so attractive that that alternative is chosen for that reason. (21)

Lexicographic: Assigning relative weights to all dimensions (criteria) and then ranking available alternatives in the order of weights assigned to each dimension. (21)

Elimination by aspect: Similar as lexicographic (start by weighing dimensions) but eliminate the alternative, if the alternative does not meet a minimum requirement for highest ranked dimension, then second and so on until a final alternative is chosen (61).

Compensatory rules: A dimension with a lower weight can be compensated by more favourable ratings with respect to another dimension. This requires the participant to be rational with regards to ratings and weights assigned, and different ratings of implications are integrated to a total attractiveness measure. (60) The participant calculates the added utilities to choose the superior alternative. It is part of the rational school of thought and is associated with the second stage of the Poliheuristic theory.

Maximizing number of dimensions with greater attractiveness: After assigning weights to the dimensions, the participant chooses the alternative with the greater number of higher weighted dimensions. (62)

Addition of utilities: After assigning weights to the dimensions, the participant chooses the alternative with the greatest sum of dimensions based on weights (21).

III. Heuristics

Heuristics are fast, frugal, intuitive and implicitly proceeded cognitive shortcuts that enable people to quickly address problems and make decisions(63). Analysis of utilized decision rules enables the analyzer to uncover the heuristics the person used to reach their final decision. When heuristics are used in the wrong circumstances, they can lead to cognitive errors, biases and poor judgments (20, 64, 65)

The use of heuristics often dominates problem solving when innovative, creative thinking is required. Under conditions of uncertainty, we default to an even greater reliance on the heuristic processing (66, 67). The heuristic approach makes decisions based on routine thinking. Since choice heuristics are quickly constructed from fragments of memory, they are often biased by previous experiences. While this is quicker than step-by-step processing, heuristic decision-making opens the risk of inaccuracy. In health care settings, mistakes, that otherwise would have been avoided in step-by-step processing, could lead to serious complications (68-72).

The following are some examples of heuristics that can occur in the medical field:

Take the best heuristic: choosing the alternative based on a single criterion alone (11).

Confirmation bias: the tendency for an individual to unconsciously search for or interpret information in such a way that it confirms their understanding of the situation (i.e. only valuing information that suits you, “cherry picking”). Here, attention is paid to data that supports the presumed alternative and ignores data that contradicts it. For example, it has been shown that once an experienced specialist makes a diagnosis, whether right or wrong, he/she often selectively looks for new information that fits their judgment. (11)

Availability heuristic: a mental shortcut that people utilize to make judgments about the probability of events based on experience or memory (e.g. avoiding to perform procedure A based on complication with a previous experience with procedure A) (16).

Anchoring and adjustment heuristic: Using an initial piece of information to make subsequent judgments. Once an anchor is set, other judgments are made by adjusting away from that anchor, and there is a bias toward interpreting other information around the anchor. For example, if a surgeon is more comfortable suturing a bleeding vessel than using new hemostasis agents, they may directly opt to suture (even if not indicated), or at least subjectively process new information to validate this decision. This heuristic shows that people tend to stick to and build from their original idea or belief, as opposed to questioning it (64).

IV. Biases:

Humans see the world through various lenses that cause degrees of misperception and defective decision processes that are collectively known as biases. These biases may cause performance to stray from the optimum. (21) Like other healthcare providers, physicians may have conscious or unconscious biases that can affect the provision of care. Understanding and being aware of potential biases can help doctors to improve the care provided to patients, reduce adverse events and reduce the medico-legal risks in their practices. (64)

Cognitive biases are tendencies commonly used to acquire and process information by filtering it through one’s own beliefs and experiences. They are flaws in judgment often resulting from heuristics. Although heuristics are indeed helpful in problem solving, under conditions of complexity and uncertainty, they are known to produce systematic errors in judgment. Numerous cognitive biases have been identified and shown to be relevant in many health care settings (64, 65, 73):

Hindsight bias: type of overconfidence bias where there is an inclination, after the event has occurred, to see the event as having been predictable, despite there having been little or no objective basis for it. Ultimately, hindsight bias matters because it gets in the way of learning from our experiences. This is usually the case in morbidity and mortality rounds. (74)

Commission/omission bias: people believe that doing nothing (omission) is worse than doing something (commission). It is the tendency toward action rather than inaction. E.g. giving chemotherapy to a terminally ill patient with virtually no chance of survival; while the chemotherapy may induce more morbidity, it may be perceived as a better alternative than not doing anything for the patient. It is more likely to occur in someone who is overconfident, and reflects an urge to 'do something.' It satisfies the obligation of beneficence in that harm can only be prevented by actively intervening. (16) However, it is more likely to violate the obligation of non-maleficence (refraining from an action that exposes the patient to unnecessary risk or harm), as well as the opening caveat of the Hippocratic oath ''Primum non nocere.''. Commission bias may be augmented by team pressures or by the patient. It may underlie ascertainment bias, which tends to result in physicians ''doing something'', committing to an action when the clinical practice guidelines promote inaction as the best course. (16)

Overconfidence bias: The subjective confidence in the decision maker's own judgments that is reliably greater than the objective accuracy of those judgments. E.g. if a surgeon is overconfident, they may not call for assistance when it is warranted.

Poliheuristic bias: will avoid alternatives that are likely to be out of their mundane comfort level or preference in the first stage of the decision. This may lead to suboptimal decisions. (21)

For example, if an obstetrician dislikes cesarean sections and therefore does not practice it often, he/she may simply not considerate in a decision making process(21).

Confirmation bias. With this, you interpret information in a way that confirms your preconceptions – instead of seeing it objectively – and you make wrong decisions as a result. The most likely reason for the excessive influence of confirmatory information is that it is easier to deal with cognitively 'distorted pattern recognition'. This may happen if you place too much faith in your own knowledge and opinions(21).

Premature closure/ alternative momentum: occurs when one of these diagnoses is accepted before it has been fully verified, can result from setting an anchor. (16) Once a specialist has fixed a label to the problem, it usually stays firmly attached, because the specialist is usually right. (11)

Cognitive Inertia: Put simply, the unwillingness to change a thought pattern in light of new circumstances(21).

Optimism Bias: A tendency to be optimistic about the procedure/outcome, rather than logically assessing the facts. An example would be a physician proceeding with a surgery when faced with major complications on the bases that 'it will most likely improve' rather than thinking about the fact that it may get worse(21).

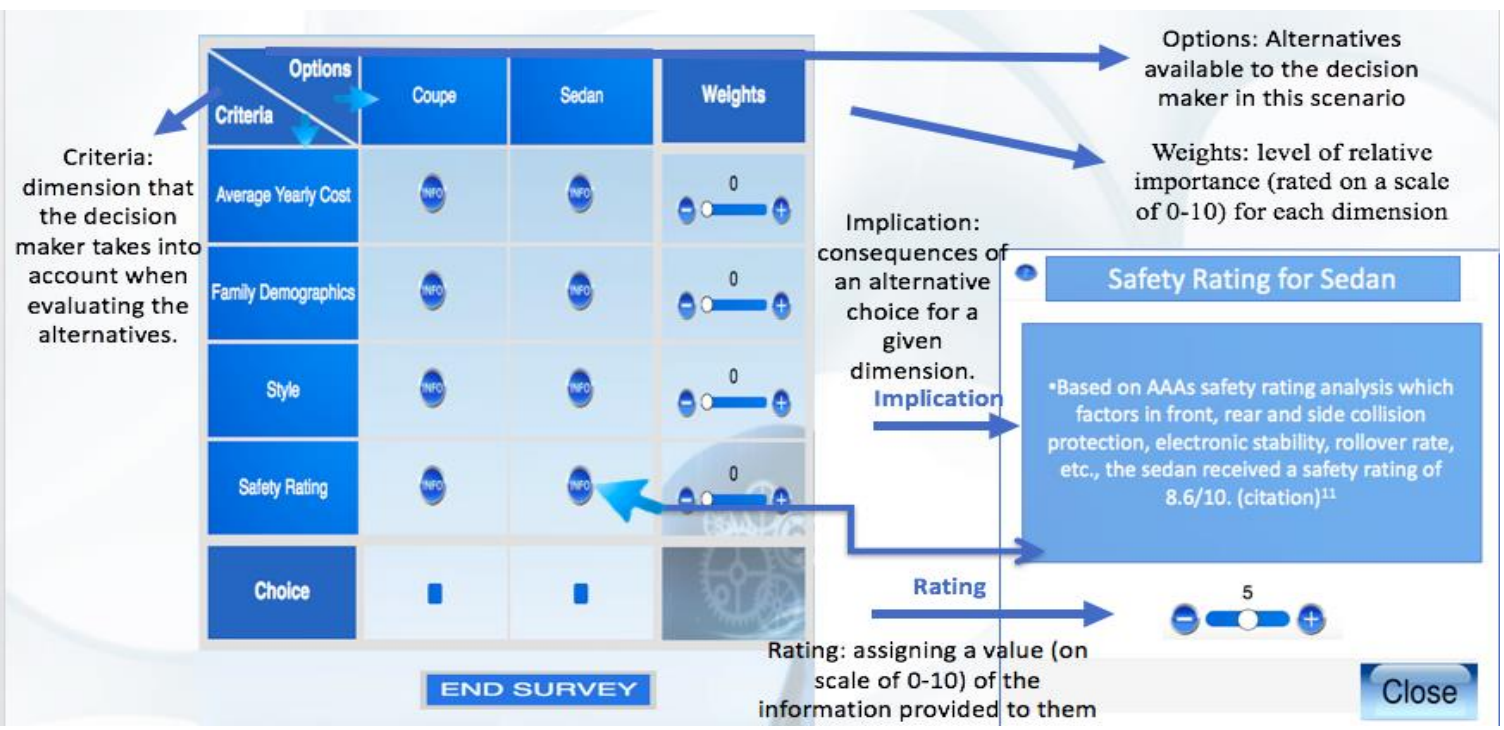
Chapter 3: Methodology

Medical decision

A decision results from a sequential process in which different decision rules and information processing strategies are used, until a final choice is made. To analyze the decision process of health care professionals, we developed a specialized web based computer software, based on the original 'Decision Board' developed by Professor Alex Mintz (21). Using clinical scenarios mimicking real life constraints, this matrix can perform an in depth analysis of the process of health care decision-making and expose cognitive mistakes. A better understanding of the errors in the decision pathway will lead to increased awareness of the heuristics and biases occurring in medical decisions, and ultimately offer possible interventions to reduce cognitive errors and decrease the number of medical adverse events. (75, 76)

We presented to clinicians a scenario that mimics real life situations. Cases were neutral in nature so there was no right or wrong answer. In our medical decision scenario, the decision process was traced, highlighting the way in which physicians seek and evaluate information on the path of reaching a final choice. The thesis objective is to understand the manner in which physicians' process data to help make their decision.

The clinical scenario was presented as a decision matrix made up of the following 5 components: alternatives, dimensions, weights, implications, and ratings (see paragraph 2b the psychology of decision making, page 9).



Pathway tracing

In our studies, the participant physician is the protagonist in the clinical scenario where he/she is choosing information to make his/her final choice.

Scenarios

Two hypothetical scenarios were presented to each subject (mdcisions.com). The scenarios and matrices were carefully created based on three rounds of a modified Delphi approach (77).

The first scenario (which will be referred to as the non-crisis scenario) assessed how physicians would acquire information and make decisions on the extent of the removal of lymph nodes (lymph node dissection) needed in early stage endometrial cancer. The second scenario (further referred to as the crisis scenario) evaluated how subjects would attempt to treat a bleeding vessel and create hemostasis following an iatrogenic vascular injury during a minimally invasive procedure for endometrial cancer. An information board (called MDcisions™) displayed a decision matrix consisting of criteria, alternatives, and implications based on relevant peer reviewed literature, to assist subjects in making the decision. Subjects were offered to access the implications, rate them, and assign importance to the dimensions.

Through computerized process tracing, the MDcisions software enabled us to track information acquisition physicians and compare the results in function of demographic criteria such as sex and medical training level (21-24) (mdcisions.com)

The MDcisions™ software traced and recorded the decision path for each participant. The program records the sequence in which each subject selects, views, ranks, and weighs items/information on the decision-matrix as well as the time taken to perform each described action. The program also records the time taken to complete the simulation and the final alternative chosen by each participant. Furthermore, the program enables the researcher to do the following:

1) Holistic vs. Non-Holistic search patterns: during the Delphi approach, a sensitivity analysis was performed and based on the results the authors agreed that when participants viewed more than 70% of the implications (peer reviewed information), it would be considered holistic.

2) The use of heuristics: defined when a participant ignored at least one full dimension or one alternative completely, when assessing the information in the decision-matrix.

3) Alternative vs. Dimensional information acquisition patterns: traces the path of implications (peer reviewed information) accessed. An alternative move is a move within the same alternative (across dimensions) whereas a dimensional move is a move within the same dimension (across alternatives). Based on the works of Billings et al (29), the search pattern variable was defined as the number of alternative moves minus the number of dimensional moves divided by the sum of these two numbers. This index was calculated separately for each matrix and was treated either as a continuous measure or dichotomized into alternative (negative values from -1 to 0) and dimensional (positive values from 0 to 1). This measure has been used in numerous studies (16-20). It was calculated separately for each scenario and was coded as alternative-based (negative values on the search pattern, from -1 to 0) or dimension-based strategy (positive values, greater than 0 to 1)(78).

4) Utility function: a function evaluating the relative importance (weights) assigned to dimensions as well as the average ranking assigned to alternatives.

Simulation

Subjects were invited to first access the simulation website at www.mdcisions.com (available online for review) and to watch a 2-minute instructional video explaining how to navigate the decision matrix. Following this demonstration, participants accessed the first of two scenarios (non-crisis clinical scenario) followed by its associated decision matrix. Subsequently, participants accessed the second scenario (crisis) and accessed the corresponding matrix. Participants were welcome to open as many cells of information (implications) as they wished prior to making a final choice. Despite no time limit enforced, participants were told at the onset of the simulation that as with "all real-life decisions, there is a trade-off between the amount of information you consider and the time it takes to make a decision based on that information."

Study Design

We designed our study as a 2 x 2 quasi experiment factorial. The first factor (within subject) was the crisis level depicted in the scenario (non-crisis vs. crisis). The second factor and the focus of this investigation was the gender of the physician (female vs. male). Our dependent measures consisted of processing parameters of the decisions: (a) time to decision (assessed as time to simulation completion in minutes); (b) extent of information acquisition prior to making the decision (holistic vs non-holistic) (c) method of information acquisition (dimension versus alternative based); (d) the importance of procedure-cost on final decision (utility) and (e) the final choice made. Student t-test was utilized and statistical significance was determined as p

<0.05. The average proportion of information used by female and male physicians during their decision-making process was compared. A 2 x 2 mixed ANOVA procedure was employed to explore the gender effects in the two scenarios

The software was designed with the capability of tracing the path taken by each participant prior to reaching a final decision. More specifically, the sequence in which each subject accessed, ranked, and weighted information on the decision matrix, the total time taken to make the decisions and the final alternative selected, were recorded.

Data is presented as mean (standard deviation) or n (%) where applicable. The Wilcoxon rank-sum test was used for continuous variables and Fisher's exact test was used for categorical variables. Two principal analyses were done to assess and compare the measured outcomes. First outcomes were compared by level of training (resident/fellow/attending) and then were analyzed by gender (male/female). Sub-analyses were further stratified by scenario (crisis/non-crisis). Participants who completed only one out of two scenarios were not included in the time analysis given that this would underestimate the time to complete the scenarios. However, each completed scenario was analyzed for outcomes regardless if the other scenario was not completed.

All statistical tests were two-sided, and a p-value < 0.05 was considered to indicate statistical significance. All analyses were made with the use of STATA statistical software, version 14.0 (StataCorp).

Chapter 4 Results

4A. In function of expertise:

There were 84 individuals who participated in the medical simulation during January 2015-June 2016 with the participant demographics shown in Table 1.

<u>Table 1: participant demographics</u>

		Trainees (Residents) n=47	**Experts** (Staff) n=37	**N=84**
Age	mean ± SD	31 (5)	46 (10)	37 (11)
Gender	Female	23	19	42
	Male	24	18	42

a) Time to decision

There was no difference detected in the total time it took to complete both scenarios between experts and trainees (8.7 minutes vs. 8.3 minutes, $p=0.72$).

b) Extent of information acquisition

A holistic approach (evaluation of more than 70% of the implications) was used by a similar number of participants for both the non-crisis scenario (35%) and the crisis scenario (32%). In both scenarios, a trend was observed that staff physicians were more holistic in their approach, in the non-crisis (49% vs. 28%, $p = 0.07$) and crisis (39% vs. 27%, $p = 0.3$) (table 2).

c) Method of information acquisition

Although not statistically significant, a trend is observed indicating that experts utilized fewer heuristics in both scenarios (table 2). Information acquisition patterns varied but were not significantly different in neither non-crisis nor crisis.

Table 2. Methods of information acquisition

	Non-Crisis			Crisis		
	Trainees	Experts	P	Trainees	Experts	P
Extent of information acquisition Holistic	28%	49%	0.07	27%	39%	0.30
Heuristic	63%	54%	0.50	70%	58%	0.30
Information-Acquisition Pattern Alternative Dimension	 23% 77%	 26% 74%	1	 19% 81%	 33% 67%	0.30

d) Importance of procedure-related costs on final decision

In both scenarios, participants spent the least amount of time and assigned the lowest ratings and weights to cost (table 3), with utility of cost contributing to less than 8% of the total information considered as important.

<u>Table 3. Utility assigned to dimensions</u>

	Dimension	Mean rating	Mean time to rate criterion (s)	Mean weight	Mean utility *
Non-Crisis	Ability to decide on Adjuvant Therapy	5.9	24.6	7.4	4.3
	Procedural morbidity	5.4	16.3	6.4	3.5
	Cost	**3.3**	**10.2**	**2.7**	**0.9**
	Survival	5.6	14.3	7.8	4.4
Crisis	hemostasis	5.9	12.4	8.8	5.3
	complications	5.0	10.8	7.0	3.5
	Cost	**3.7**	**6.9**	**2.0**	**0.7**

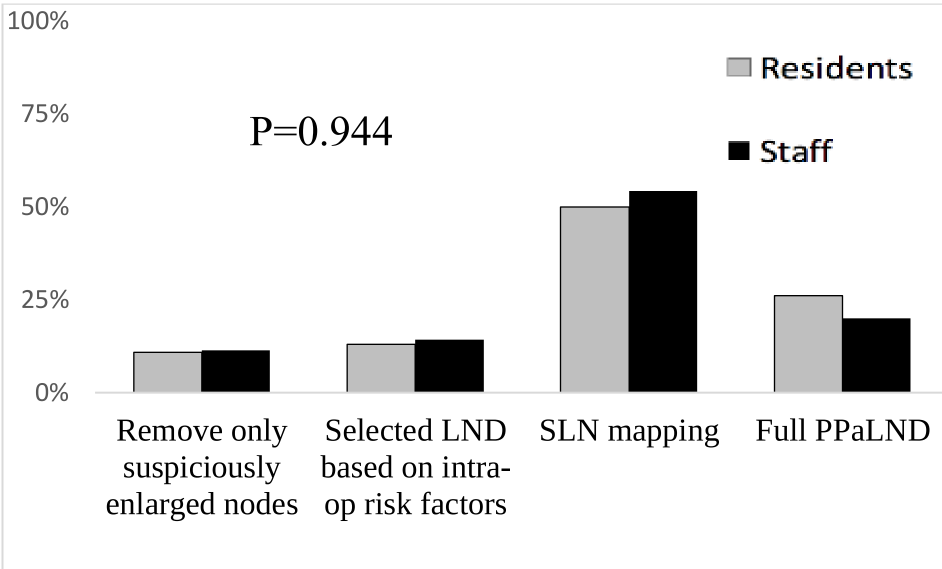
e) Final decision chosen

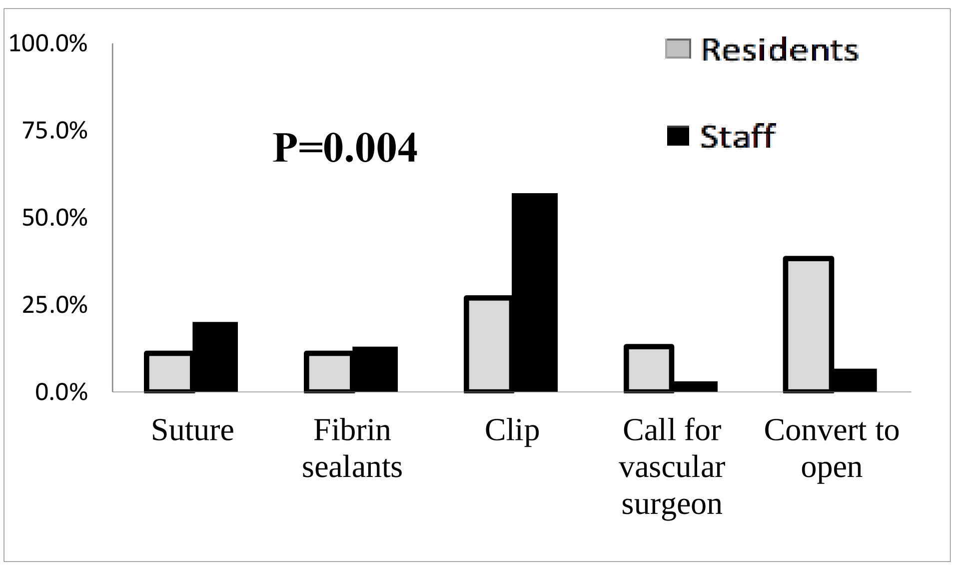
The final alternative chosen is shown in figure 1. In the non-crisis scenario, the distribution of final alternatives chosen did not differ based on level of training (p=0.944). In the crisis scenario, there was a statistically significant difference (p=0.004) in final alternative chosen based on level of medical training. Here, trainees were most likely to convert to open surgery compared to experts who were more likely to place a clip to control hemostasis (38% vs. 7% for conversion and 27% vs. 57% for clip placement).

Figure 1

a. Extent of lymph node dissection (non-crisis)

b. How to control vascular bleed (crisis)





4b. In function of gender

The same participant population was utilized (see table 4)

a) *Time to decision*

Male doctors took less time to perform the decision-making process than female doctors (8.35 vs. 11.03 minutes respectively, t (1,82) =2.72, p<0.006).

b) *Extent of information acquisition*

Overall, more information was accessed in the non-crisis scenario (42% vs. 33%, [F (1,74) =5.25 p<.001]). In both crisis and non-crisis, female physicians accessed information in a more holistic (46%) approach compared to males (28%), [F (1,74) =5.52 p<0.03].

Table 4. Proportion of information rated by male and female physicians

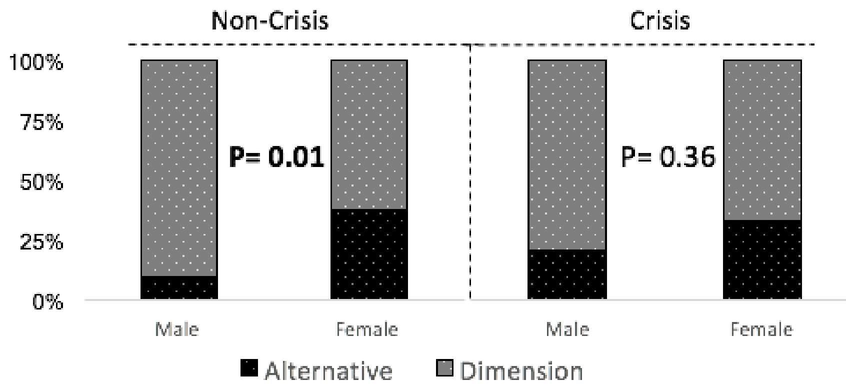
	Male doctors	Female doctors	All subjects
Non-Crisis Scenario	31%	52%	42%
Crisis Scenario	25%	41%	33%
	28% (N=39) *	46% (N=37) *	

*Participants were excluded (0 males and 1 female in the non-crisis scenario; 3-males and 4 females in the crisis scenario) since they did not complete the scenario.

c) *Method of information acquisition*

Significantly more females utilized the alternative-based information acquisition process (36% of females vs. 10% of males, p=0.01) in the non-crisis scenario. A similar trend was observed in the crisis scenario (33% of females vs. 21% of males, p=0.36).

Figure 2. **<u>Alternative versus dimension-based information processing by male and female physicians</u>**



d) *Importance of procedure-related costs in decision-making*

Female physicians assigned a lower importance to the cost of the medical procedure in determining their final decision in the non-crisis scenario (average weight of 2.1 among females vs. 3.2 among males, p=0.038). However, in the crisis scenario, there was no statistically significant difference between genders (1.9 among males vs. 2.2 among females, p=0.634).

Overall, compared with other dimensions, cost was not an important consideration. Among all participants, subjects rated cost significantly less than the average of non-cost dimensions both in the non-crisis scenario (average weight of 2.7 assigned to cost vs. average of 7.1 to non-cost dimensions, p<0.0001) and the crisis scenario (2.0 vs. 8.0, respectively, p<0.0001).

Table 5. Weight associated to cost versus other dimensions.

		M	F	T-test*
Non-crisis	cost	3.2	2.1	T(69)=2.1 p=0.038
	other dimensions	7.2	7.04	T(73)=0.4 p=0.703
Crisis	cost	1.9	2.2	T(65)=0.5 p=0.634
	other dimensions	7.6	8.3	T(67)=1.7 p=0.098

* Significance tests between male and female physicians for average weights assigned to cost as well as average of all non-cost variables for both non-crisis and crisis scenarios

e) Final decision

There were no differences in the non-crisis scenario in the selected final procedure by female and male doctors (Table 3A, p=0.7), however, female and male doctors tended to select different procedures in the crisis scenario (p=0.07), with more than half of female doctors choosing clipping (alternative C) compared to less than a quarter of male doctors (Table 3B). Male physicians more frequently converted to open procedure (alternative E).

Table 6A: Alternative chosen in the non-crisis scenario (lymph node dissection)

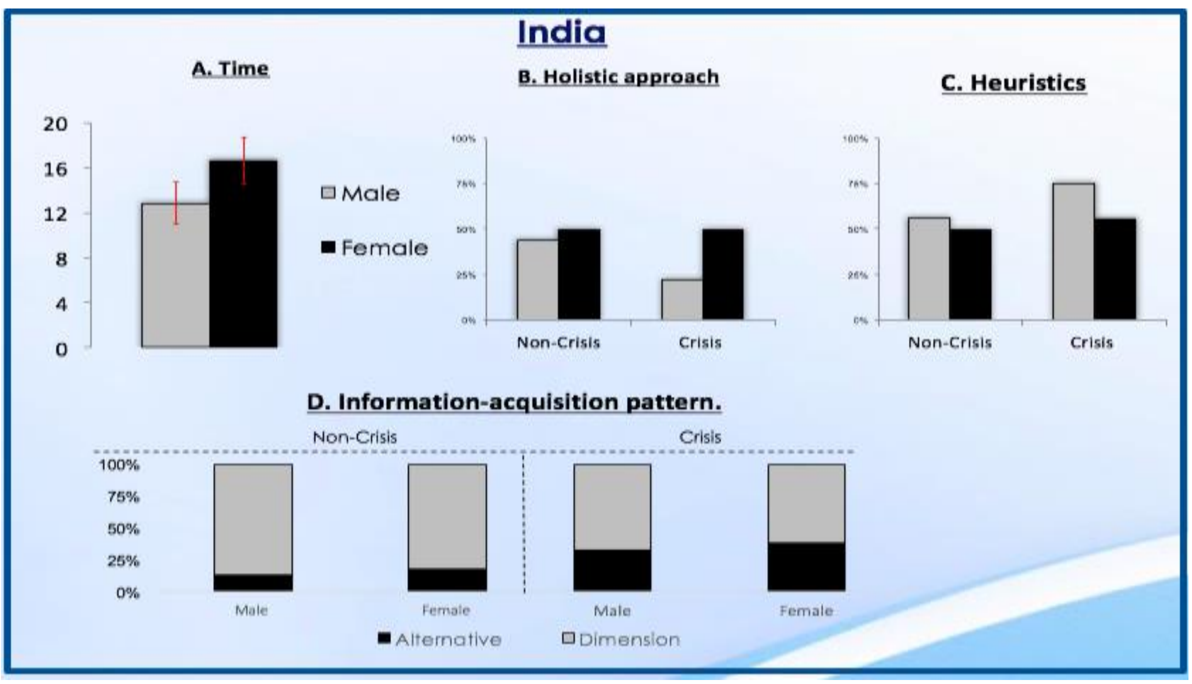
	A Remove only suspiciously enlarged nodes	**B** Selective Lymph node dissection based on intra-operative risk factors	**C** Selective lymph node mapping	**D** Full pelvic and periaortic lymph node dissection	total
Male Doctors	4 (10%)	6 (14%)	23 (55%)	9 (21%)	**42**
Female doctors	5 (13%)	5 (13%)	19 (49%)	10 (25%)	**39**
	9	**11**	**42**	**19**	**81**

Table 6B: Alternative chosen in the crisis scenario.

	A Suture	**B** Fibrin sealants	**C** Clip	**D** Call for vascular surgery	**E** Conversion to open	
Male Doctors	7 (18%)	6 (15%)	9 (23%)	4 (10%)	13 **(33%)**	**39**
Female doctors	4 (11%)	3 (8%)	20 **(56%)**	3 (8%)	6 (17%)	**36**
	11	**9**	**29**	**7**	**19**	**75**

4c. International Cohort

In a smaller cohort (12 female and 9 male physicians) in India, we identified similar trends for each of the outcomes of interest, but these did not reach statistical significance in view of the lower number of participants. Similar to their Canadian colleagues, male physicians in India averaged 12.8 minutes vs. 16.6 minutes for female physicians. In both scenarios we observed a trend that females considered more information and utilized less heuristics. With respect to information-acquisition patterns, a trend was observed that female physicians in India used a more alternative based process approach than male counterparts. Similarly, to the Canadian cohort female doctors in the Indian sample chose more frequently to use clips and male doctors to convert to open surgery.



Chapter 5: Discussion

We present a computerized decision making software (*MDcisions*™) to trace the processes of how physicians make medical decisions, by examining their processing patterns and information-acquisition. Differences appeared in the decision-making processes with respect to level of medical training and gender during non-crisis and crisis situations.

5a: differences by level of training

A significant difference was demonstrated in the final choice on how to control vascular injury (crisis) in function of medical training. The use of clips increased with experience, whereas the conversion to open surgery (considered less technically challenging) decreased alongside the option of calling for help from a vascular expert. Studies in aviation have similarly found that when faced with tougher flight standards, more time constraints, or uncertainty (i.e. similar to crisis scenario), expert pilots were least likely to abandon the planned flight, similar to staff physicians who were least likely to abandon the minimally invasive surgery approach and convert to open surgery. (79).

There was no difference in time to complete the module in function of medical training/level of expertise. Analysis of the matrix indicated that there was a trend towards staff (experts) being more holistic and using less heuristics in both scenarios denoting that staff examined more information. Some psychology studies have described this trend, indicating that experts "generally have highly developed perceptual/attentional abilities" and "are able to extract information that non-experts either overlook or are unable to see" (80). Similar results were found in other fields of research like accounting, in which experts used more complex decision making processes (81).

Further analysis of the crisis scenario revealed a different trend in the information-acquisition pattern in function of medical training. A trend was observed that experts used a more alternative information-acquisition pattern than trainees. An alternative-based information acquisition pattern is associated with a more analytical process, and experts in-fact were observed to be more analytical when it came to the crisis at hand. Similarly in a military study where a scenario was less mundane for soldiers, they employed a more alternative based processes (24).

Our study had several limitations. First, there were many trends were observed that did not reach statistical significance but may have been underpowered due to the smaller sample size. As well, while the current study takes place in a Canadian context, place of training may affect how participants approached some of the medical scenarios, and although recorded this was too diverse to analyze. All participants worked in academic centers, so our data may not be generalized to community settings. Furthermore, Participants were classified as residents or attending staff regardless of years of experience. Biases and more complex decision-making aspects were not presented in the current study, but will be integrated in future studies. To the best of our knowledge, this study presents the largest physician population evaluated through an interactive matrix with capacities of tracing information-acquisition-patterns and decision making processes (20).

5b: **Gender Discussion**

Historically, medicine has been a male-dominated specialty with only 7% of total physician-composition being women in Canada and the United States in 1960 (82, 83). However, the demographics of physicians are rapidly shifting in North America, with an exponential growth of female enrolment into medical schools, currently reaching as high as 60% (82-84). With a change in physician composition, studies have shown disparities in clinical interactions between the patient and the physician that were attributable to the gender of either party (59, 85-87), but research on the decision-making pathway and the way physicians make decisions has been ponderously slow to enter medicine. Given the shift in the gender makeup of physicians over the years, we sought to explore the role of gender on clinical decision-making processes. Utilizing actual decision makers, (i.e, male and female doctors), MDcisions™ traced the decision making path leading to several significant outcomes in terms of information processing, indicating that male physicians examined less information and performed more cognitive shortcuts, while their female counterparts tended to be more comprehensive in searching for information, used more time, and used more alternative based processing, which is typically more meticulous compared to dimension-based searches (24)

This analysis does have some limitations. First, our sample consists only of Canadian physicians. This study also examined a clinical scenario in the field of gynecology which does not necessarily represent other medical fields. As well, to cross validate our findings, we evaluated a second, albeit smaller cohort of physicians from India. Similar trends for the key outcomes measured were observed in both cohorts, supporting the finding that the differences in the decision making process by gender are not restricted to Canada and were similar in India.

Furthermore, our findings in medical decision making are similar to online consumer shopping studies, in which females have been found to comprehensively acquire more information and take longer to shop "whereas males appeared to heuristically [cognitive shortcut] limit their search" (88, 89). In marketing, a "Selectivity Model" was developed, demonstrating that males do not process all available information to the extent of females, but rather use more cognitive shortcuts (90, 91). In the medical field, female physicians were seen to spend significantly more time with their patients (59, 85-87), and suggested an association between gender and clinical outcomes (92). The shift in gender amongst physicians affects the clinical decision making process. Further understanding of these differences should impact and will allow to refine medical education, and ultimately improve clinical care.

Chapter 6: Conclusion

Although heuristics can lead to cognitive errors and biases, these shortcuts more often than not result in quick and effective decisions. Despite extensive literature on cognitive errors, they appear inevitable in general (93), and have been 'ponderously slow to enter medicine' (13). This can be explained by the difficulty to evaluate cognitive errors in health care and the importance of trust in the special relationship between the doctor and the patient, in which confidence is often confused with competence. In this context there is a lack of perception for the need to change.

Despite the overall attitude that cognitive errors are an inevitable human process, the outcomes of medical errors are not inconsequential and are more pervasive than previously thought (2). In a study published in 2016, Markary and Daniel highlight that medical errors are the third leading cause of death in the United States. Given the much larger than anticipated role of medical errors on patient outcomes highlighted in this study, there is an urgent need to evaluate medical decision making and investigate how to transform current approaches..

(94). In this thesis, we evaluated a healthcare oriented decision-matrix software to trace the decision making processes of physicians. We established the feasibility of the MDcisions™ platform to trace the decisions of participants and highlight variations and trends in function of training and gender. Moreover, these trends differed between crisis and non-crisis situations.

This novel approach has allowed to dissect the medical decision processes at a granular level highlighting heuristics and teasing out biases, allowing to analyze how health care professionals reach their decisions. Understanding physicians' cognitive processes not only allows us to infer the decision strategy used, but might also make it possible to predict future decisional behavior and decision outcomes. Furthermore, a better understanding of physicians' decision strategies, could facilitate the design of educational efforts to influence proper decision making processes and decrease adverse events in medicine (75), leading to the concept of "cognitive pills for cognitive ills" (94), and improved patient care.

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