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Error, error potential, and risk mitigation in medicine from the perspective of a diagnostician

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ABSTRACT
The nature of error is discussed by referring to its sources. The notion of the error potential is presented for assessment of uncertainty due to error. As an a priori measure, the error potential can guide efforts to reduce risk in medicine. Risk mitigation may essentially be achieved with quality assurance, knowledge sourcing, and diagnostic trialing. The purpose of this manuscript is to contribute to the efficacy and safety of medical interventions. It can also serve as an introduction to error and risk within the study curricula of the medical professions.

Keywords: error; measurement; diagnosis; health; risk; risk mitigation.

PART 1: ERROR AND ERROR POTENTIAL
Introduction
Any intervention (act) into the state of reality (to modify or to maintain) by an operator (purposeful), from the present (observed) to the future (desired) state of reality, consists of steps (regardless of how elaborate or rudimentary each may be on a case-by-case basis). Reality must be demarcated and separated from the rest of reality to become the object of the intervention. Reality interacting with the object may subsequently be demarcated to become another object (co-object) of the intervention. The object is unique, even though it can belong to a set of identical objects. It is implicitly assumed that the object exists at any moment in a single state characterized by an unique set of features produced and evolving through one causality. Leaving aside quantum uncertainty, this is the general assumption for objects of any intervention.

During the intervention the object is observed through a set of variables (quantitative, qualitative characteristics). Readings of these variables are obtained with a measurement system or measurement tool/senses and are interpreted as features of the state of the object. Causality is interpreted by cause-and-result interrelationships
between features determining the evolution of the state. A model is devised to render or reveal the evolution of the state and to plan a procedure (interaction with the object) that will be performed to achieve modified, maintained, eliminated or prevented features presenting as the desirable outcome (desirable state of the object) of the intervention. All along the way from observing the object to achieving an outcome, interferences can happen which may result in an undesirable outcome (undesirable state with undesirable features). The more sophisticated and demanding is the intervention, the greater is its predisposition to interference.

It is thus a matter of fact that every intervention is prone to interference. Interferences that are conducible to undesirable outcomes will now be termed errors. Firstly, errors do not necessarily produce undesirable outcomes, but when they do, errors should have been prevented. Secondly, prevention does not directly target errors in the intervention, which by their nature are detected *a posteriori* and as such are not preventable. Prevention directly targets the predisposition of the intervention to error, which will now be termed the error potential*. The error potential corresponds to uncertainty which is a broader term and does not imply a direct and sole link with error. Furthermore, it is a practical feature of the error potential that it can be assessed *a priori*. By reducing the error potential, desirable outcomes are promoted and undesirable outcomes are prevented.

In summary, the error potential should be assessed for the measurement, interpretation, and performance steps of the intervention and should be reduced as much as necessary, ideally to free the intervention from error. Reduction of the error potential is contingent upon elucidation of error as to its sources and types. Thus, the error potential will arise from errors discussed hereunder. Excluded are accidental errors attributable to unforeseen interferences. Even though the impact of an accidental error on the outcome of the intervention may be severe, this error can be prevented.

**Error in measurement**

The object will possess at least one measurable variable. A measurable variable has a quantitative and qualitative content. Thus, there are quantitative and qualitative variables depending on the content which is measured; interconversion between both

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*Not to be confused with the error-related potential in electroencephalography.*
types is possible. Variables to be measured are selected spontaneously (ad hoc) or according to a scheme (algorithm). Readings of variables (measurements) are done to disclose features of the state of the object and to establish interrelationships between features. The measurement step is complete when the variables of the state of the object have been measured for the interpretation step of the intervention.

Measurement of a quantitative variable assigns a quantity (number, size, intensity, speed, titer, etc.) to the variable. For a quantitative variable, error is defined as the difference between the measured (assigned) and the true quantity. In the absence of other sources of error, the difference between the measured quantity and the true quantity is the source of the accuracy error at the measurement step of the intervention. This difference can only be calculated when the true quantity is known, but as measurements provide the measured quantity, error cannot be determined without checking against a quantity that is predetermined as true. Checking against such a quantity (calibrating quantity) is called calibration of the measurement. The ultimate calibrating quantity is defined through a standard in a system of measurement units. It is desirable to adopt standards (units) that are physical constants (unaffected by time and place), and so it is with the actual SI system of measurement units. However, other measurement units can be used, as long as they can be defined, kept constant, and accessed. When counting is done for a measurement, whatever is counted shall be defined and thereby becomes the unit of measurement. For practical purposes, calibration is done with a calibrating quantity deemed to be the true quantity for calibration purposes (reference measurement). Technicalities underlying the reference measurement are beyond the present subject matter. Calibration may be lost (decalibration); measurements may require recalibration at specified time intervals.

In general, quantities are measured as elements of the set of real numbers. On the one hand, there are quantities than can be measured exactly; these belong to a subset of rational, integer or natural numbers. On the other hand, quantities than cannot be measured exactly will be rounded off to the nearest greater or smaller quantity measurable exactly. The amount rounded off is predetermined by the maximal number of digits in the reading of the measurement. Rounding off is one source of the precision error at the measurement step of the intervention. The other source of precision error is attributable to fluctuations inside and outside the measurement (changes in temperature, pressure, airflow, sampling, etc.). Fluctuations will be a source of precision error when they are large enough in comparison with the amount
that is rounded off. The greater is the amount rounded off and the greater are fluctuations, the less precise (more imprecise) is the measurement. It should also be noted that measurements are governed by universal laws (e.g. quantum uncertainty), which impose a limit on the precision that can be attained.

To acknowledge the fact that the measured quantity may deviate from the true quantity due to error, an interval is set up around the measured quantity, in which the true quantity is most likely to exist. Thus, the measured quantity presents itself as an element of its confidence interval. When setting up the confidence interval, its width should encompass coincident precision and accuracy errors of the measurement.

Measurement of a qualitative variable assigns an element from a set of qualities to the variable. For a qualitative variable, error is defined as the difference between the measured (assigned) quality and the true quality. Ideally, every quality in the set shall be unique and all qualities shall be represented, i.e. no other quality assignable to the variable can be added to the set. When only one quality is assignable, its set consists of two elements, the other element being absence of this quality. Qualities merged into one element of the set shall be the source of the precision error. Only one element of the set shall be the true quality assignable to the variable. Qualities substitutable for the true quality shall be the source of the accuracy error. Measurements of qualitative variables need to be calibrated to ensure correct assignment of qualities. Reference measurements are done and decalibration is possible.

Compromised readings of the variables as a composite of accuracy and precision errors will be commensurate with the error potential at the measurement step of the intervention.

**Error in interpretation**

The state of the object evolves by no more than one interpretable causality. Causality presents as cause-and-result interrelationships between features of the state of the object, in which some features will be causal, while other features will be resultant. Interpretation of the readings of the variables is done to disclose features characterizing the state of the object and to establish cause-and-result interrelationships between features exposing causality. Features and their interrelationships are then applied to devise a model that will render or reveal the evolution of the state of the object. The process of disclosing features and establishing interrelationships between them from readings of the variables is beyond the present
subject matter. The model will be used to plan a procedure through which the desirable outcome of the intervention will be achievable. The interpretation step is complete when the model of the state of the object has been devised for the performance step of the intervention.

The interpretation step ends with a diagnosis defined as thorough knowledge of the object. In fact, the diagnosis is expected to describe the state of the object and its evolution rendered or revealed through readings of variables at any moment and with any interaction. The operator cannot be purposeful without a model to plan the procedure which will be performed to achieve the desirable outcome. Thorough knowledge of the object would be applied to devise a digital model of the state of the object with causality in the form of equations and correlations of the variables explaining interrelationships between features of the state of the object and rendering the evolution of the state (prognosis). A digital model is devised under two assumptions. Firstly, the laws of reality in the form of equations and correlations for the model are known. Secondly, interactions of the co-object with the object can be controlled or prevented. Consequently, the outcome as the effect of the procedure of the intervention on the readings of the variables (features of the state of the object) will present as a solution of these equations and application of correlations. Desirable features cannot be achieved or maintained and undesirable features cannot be eliminated or prevented in violation of causality. Desirable states will be restricted to those rendered by the model. Thus, the digital model would serve to assign desirability to features of the state of the object and to render outcomes of procedures at the performance step of the intervention.

A digital model cannot be devised for an object disclosing features that cannot be interrelated through solvable equations and strict correlations. A digital model devised for an object evolving stochastically or with complex interrelationships may be mathematically intractable. A digital model cannot render evolution if interactions with the co-object are not controlled or prevented. Last but not least, the time needed to explain interrelationships between features of the state of the object through equations and correlations of all variables of the state of the object may exceed the timescale of the intervention. An analog model is devised instead under two assumptions. Firstly, the object is no longer unique; it will belong to a class of identical objects. The class is unique through a state always disclosing some features and not disclosing other features. This state is the paradigmatic state and its features are the paradigmatic
features for their paradigmatic class. Secondly, knowledge will accumulate from interventions in the object and in objects of its paradigmatic class. Thus, thorough knowledge will be replaced by accumulated knowledge.

Knowledge accumulates from measurements done in objects belonging to the class, disclosing features of states and interrelationships between features of each state in the class. Knowledge will further accumulate by recording evolutions of the states and outcomes of procedures performed in objects of the class. Accumulated knowledge will be applied to devise a separate analog model of each state in the class. Knowledge will be applied to attribute an analog model to the state of the object of the intervention and to identify an analog model with the desirable features, deemed to be in the desirable state. Conservation of causality will restrict desirability to features of states of objects in the class. The procedure to achieve the desirable outcome will be a constituent of the analog model of the state of the object. Thus, evolutions of states and outcomes of procedures will not be rendered by the analog model. Instead, the analog model will reveal evolutions and outcomes by applying knowledge accumulated about the state of the object and about this state in the paradigmatic class.

Interpretation will be simplified by fragmenting the object of the intervention into its components. Fragmentation is done under two assumptions. Firstly, the desirable state of the object will be attributable to the desirable state of some components of the object. Secondly, the procedure will not affect the desirability of the state of other components of the object. A digital model can be devised, if possible; otherwise, an analog model will be devised for the component. Interpretation will be further simplified by identifying a single state as desirable for all objects belonging to the paradigmatic class. This state will be the normal state. The normal state will disclose normal (desirable) features and will not disclose abnormal (undesirable) features. Only procedures that achieve the normal state will be planned for the object of the intervention. Thus, desirability will be replaced by normality in the model of the state of the object.

In one case, the diagnosis will explain interrelationships between features of the state of the object in the form of thorough knowledge that can be applied to devise a digital model of the state of the object of the intervention. In another case, the diagnosis will identify the state of the object as normal or specifically abnormal and accumulated knowledge will serve to devise analog models of the normal and abnormal states. For
a true diagnosis in every intervention, either all equations and correlations must be formulated or all features of normality and abnormality must be known.

For features of the state of the object, error will be defined as the difference between the true state and the modeled state. The difference will be attributed to inexact interpretation of the readings of the variables to disclose features (precision error) and to incorrect set of features characterizing the state of the object (accuracy error). For interrelationships between features, error will be defined as the difference between the evolution of the state and evolution rendered or revealed by the model. The difference will be attributed to incorrectly established interrelationships between features (accuracy error) and to inexact equations and correlations of the variables (precision error).

Interpretation may proceed as a sequence in which variables are selected for measurement depending on the features and their interrelationships that have been disclosed. The measurement step may begin with a group of variables (panel) to disclose lead features and may include repeated measurements of some variables (monitoring). The sequence may be planned in the form of a directed graph (digraph) with features disclosed as edges and variables measured as vertices. Sequential measurements are done to improve efficiency of interpretation in terms of time and resources by avoiding unnecessary measurements. The interpretation step will proceed until the evolution rendered or revealed by the devised model is deemed to be consistent with the evolution of the state of the object.

Compromised modeling as a composite of accuracy and precision errors will be commensurate with the error potential at the interpretation step of the intervention.

**Error in performance**

The model devised at the interpretation step serves to plan an available procedure to achieve the desirable outcome. The desirable outcome shall be rendered by the digital model or shall be revealed by the analog model. Otherwise, desirability should be modified to meet the constraints of the model. Desirability should be modified accordingly if the procedure is not available. The plan of the procedure describes methods (software) and tools (hardware) and may proceed in parts (subprocedures). Subprocedures may be planned when the outcome evolves through intermediate states with assignable desirability. A subprocedure will be performed to continue the desirable outcome; other subprocedures will be performed to correct the undesirable
outcomes. Subprocedures may thus be planned to suppress errors at the measurement and interpretation steps of the intervention. The plan of the procedure may be in the form of a digraph with outcomes as vertices and subprocedures as edges of the graph. The plan may emerge directly from knowledge and will be straightforward. Otherwise, planning will be guided by knowledge and will be complex enough to be beyond the present subject matter. The performance step is complete when the outcome of the intervention has been achieved.

Failure to plan the procedure according to the model of the state of the object shall produce the accuracy error. Failure to perform the procedure according to the plan shall produce the precision error. Compromised performance as a composite of accuracy and precision errors will be commensurate with the error potential at the performance step of the intervention.

Properties of the error potential

The error potential is a composite of accuracy and precision errors at each step of the intervention. The magnitude of the error potential follows the magnitude of errors. Suppression of errors at their source will reduce the error potential. The error potential propagates through the intervention and eventually emerges as an undesirable outcome. Propagation can be suppressed with countermeasures at subsequent steps of the intervention. The ultimate countermeasures are instituted at the performance step.

Perfection of the intervention

A perfect intervention achieves desirable outcomes only. Assessment of the error potential will be a guide to perfection before the intervention is undertaken. The intervention is perfected by reducing the error potential and suppressing its propagation. With all these efforts, the intervention will be deemed to achieve the desirable outcome.

In the real setting, the outcome can only be foreseen as a chance of being achieved, as a risk of failure, or jointly as a probability of an outcome among other outcomes. Probability was initially used in games of chance to make choices (bets) basing on their potential chance versus risk to the player. Since then, probability has moved beyond the theory of games and has gained the status of an immanent feature of reality (e.g. quantum mechanical probability equations).
An imperfect intervention will achieve undesirable outcomes. Probabilities (risks) of undesirable outcomes can be calculated and perfection of the intervention will be guided by risk reduction (mitigation). Thus, risk can serve as a companion to the error potential for perfecting interventions, with the advantage that risk is quantifiable. Risk will also serve as a comparator (benchmark) of various procedures performed to achieve the same outcome. Furthermore, benchmarking is done to evaluate the skills of the same operator (intra-operator) and of several operators (inter-operator), factually their capabilities to deal with the error potential in the intervention. Objects at high risk of undesirable outcomes of the intervention disclosed by some features of their states will be excluded from the intervention (risk scoring).

Ultimately, perfection of the intervention is guided propter hoc by the error potential and post hoc by risk mitigation.

PART 2: RISK MITIGATION IN MEDICINE

Introduction

Contemporary medicine is a discipline based on evidence and procedures and is aimed at maintaining and restoring human health. The object of the intervention is the patient and the operator is the medical professional. Evidence are features consisting of symptoms, signs, results of tests and examinations, and all other information relevant to the state of the patient. The patient may be in the desirable state, which is the normal state called health; otherwise the state of the patient will be abnormal. The normal state shall be maintained, whereas the abnormal state may be modified through procedures collectively called treatment. However, it is not because of the change in terminology that medical interventions demand a separate discussion of their specificities. Let it suffice to list three of them. Firstly, the patient may be able to cooperate at every step of the intervention to provide information and participate in procedures. Secondly, the human organism maintains a dynamic equilibrium called homeostasis which may respond to treatment with synergism or antagonism. Thirdly, one outcome stands apart from all other undesirable outcomes and for which risk mitigation should go all the way to risk prevention. This outcome is mortality.

Health and normality

Health is this state of the patient that is referred to as normal; health represents the ultimate desirable outcome. Health is a unique state that exists in opposition to all
undesirable states collectively called the disease. It follows that if a feature is not a feature of health, the diagnosis of disease should be made. Unfortunately, the unresolved problem is that the diagnosis of health cannot be made with certainty when no features of disease have been disclosed. In other words, it is not exactly agreed and defined what is the normal state for human beings. This fact contributes to the error potential at the interpretation step of the intervention.

For now, health is usually identified with wellbeing, a tautology proposed by the World Health Organization in 1948: “Health is a state of complete physical, mental, and social wellbeing and not merely the absence of disease or infirmity” [1]. Wellbeing is felt and identified by everyone with the absence of physical, mental and social problems, but feelings are subjective. What is needed is an objective definition of health, through measurable variables the readings of which can be interpreted accordingly. It would be tempting to skip the notion of wellbeing and restrict the definition of health to the absence of disease or infirmity, both states presenting with evidence that is measurable and thus objective. However appealing, this temptation should be resisted; along with progress in medicine, new evidence of disease will be found that is unknown today. The second part of the WHO definition of health accommodates for this situation.

Consequently, wellbeing does not imply the absence of disease or infirmity. Conversely, patients with a disease or infirmity may still feel well enough and this feeling is absolutely desirable. Perhaps both parts of the WHO definition can be reconciled in this sense that medicine will be charged with maintaining and restoring health as a state with no evidence of disease or infirmity understood as states associated with functional impairment or loss and/or with reduced survival time, and still focusing on wellbeing, with generous assistance from other professions, especially when wellbeing can be restored by treatment other than medication or surgery. Wellbeing is helpful from another perspective; its analogy with health can be monitored through a limited number of variables. Measurements of too many variables, all too many from the point of view of safety and comfort to the patient, with time and resources available in mind, can be avoided, i.e. measurements can be restricted to those variables included in preventive calendars (health checkups) because of their value for the early diagnosis of disease.

The overwhelming majority of variables when measured in apparently healthy humans, whether from time to time or from person to person, will give varying readings.
The same applies to variables measured in disease. Moreover, the readings in health and disease may partly or fully overlap. To accommodate for this fact, normality is represented by a range of readings. The normal (reference) range [2] usually includes 95% of the readings in a representative group of healthy humans (paradigmatic class) with the extreme 5% cut off as abnormal. Due to the overlap and cutoff, interpretation of readings as features of normality is subject to the error potential. Abnormal readings may differ as to severity or weight of evidence. Criticism of the normal range as a discriminator between health and disease does not disqualify its use as a comparator in decision-making [3]. From this perspective, it has been proposed to define decision intervals as a replacement for the normal range and to use information arising therefrom to plan treatments [4], with the intention to reduce the error potential as well.

Description of the state of the patient as regards normality (health or disease) may require measurements of many variables. Variables cannot be selected chaotically and in too many a number, but in an orderly manner, with due respect for the safety and comfort of the patient, for time and resource constraints, optimally with each subsequent variable adding evidence, revealing and confirming causality, thus increasing confidence in the diagnosis. Implementation of this recommendation is regarded as diagnostic excellence [5-10].

Decisions and probability

Humans are the only operators known to be able to assess probabilities and make interventions basing on this assessment. Many selections (decisions) during the intervention are straightforward, i.e. are made without recourse to probability. Such are the decisions in medicine that are dictated, i.a. by reason, good practice, expert advice, guidelines issued by professional bodies, economic constraints, legal provisions, and the like. Irrespective of any compelling circumstances, the wellbeing of the patient shall always govern decision-making, which means that consequences of the decision for the patient should be contemplated. Perhaps the most prominent decision which involves probability, i.e. assessment of risk, is whether to undertake treatment. This decision must be approved by the patient or his/her proxy in the form of informed consent, subsequently to explanation of the risk relative to treatment and to the untreated state of the patient. There may be alternative treatments which would be acceptable to the patient because of their lesser risk, even though their outcome might be inferior to the primary treatment. It goes without proof that anyone will rather accept
smaller than greater risk. Thus, risk attached to the treatment should be assessed. This is possible because probabilities of diverse outcomes, whether differentiated by the state of the patient or by the intervention, have been studied and are published in the literature.

For it is our goal to make medical decisions with the highest chance of desirable outcomes, or conversely, with the lowest risk of undesirable outcomes, making due provisions for the judgement of risk by the patient.

**Risk assessment**

It can safely be said that probability has pervaded medicine ever since it was conceived and used to study the prospects of medical interventions. Nowadays, every treatment modality (method and tools) is first tested with the so-called clinical trials and the probabilities of desirable and undesirable outcomes are determined. Probability studies are done with statistical methods and represent a significant part of the medical literature. Risks are revealed and are usually classified in several categories, from very high to very low. Almost all medications available at pharmacies are provided with information on the risk of adverse events as deviations from their intended action. Among those deviations are interactions with other medications, organ function, and immunity, each posing a serious risk to the patient. Thus, there is a necessity of studies on the risk attached to novel medical interventions and in diverse classes of patients [11]. Sophistication of such studies has become possible with growing power of computer systems, big data processing, and artificial intelligence.

Likewise, reports are aplenty in the medical literature on probabilities of outcomes depending on features of the state of the patient. Probability patterns are the basis for prognostication and decision-making. Particular attention is focused on the risk of malignant neoplasms. The Breast and Ovarian Analysis of Disease Incidence and Carrier Estimation Algorithm (BOADICEA) [12,13] is a computer program used to assess the risk of breast and ovarian cancer in women basing on their family history, as well as to calculate the probability of carriership of cancer-associated mutations in the BRCA1 or BRCA2 gene. It is self-evident that patients at high risk of cancer require a more focused approach than those at low risk.

There is a growing number of risk-assessment computations correlating the outcome of a treatment with features of the state of the patient. Of special importance is the assessment of the risk of death from surgical procedures. One of the prominent
examples here is the EuroSCORE index [14,15]. Basing on this index, patients at high risk of death from Coronary Artery Bypass Grafting (CABG) can be justifiably excluded, while patients at low risk can be confidently offered CABG. This index and similar ones go as far as to identify hospitals and surgeons less successful than average, i.e. requiring improvements but avoiding unfair judgements as to performance. Moreover, the risk of death of the untreated and treated patient can be compared with a computation called the Time until Treatment Equipoise (TUTE) [16]. When the time needed for the chance of survival after treatment to exceed the chance of survival without treatment is long enough, some elderly patients may not benefit from treatment in terms of survival (actually, they may be exposed to unjustified risk).

For many reasons, the complexity of the human body being a formidable one, medicine will rely on probabilities in decision-making. However, no medical professional will be satisfied with just risk assessment. Medicine is admired for its power to overcome the multitude of risks to health. The real purpose of risk assessment must be risk mitigation.

Risk mitigation

To write about risk mitigation in medicine with regard to the details is too bold an undertaking. Medical knowledge is vast and increasing every day. Progress in medicine is usually expected to increase the chances of restoring and maintaining health in more and more patients. It is perhaps less noticeable that the risk of undesirable outcomes is concurrently reduced. Risk mitigation relies on improvements at each step of the intervention. At the measurement step, the number of variables that can be measured is growing as more is known about the human body and more measurements become practicable. Just to mention some improvements: readings of quantitative variables are more accurate and precise, more features of the state of the patient emerge, images and other qualitative variables are obtained with greater resolution, waiting times are shortened. At the interpretation step, the state of the patient with its underlying causality is disclosed with growing sophistication. Progress here follows discoveries, i.a. of components of the organism and of their interrelationships, of internal and external factors/phenomena that are harmful (noxious) to health, and of protective (homeostatic) responses (mechanisms). Computers are used to process large volumes of data in the quest for features of health and disease and for a diagnosis.
At the performance step, there is growing specificity and diversity of treatments. On the specificity side, treatment methods and tools (chemical, mechanical, etc.) are increasingly more controlled as to their effects (precision medicine) meaning that specific components of the organism are targeted and adverse effects are limited, to the extent that treatments are tuned to the individual patient (personalized medicine). On the diversity side, various modalities are combined as the desirable outcome becomes more complex and involving the bodily response to a greater extent (holistic medicine). For the sake of exemplification: biochemistry-based interventions increasingly rely on monoclonal antibodies, automated drug delivery systems, engineered cells, genome editing, and the like, while anatomy-based interventions engage robots and are directed towards minimally-invasive procedures. Last but not least, interventions must be timely, particularly those with vestigial measurement and interpretation steps when symptoms suffice to begin treatment. Here, emergency medicine in urgent cases and online visit scheduling in non-urgent ones are just two of the beneficiaries of progress.

Leaving aside improvements attributable to progress in medicine, there are approaches discussed hereunder to mitigate risk for any intervention.

**Risk mitigation by quality assurance**

Quality assurance will reduce the error potential and mitigate risk by ensuring that everything used in the intervention is reliable. Reliability is a multifaceted property which includes repeatability, clarity of use, and resistance to deterioration (wear and tear). The quality of tools is of special importance. Tools can be simple, like the thermometer or the scalpel, or complex, like the magnetic resonance scanner or the da Vinci robot. Simplicity is no guarantee of reliability. However, complex tools have greater requirements to achieve and maintain reliability. Checking, double checking, cross-checking, standardization and certification, use of high-quality tools, frequent servicing, and adequate training and experience of medical professionals are among the means of quality assurance. From the external viewpoint, the intervention should be performed reliably, so quality assurance applies to methods as well. Thus, the procedure as a whole is subject to quality assurance.

Medical professionals are of pivotal importance for quality assurance. Training and experience have been mentioned among the requirements for reliability. But medicine has long ceased to be confined to the doctor’s office; contemporary medicine
is practiced by teamwork. In fact, it is the health care system as a whole, with its institutions, workplaces, specialists, manufacturers, health insurance, and more, that is encompassed by quality assurance. Rankings of health care systems by country are done to compare quality; one of the qualifiers is the predisposition to error.

Quality assurance is increasingly vested in local and international organizations which develop quality standards, perform compliance investigations, and issue quality certificates (ref. International Organization for Standardization).

Risk mitigation by knowledge sourcing

Risk will be mitigated by extending (sourcing) knowledge for the intervention. Knowledge can be sourced from medical records of the patient, medical literature, experts and professionals, and other sources pertinent to any step and any detail of the intervention. Knowledge is sourced in pieces called information. Thus, information is gathered and processed to accumulate as knowledge and ultimately to represent thorough knowledge incorporated in the diagnosis. Knowledge sourcing at every step of the intervention is increasingly being assisted by computers. Here, software has been developed to quickly process large databases (big data). Computers have greatly outperformed humans with this task to the extent that they are deemed to be bestowed with artificial intelligence even though, unlike intelligent beings, they are still unable to source knowledge on their own (this may happen with advances in hardware and software, through neural networks, and the like). Computers, robots, and other types of automata are increasingly being used to exchange information, monitor, assist, and replace humans at every step of the intervention. It can be said that machines and systems have also sourced knowledge that went into their construction and programming (algorithms). Machines, better than humans, are particularly suited to perform repetitive tasks in an almost endless manner with error elimination through surveillance arrangements. Thus, more than relieving humans from tedious tasks, automation and robotization reduces the error potential that otherwise would be attached to human-mediated action. At least for this reason, even though new sources of error are so created, the process of replacing humans with machines will go on, perhaps to the point that critical decisions only will be left to humans, viz. when the measurement and the interpretation steps are declared completed and when the performance step is declared planned.
Risk mitigation by diagnostic trialing

The risk of an undesirable outcome due to errors in the intervention is compounded by the risk generated from the evolution of the state of the patient. Thus, prompt treatment is of paramount importance in medicine. The problem of optimizing the intervention so as to minimize the time to begin treatment and still to suppress errors appears as the most formidable one faced by medical professionals. A general approach is to focus treatment on lead features of the state of the patient which are known to herald evolution of the state of the patient to undesirable outcomes. The response to treatment is observed and used for further planning at the performance step. Subsequently, treatment may continue or a modified or alternative treatment will be planned, with continued observation of the response, in time for safe and effective countermeasures. The diagnostician, however, regards this approach as diagnostic trialing, through which knowledge of the state of the patient accumulates, perhaps justifying regression to the measurement and interpretation steps of the intervention. For it is the role of the diagnostician to provide stewardship towards thorough knowledge of the state of the patient.

In conclusion, every medical intervention is undertaken to achieve the desirable outcome called health, even though this outcome may not always be achievable. Medical interventions are undertaken with probabilities in mind and thus with utmost care and countermeasures at hand to mitigate risk. By identifying the sources of error and reducing the error potential of the intervention, the best efforts of medical professionals devoted to risk mitigation will be successful.

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