Langenbecks Arch Surg (2011) 396:31–40
DOI 10.1007/s00423-010-0713-3

OVERVIEW

The formal requirements of algorithms and their implications in clinical medicine and quality management

Philipe N. Khalil · Axel Kleespies · Martin K. Angele · Wolfgang E. Thasler · Matthias Siebeck · Christiane J. Bruns · Wolf Mutschler · Karl-Georg Kanz

Received: 27 May 2010 / Accepted: 9 September 2010 / Published online: 2 November 2010

Abstract

Purpose Clinical algorithms contribute to the problem- and priority-orientated management of patients and their disease in healthcare. Algorithms are of particular importance in all aspects of emergency medicine where the fast completion of a complex problem according to a hierarchy is required. The advantages and success of this priority- and problem-orientated concept led to its expansion to other subspecialties in medicine in recent years. However, in spite of algorithms being created based on defined norms, they are frequently violated in the literature, which renders the algorithm useless in a particular case.

Methods The present debate addresses these issues and provides the formal criteria and their necessary modification for creating sufficient clinical algorithms. In this context, we also clarify the misunderstandings between step-by-step schemes, decision trees, and algorithms, which are often used synonymously, and discuss their implications in clinical medicine and quality management.

Results A clinical algorithm can easily be created with the present derivation of the algorithm by its formal mathematical function using the corresponding norms describing specific symbols for a single criterion. Some symbol modifications as well as the usage of checklists to focus on the major criteria led to a rigorous reduction of the algorithm length and results in a clearer arrangement for routine clinical use. In clinical medicine, algorithms cannot only provide a fast access for solving complex problems but must also assure a transparent protocol and democratic treatment such that every patient receives the same quality of treatment. Thus, a treatment by chance can be excluded by standardization, which might impact the overall work needed to guide patients though diagnostics and therapy and may ultimately reduce cost. Algorithms are useful not only for quality in healthcare but also for undergraduate and continuous medical education. From a more philosophical point of view, we can raise the question of whether medical pathways and thereby the medical art should be disclosed to the general public by algorithms. *Hippocrates form Kos* held the view in the so-called Hippocratic Oath that medical art should only be revealed to medical scholars.

Conclusions The present derivation and nomination of the formal requirements may lead to a better understanding of algorithms themselves as well as their development and generation.

Keywords Flowchart · Algorithm · Step-by-step scheme · Decision tree · Norms · Symbols · Clinical medicine · Quality management

P. N. Khalil (✉) · M. Siebeck · W. Mutschler · K.-G. Kanz
Department of Surgery, Campus Innenstadt,
Ludwig-Maximilians University,
Nußbaumstr. 20,
80336 Munich, Germany
e-mail: philipe.khalil@med.uni-muenchen.de

A. Kleespies · M. K. Angele · W. E. Thasler · C. J. Bruns
Department of Surgery, Campus Großhadern,
Ludwig-Maximilians University,
Munich, Germany

Background

An algorithm is a widespread instrument for increasing efficacy and managing quality in medicine by the implementation of specified standards into a systematic, logical, evidence-based, and rational concept. A formalized sequence of instructions for solving a complex problem in finite processing steps is generally named an algorithm. The term algorithm goes back to the Arab mathematician and astronomer Al Khwarismi and the book *About Calculating with Indian Numerals*, written around 825 A.C. This book was translated in the twelfth century to Latin, beginning with the words *dixit Algorisimi*; at this time, algorithm became also the linguistic modification of the name Al Khwarismi, composed of the name *Algus* for the creator of the art and the Greek word *arithmos* for number [1–3]. Thus, it becomes clear that the term "algorithm" cannot be derived from *rhythmos* (an expression of a recurring condition), which is a common phonetic mistake, although both have the same phonetic roots.

When focusing on more complex problems in medicine, algorithms may help process a fast priority-orientated diagnostic or therapeutic process where single actions are based on a fixed logical sequence [4]. In recent years, a trend toward the formalization and standardization of healthcare can be observed [5]. These changes are most likely attributed to the need for quality assurance in healthcare. However, quality does not only imply the "what" but also the "why" and "how" of treatment. Thus, the often nontransparent and unstable concept of clinical opinion of leadership at single institutions based on experience has yielded to a more evidence-based approach to medicine. In recent years, algorithms formulated in direct accordance with the evidence in the literature are found to be used increasingly in both scientific papers and textbooks. However, a lack of understanding of the formal requirements of algorithms can often be observed, which sometimes makes the algorithms illogical and useless with regard to what was intended by their authors. Moreover, step-by-step schemes and decision trees have been equated to, or mistaken for, algorithms that may be of some clinical relevance. Hence, the present paper addresses these issues and clears up some misunderstandings regarding algorithms. We provide the technically correct basic symbols that should be used, their meanings, and the ways to generate an algorithm. In addition to that, clinical examples from different medical areas are provided for better clarification. Furthermore, we define the differences between step-by-step schemes, decision trees, and algorithms with respect to their specific characteristics and provide graphic examples. Finally, we discuss the current implications and limitations of algorithms in clinical medicine and quality management.

Results and discussion

Norms and symbols

Algorithms are correctly formulated in accordance with technical regulations by the International Organization for Standardization (ISO) norm where different symbols graphically characterize the program sequence for the solution of a problem [4]. In particular, the ISO 5807 norm defines different symbols for the single operation to create an operation plan having only one input and output [6]. On the basis of these norms, International Telecommunication Union (ITU-T) norm symbols have been incorporated almost 15 years ago to adapt the algorithm for clinical practicability [4, 7–14]. The basic symbols an algorithm should contain

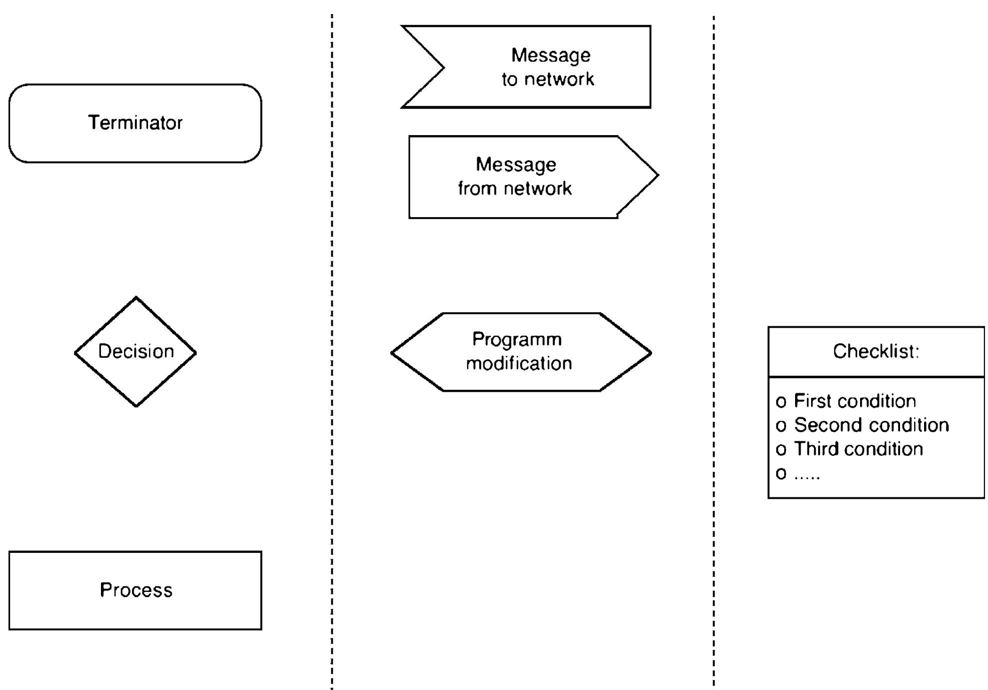

Fig. 1 List of symbols and their meanings. Basic symbols from the ISO 5807 norm (*left*) and their modifications taken from the ITU-T norm (*middle*). The terminator symbol from the ISO norm is replaced by directed "message to network" and "message from user" symbols from the ITU-T norm for better overview (*right and middle*). The program modification symbol (*hexagon*) was reinterpreted and used as a decision symbol to allow more writing inside compared to the decision symbol from the ISO norm. Checklists can reduce the number of decision and process symbols by referring to summarized single decisions as one general operation where appropriate (*left*)

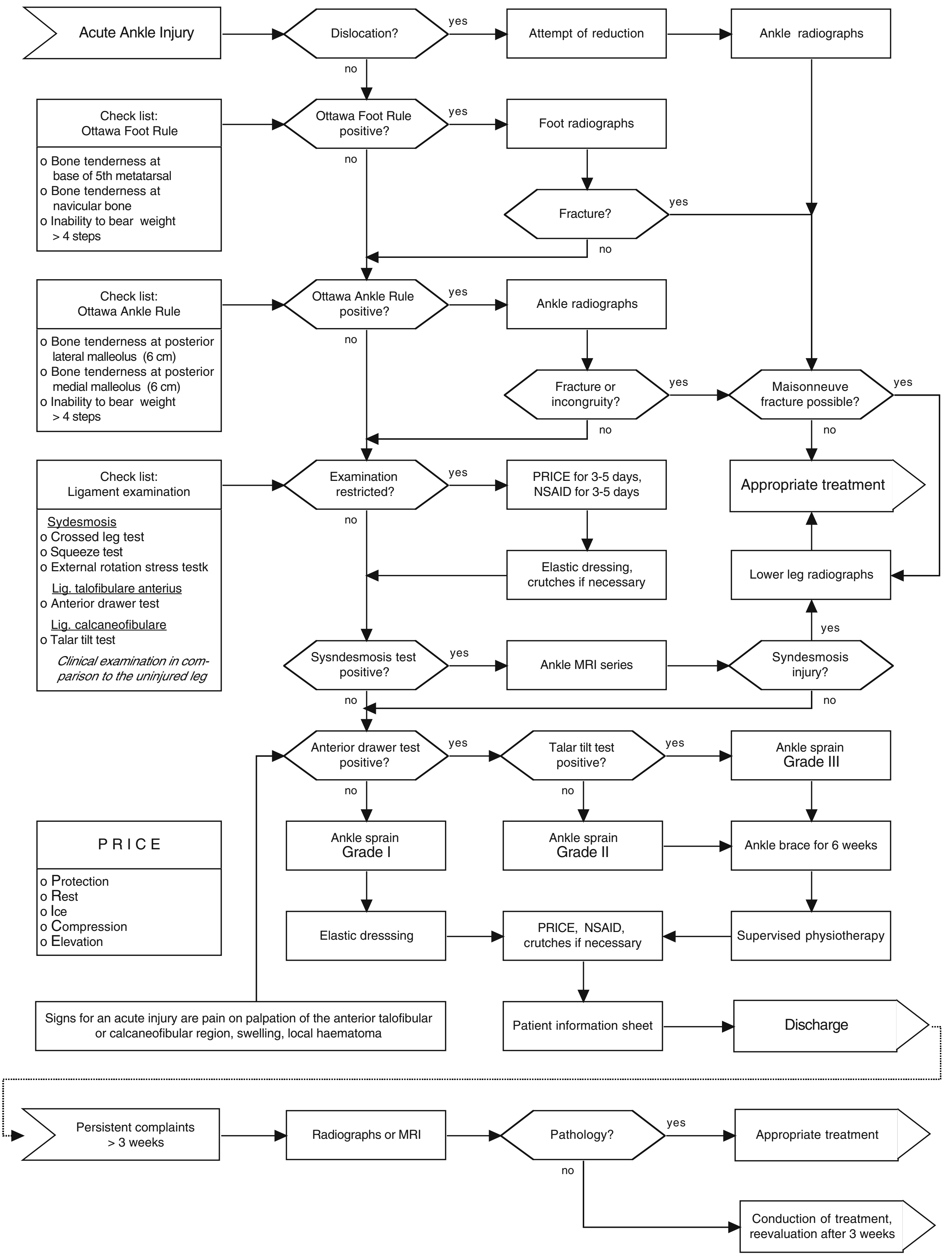

Fig. 2 Clinical algorithm for acute ankle injury

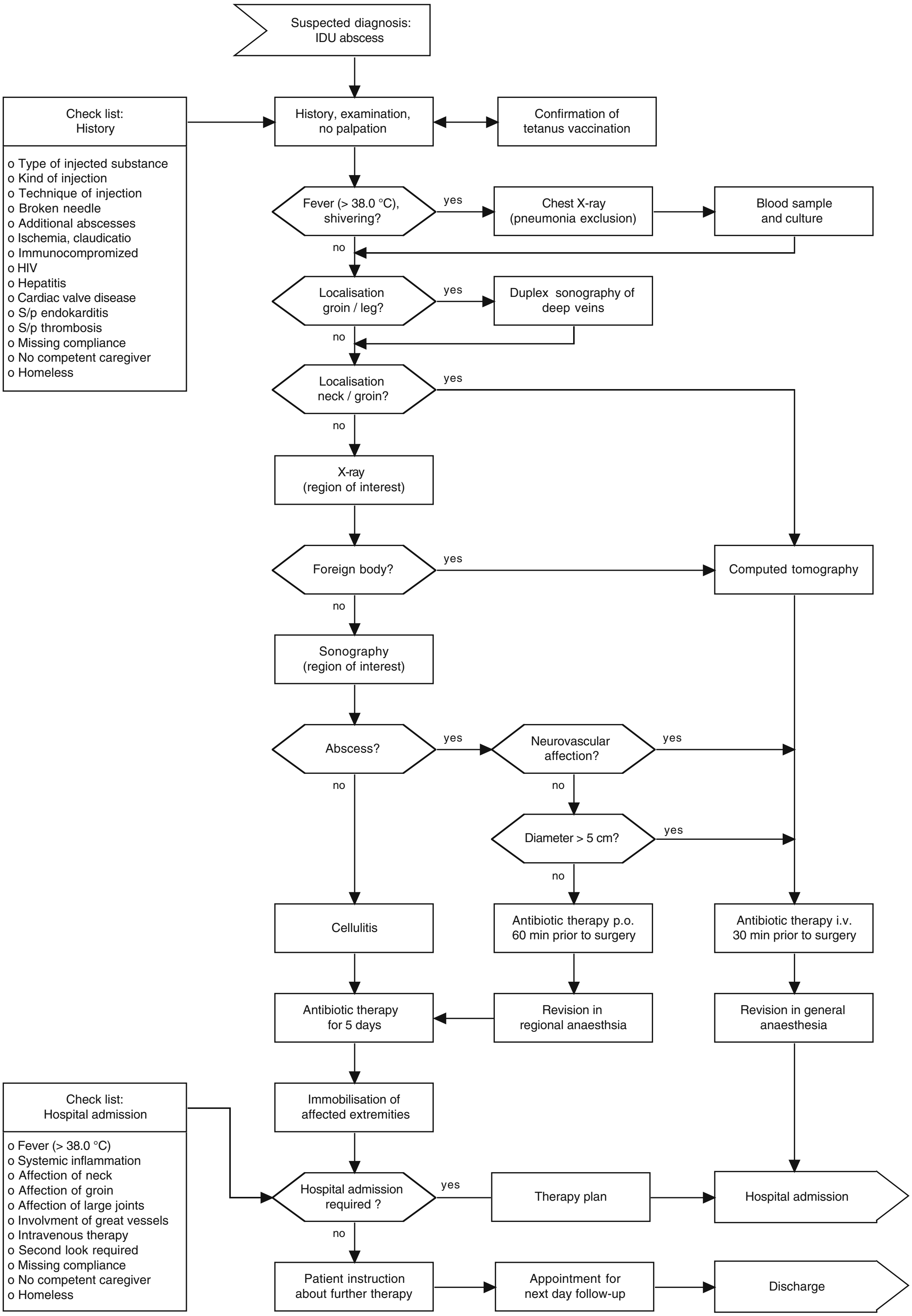

Fig. 3 Clinical algorithm for suspected abscess in injecting drug users (*IDU*). Modified from [8]

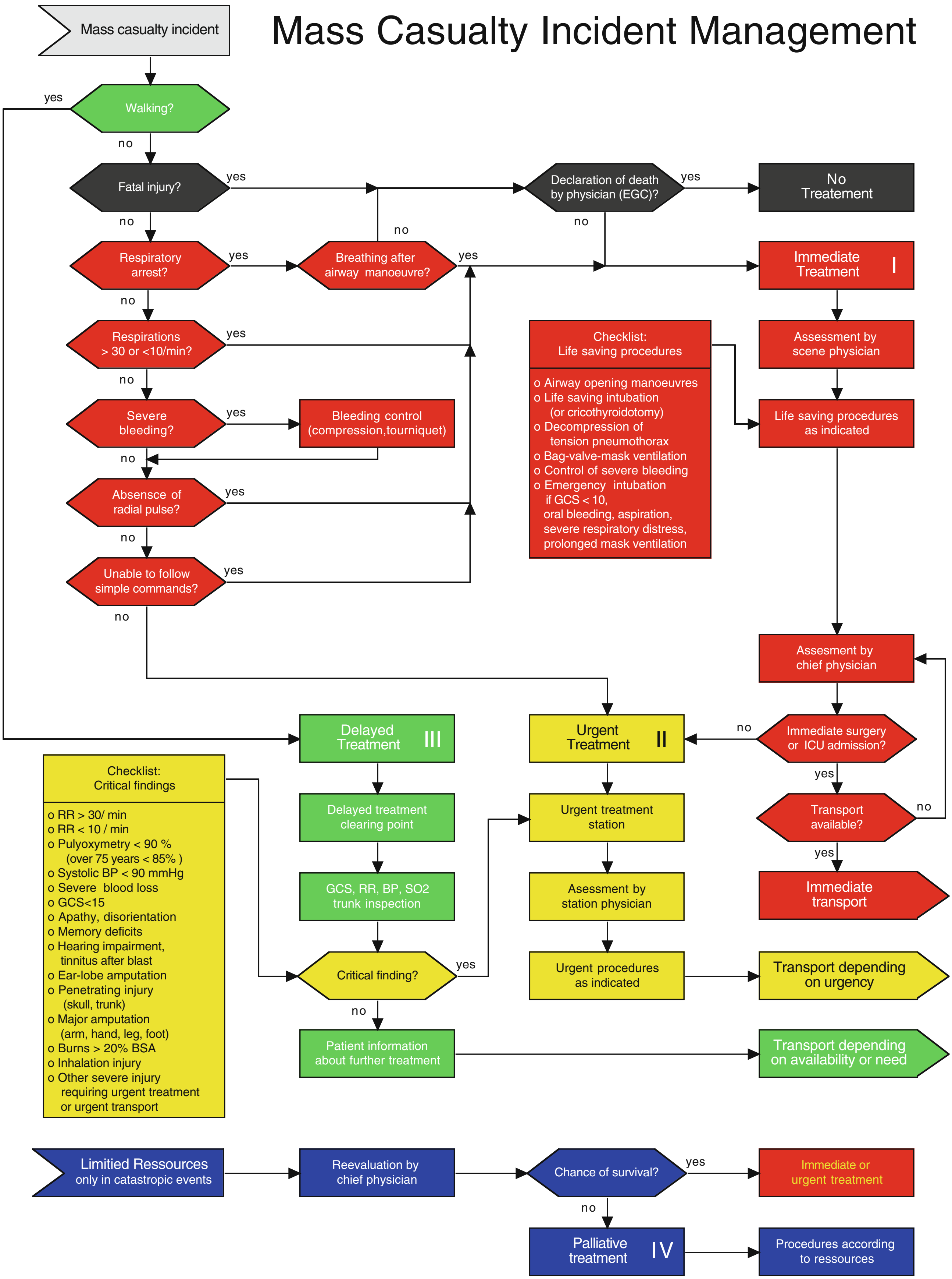

Fig. 4 Clinical algorithm for managing a mass casualty incident. Modified from [13]

are: (1) a directed symbol for the *message to network* that indicates the initial criteria of the algorithm, while the endpoints (2) are characterized by the directed symbol *message from user*, which stands for output criteria. Both (1) and (2) signal the direction of the algorithms by the use of the arrow-shaped form, as opposed to the terminator symbol from the ISO norm, and are therefore more suitable for clinical use [4, 15]. The core symbols in between are the single processes (3) and decision (4) symbols. While the process symbol indicates an action or treatment with a monodirectional nature, the decision symbol indicates a binary decision between two options: yes and no. However, this typically diamond-shaped symbol for decision is not graphically optimal for clinical use because it needs too much vertical space and does not allow enough writing of text inside. Therefore, it should be replaced by the hexagon-shaped symbol indicating program modification. These symbols are generally enough to generate a clinical algorithm, although many other symbols are available. An illustration of the different symbols is given in Fig. 1. Although additional symbols can be used, they are not accessible to the general user and should be used with care.

Organization of an algorithm and clinical examples

For practical considerations, an algorithm should generally fit on a single page. Moreover, it has to be organized logically and be priority-orientated. The direction of the decisions and treatments should be organized from the top to the bottom of the page. Problem solving loops will branch off to the right while checklists are located to the left side, where appropriate. These checklists are not integral components of the algorithm themselves but may reduce the total number of decisions and lead to a better overview. When a treatment loop branches off to the right, it should return to the main trunk of the algorithm. The single symbols are connected by horizontal and vertical flow lines with arrows. When a bidirectional decision is made, a “yes” or “no” should be written near the symbol. Examples of clinical algorithms from different medical areas including trauma and orthopedics, general surgery, and emergency medicine are provided in Figs. 2, 3, and 4.

Attributes of different schemes, trees, and algorithms

Step-by-step schemes, decision trees, and algorithms are often used synonymously, although they represent different types of formal instructions for handling a particular subject [4, 15]. They differ with respect to problem and priority orientation as well as in their basic linear structure, with regards to the presence of branching, loops, and endpoints [4]. Table 1 summarizes the attributes and differences of the step-by-step scheme, decision tree, and algorithm. Step-by-step schemes can be used in clinical medicine when the decision-making process has already been completed, for example, to process a further staged therapy. However, step-by-step schemes do not allow loops, branching, and more than one endpoint. Their nature follows a priority orientation, but not a problem orientation. In contrast, decision trees are characterized by a problem-orientated approach without a priority orientation. However, although branching of the decision is a characteristic feature of decision trees, their loops often do not lead to more than one possible endpoint. Finally, algorithms are characterized by both a problem-orientated as well as a priority-orientated approach. Furthermore, algorithms allow branching and loops and may lead to more than one endpoint (Figs. 5a–c).

Implications in clinical medicine and quality assurance

There are only a few different symbols necessary for creating an algorithm. However, the challenge of a technical and qualitative algorithm is the development of a logical, priority-orientated, and practical flow [4, 15]. In algorithms, the time and process of an action is defined and should be carefully considered during its initial formal creation. The problem- and priority-orientated standardized structure for fast access of a complex problem led emergency medicine to the cutting edge of the development of clinical algorithms back in the 1970s [16–18]. However, algorithms were also used in other diverse medical subspecialties at the time. This circumstance might be attributed to the trend of formalization and the shift toward standardization in healthcare driven by the need for quality management [5]. Standards are needed to assure quality in healthcare, which in general is based on three components: (1) *structure*, (2) *process*, and (3) *outcome*. An

Table 1 Characteristics of step-by-step schemes, decision trees, and algorithms

	Step-by-step scheme	Decision tree	Algorithm
Problem-orientated	−	+	+
Priority-orientated	+	−	+
Branching	−	+	+
Loops	−	−	+
Linear structure	+	−	+
Several endpoints	−	+	+

(+) indicates yes/possible; (−) indicates no/not possible

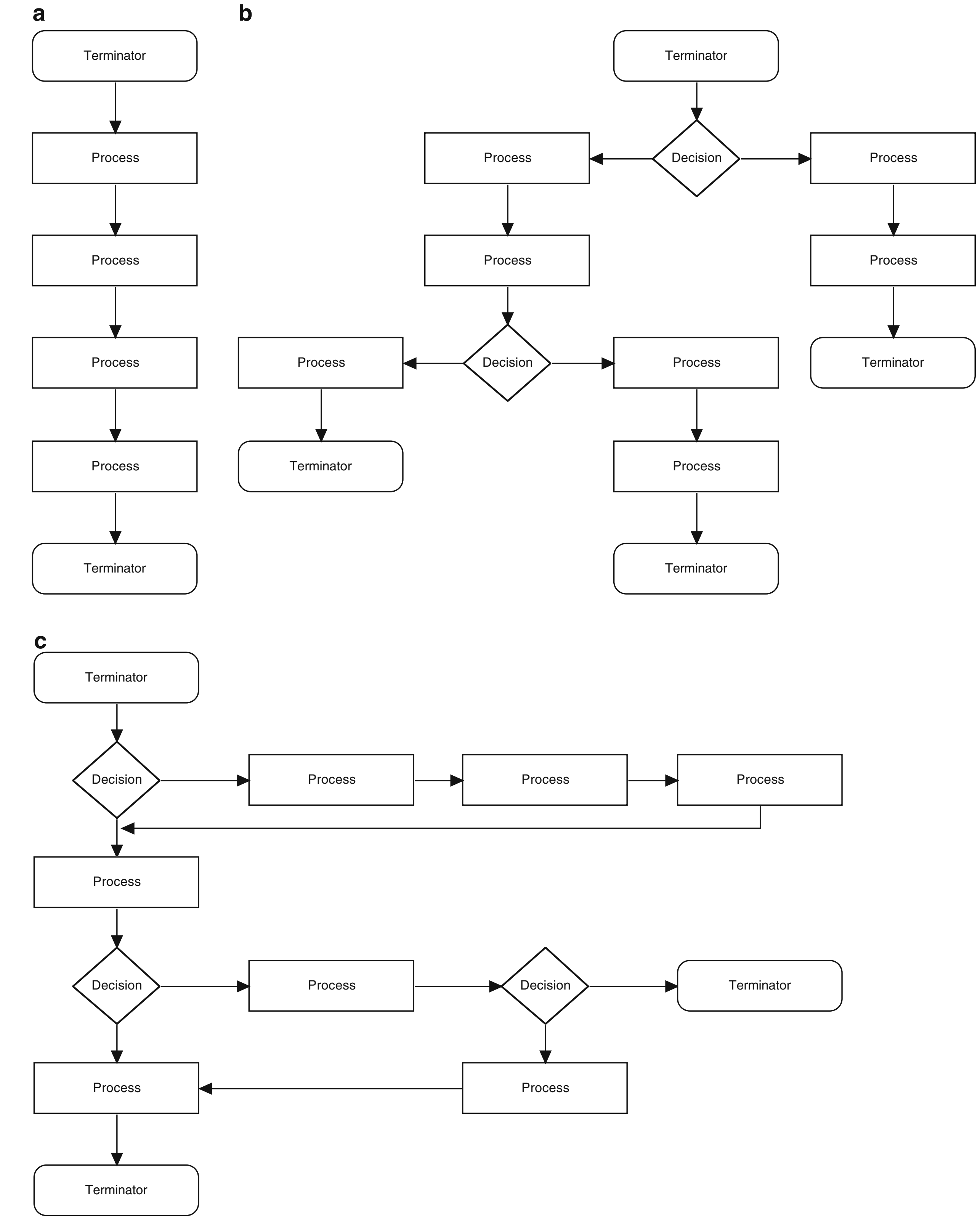

Fig. 5 Graphical structures of a step-by-step scheme, decision tree, and algorithm. A step-by-step scheme has a linear structure and allows a priority-orientated process without branching and loops (**a**). In contrast, a decision tree is not arranged linearly and allows a problem-orientated flow with multiple possible endpoints (**b**). Algorithms allow both priority-orientated and a problem-orientated processing of a complex problem using branching and loops, where necessary (**c**). The terminator and decision symbols should be changed according to Figs. 2, 3, and 4 for clinical usage

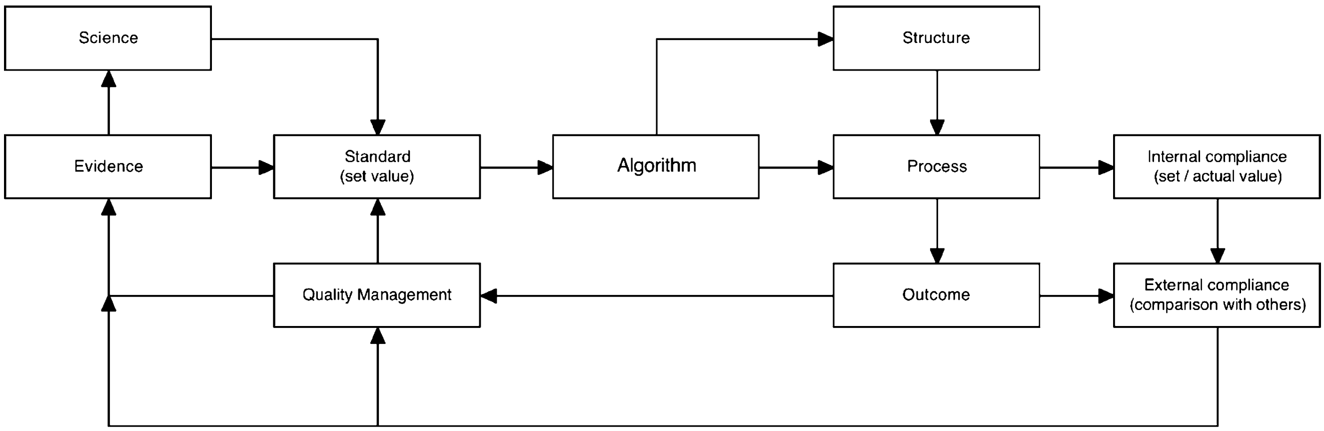

Fig. 6 The algorithm as a central interface in quality management and science. Evidence by external compliance and quality management influences the standard which determines the algorithm that influences the outcome by the structure and process, respectively. The process itself depends on the structure. Internal and external compliance, as well as the outcome, influences the quality management that determines the standard

algorithm can build a central link between a set value (standard) and an actual value (process). The standard itself is influenced by both the science provided by evidence and the quality management influenced by the outcome (Fig. 6). In this context, *structure* means the necessary infrastructure such as diagnostic equipment, while *process* describes how it should be done and *outcome* provides the final results. The internal compliance describes the proportion between the *set value* and *actual value* at one institution, which influences *quality management* and can also be compared to other institutions (external compliance). The importance of algorithms in this canon has been shown previously [4]. Thus, evidence has been provided that clinical algorithms can contribute to better results, e.g., in major trauma patients [19–24]. In addition, there is a worse outcome within this particular collective that is predominately related to errors in management rather than the treatment itself [24]. Therefore, it is imperative that management errors are minimized to increase outcome and, thereby, quality; this can be figuratively equated to the Gaussian distribution where a variable part under the curve at the left side with a negative prefix can be deleted to support an overall higher percentage with a more favorable qualitative outcome. A widespread approach in medicine and quality management is to focus on the operative side (do) rather than to analyze (check) what might further improve the plan (plan) by action (act) on the science side (Fig. 7). In our hands, algorithms can become the central interface that promotes both the operational and science sides which might stimulate research where *actual* and *test values* are frequently compared by random samples and may lead to the improvement or retention of the algorithm or parts of it. Evidence is largely lacking in some medical areas, including emergency medicine. The implementation of study protocols may be promoted by algorithms and their further analysis. For clinical use, it is recommended that the total number of operations be reduced to fit the whole algorithm on one page whenever possible. Otherwise, the algorithm's strength, such as the fast problem-orientated access and ease of survey, might be lost. Thus, checklists located at the left or right side of the algorithm referring to single decisions summarized as one general operation are appropriate for reducing the total number of operations listed, and should be used. It is obvious that algorithms have features of step-by-step schemes and decision trees but allow both problem-orientated and priority-orientated approaches for solving a complex problem in medicine. However, it is imperative that the algorithm, as a formalized process canon, is based on standards and evidence rather than on individual opinion. Step-by-step schemes can be used in clinical medicine, for example, when a diagnosis has already been made to run a fixed priority-orientated protocol step-by-step without any further alternatives in the decision or treatment.

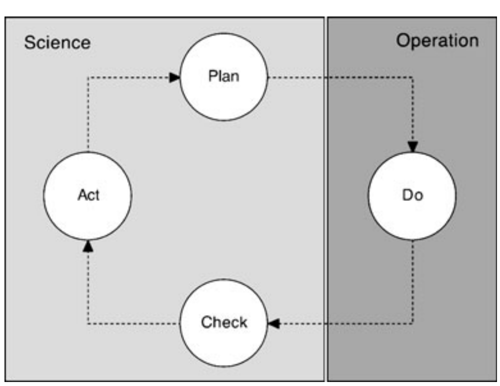

Fig. 7 Operation and science sides in quality management according to the plan–do–check–act principle

Decision trees and algorithms differ most with respect to the priority orientation and loops, which are possible in algorithms. In algorithms, a complex situation or circumstance is solved problem-by-problem, as illustrated by the classical example of the ABCDE survey of trauma care for identifying life-threatening conditions [25]. In contrast, decision trees are more appropriate when a diagnosis is made by step-by-step schemes and different therapeutic strategies exist according to various clinical constellations. Here, changes of the protocol, for example, based on new findings, are not possible due to missing loops. In clinical medicine, algorithms cannot only provide a fast access for solving complex problems but must also assure a transparent protocol and democratic treatment such that every patient receives the same quality of treatment. Thus, a treatment by chance can be excluded by standardization, which might impact the overall work needed to guide patients through diagnostics and therapy and may ultimately reduce cost. Algorithms are useful not only for quality in healthcare but also for undergraduate and continuous medical education as well as paramedical professionals such as those in emergency medical services or nurses. It is obvious that algorithms have a clinical application characterized by fast access, evidence-based externalized supports and target-orientated learning. From a more philosophical point of view, we can raise the question of whether medical pathways and thereby the medical art should be disclosed to the general public by algorithms. *Hippocrates form Kos* held the view in the so-called Hippocratic Oath that medical art should only be revealed to medical scholars. However, reality might have changed compared to past ideals [26, 27].

Conclusions

Step-by-step schemes, decision trees, and algorithms are often used synonymously, although they represent different types of formal instructions for handling a particular subject. Thus, they differ with respect to problem and priority orientation as well as in their basic linear structure, with regards to the presence of branching, loops, and endpoints. When focusing on more complex problems in medicine, algorithms may help process a fast priority-orientated diagnostic or therapeutic process where single actions are based on a fixed logical sequence. However, a lack of understanding of the formal requirements can often be observed, which sometimes makes algorithms, step-by-step schemes, and decision trees illogical and useless with regard to what was intended by their authors. In clinical medicine, algorithms cannot only provide a fast access for solving complex problems but must also assure a transparent protocol and democratic treatment such that every patient receives the same quality of treatment. Thus, a treatment by chance can be excluded by standardization, which might impact the overall work needed to guide patients though diagnostics and therapy and may ultimately reduce cost. Algorithms are useful not only for quality in healthcare but also for undergraduate and continuous medical education.

Conflicts of interest None.

References

1. Folkerts M (1997) Die älteste lateinische Schrift über das indische Rechnen nach al- wārizmī. Verl. der Bayer. Akad. der Wiss., München
2. Al Daffa AA (1977) The Muslim contribution to mathematics. Croom Helm, London
3. Gandz S (1936) The sources of al-Khowarizni's algebra. Osiris 1:263–277
4. Kanz KG, Eitel F, Waldner H, Schweiberer L (1994) Development of clinical algorithms for quality assurance in management of multiple trauma. Unfallchirurg 97:303–307
5. Eitel F, Kanz KG, Hortig E, Tesche A (2000) Do we face a fourth paradigm shift in medicine—algorithms in education. J Eval Clin Pract 6:321–333
6. International Organisation for Standardization (1985) ISO 5807: information processing—document symbols and conventions for data, program and system flowcharts, program network charts and system resource charts. ISO, Geneva
7. Khalil PN, Huber-Wagner S, Ladurner R, Kleespies A, Siebeck M, Mutschler W, Hallfeldt K, Kanz KG (2009) Natural history, clinical pattern, and surgical considerations of pneumatosis intestinalis. Eur J Med Res 14:231–239
8. Khalil PN, Huber-Wagner S, Altheim S, Bürklein D, Siebeck M, Hallfeldt K, Mutschler KG, Kanz KG (2008) Diagnosis and treatment options for skin and soft tissue abscesses in injecting drug users with consideration of the natural history and concomitant risk factors. Eur J Med Res 13:415–425
9. Khalil PN, Hallfeldt K (2008) Diagnosis and therapy of primary hypertparathyroidism. MMW Fortschr Med 150:39–41
10. Khalil PN, Ockert B, Huber-Wagner S, Grote S, Kanz KG, Mutschler W (2009) Broken glass injuries: does every splinter have to be removed? MMW Fortschr Med 151:38–40
11. Kanz KG, Schmöller G, Enhuber K, Hölzl G, Sturm JA, Mutschler W (2002) Algorithm for extrication and medical care in vehicle trauma. Unfallchirurg 105:1015–1021
12. Kanz KG, Sturm JA, Mutschler W (2002) Algorithm for prehospital blunt trauma management. Unfallchirurg 105:1007–1014
13. Kanz KG, Hornburger P, Kay MV, Mutschler W, Schäuble W (2006) mSTaRTAlgorithmus für Sichtung, Behandlung und Transport bei einem Massenanfall von Verletzten. Notfall Rettungsmed 9:264–277
14. Nast-Kolb D, Waydhas C, Kanz KG, Schweiberer L (1994) An algorithm for management of shock in polytrauma. Unfallchirurg 97:292–302
15. Dick WF, Ahnefeld FW, Knuth P (1997) Logbuch der Notfallmedizin: algorithmen und checklisten. Springer, Berlin
16. Bietz D (1977) Algorithm for critically injured patients. J Trauma 17:55–60
17. Larson KT, Vickery MD, Collis PB (1973) Triage: a logical algorithmic to a non-system. JACEP 2:183–185
18. Shoemaker WC (1975) Algorithm for resuscitation: a systematic plan for immediate care of the injured or postoperative patient. Crit Care Med 3:127–131

19. Bernhard M, Becker TK, Nowe T, Mohorovicic M, Sikinger M, Brenner T, Richter GM, Radeleff B, Meeder PJ, Büchler MW, Böttiger BW, Martin E, Gries A (2007) Introduction of a treatment algorithm can improve the early management of emergency patients in the resuscitation room. Resuscitation 73:362–373
20. Waydhas C, Kanz KG, Ruchholtz S, Nast-Kolb D (1997) A time and priority-orientated algorithm. Langenbecks Arch Chir Suppl Kongressbd 114:966–969
21. Waydhas C, Kanz KG, Ruchholtz S, Nast-Kolb D (1997) Algorithms in trauma management. Unfallchirurg 100:913–921
22. Shoemaker WC, Corley RD, Liu M, Kram HB, Harrier HD, Williams SW, Flemming AW (1988) Development and testing of a decision tree for blunt trauma. Crit Care Med 16:1199–1208
23. Liu M, Shoemaker WC, Kram HB, Harrier HD (1988) Design and prospective evaluation of an algorithm for penetrating truncal injuries. Crit Care Med 16:1191–1198
24. Ruchholtz S, Zintl B, Nast-Kolb D, Waydhas C, Lewan U, Kanz KG, Schwender D, Pfeifer KJ, Schweiberer L (1989) Improvement in the therapy of multiple injured patients by introduction of clinical management guidelines. Injury 29:115–129
25. American College of Surgeons (2008) Advanced trauma life support—program for doctors: 8th edn. American College of Surgeons, Chicago
26. Jotterand F (2005) The Hippocratic Oath and contemporary medicine: dialectic between past ideals and present reality? J Med Philos 30:107–128
27. Markel H (2004) "I swear by Apollo"—on talking the Hippocratic Oath. New Engl J Med 350:2026–2029