



Development, implementation and evaluation of an ECG algorithm for ambulance service

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ABSTRACT

In order to facilitate and accelerate the interpretation of ECG images in preclinical emergency medicine, an algorithm was developed to test this. In an online test, 357 staff of emergency medical service tested the functionality of the analysis procedure. Defibrillation-worthy ECG images are not included in this work because they belong to the resuscitation, has already been extensively published. The development of the algorithm involved three levels: The first was to define the properties of preclinical ECG images based on questions that needed to be answered dichotomically, such as "Are P-waves present?" "Yes" or "No". The answers were summarized in a table, from which the graphic processing of the information in the form of a search tree took place as a second level of development. The algorithmic query always started with the question "Did the patient have a pulse?" And ended with a defined ECG target image. This created a complex primary algorithm. As a third step, the primary algorithm was compressed to make it practical. The 11 questions are tested in this study. The study population was guided online through a web-based test. Each study was randomly assigned to the group with or without algorithm. In the case of using the secondary algorithm, it appeared of the screen throughout the duration of the interpretation. The test persons had to interpret 15 ECG images in succession, each with 5 predefined answers. The results of the query were collected in a database and formed the basis of the statistical calculations. From 15.05.2013 to 10.07.2013, a total of 387 people took part in the online survey. $n = 357$ subjects (92.25%) completed the complete ECG study with input questions and the interpretation of 15 images. All of the following results refer exclusively to the participants with closed interpretation: group without algorithm (μ) $n = 175$: correct answers $\bar{x} = 11,70$; $\sigma = 2.024$ and total time in sec. $\bar{x} = 392.35$; $\sigma = 294,687$. Group with algorithm (μ) $n = 182$: correct answers $\bar{x} = 12,17$; $\sigma = 2.877$ and total time in sec. $\bar{x} = 316.83$; $\sigma = 149.56$. The statistical mass consisted of 154 (43.1%) paramedics, 77 (21.6%) paramedics, 63 (17.6%) paramedics and 35 (9.8%) specialists. The remaining participants had a qualification as first responder or fireman. 62.7% of the study participants worked full-time in the rescue service. The average age was 31.6 years. 62.7% interpreted an ECG 1 to 10 times a month, 15.7% 11 to 20 a month. 82.3% of the subjects rated their ECG interpretability as medium good. The hypothesis that the number of correct answers in the interpretation of preclinical ECG images increases with the aid of the algorithm was again rejected in favor of the null hypothesis - for lack of significance $\alpha = 0.072$. By contrast, the analysis time for ECG interpretation decreases as expected by using the developed algorithm. H_1 was retained, with $\alpha = 0.003$, validated by t-test in independent samples. Neither age nor gender influenced the number of correct answers or interpretation time. $R_s = 0.387$ with $\alpha = 0.05$ between the medical qualification and the number of correct answers. Furthermore, with $r_s = -0.261$ and $\alpha = 0.05$, a correlation between the medical qualification and the analysis time was to be recorded. $r_p = 0.362$; Significance 2-sided $\alpha = 0.05$ was found in the self-assessment of the subjects. This means that they have generally assessed their ECG interpretation skills correctly. For emergency responders there was a higher number of correct responses with $\alpha = 0.05$, but no faster interpretation time. The frequency of the ECG interpretation in each case exercised had an influence on the number of correct answers when using the algorithm. $r_s = 0.362$; Significance 2-sided $\alpha = 0.05$. The time span since the acquisition of the last and highest medical qualification has a highly significant influence of $\alpha = 0.005$ on the number of correct answers when using the algorithm. That is, the shorter the distance to the end of the training, the more correct answers. In addition, it could be shown that subjects with a low medical qualification using the algorithm were able to increase the number of correct interpretations most strongly ($\alpha = 0.05$). In summary, the interpretation of preclinically relevant ECG images using the newly developed algorithm is recommended on this data basis. All occupational groups involved in the study benefited from it.

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Introduction for error reduction

Human failure in rescue medicine can have serious consequences, especially with regard to incorrect diagnosis or rare clinical pictures due to the broad medical spectrum that must be controlled. In other disciplines, such as aircraft, power plant or control centre operation, much time is invested in the appropriate presentation of instructions for action [1,2]. Examples of this are the accident at the Three-Mile-Island nuclear power plant in 1979 and the catastrophe at the Chernobyl nuclear power plant in 1986. Both were caused by human error and misinterpretations [3]. Various investigations have shown that humans play a major role in the causes of accidents [4]. In general, it is repeatedly stated that between 70 % and 80 % of all malfunctions in complex systems are attributable to human error [5]. The improvement of human reliability is therefore an important challenge to ensure the functionality and safety of a system [4]. In addition to other requirements from the field of human factor engineering, such as the layout of operating elements, the ergonomic design of the working environment and the design of ergonomic interfaces, the availability of clear and easy to understand instructions is an essential building block in the avoidance of human error [6]. Since not all emergency scenarios can be practiced regularly anymore, structured and clear instructions are indispensable. At present, various industry-specific approaches to handling instructions can be found in practice.

Fast ECG interpretation in rescue medicine is a typical example for the application of algorithms for error reduction. For the definition of an algorithm there is still no generally valid definition. For its graphical elaboration, however, already [7]. However, there are no discrepancies about the basic properties of the algorithm. Robert Sedgewick defines it as follows: "Algorithms: Methods for solving problems which are suited for computer implementation" [8]. Algorithms, especially in emergency medicine, are a recognized and proven means to make a professional diagnosis for patients in emergency situations and to treat them accordingly. The most common trauma care algorithms are ITLS [9], PHTLS [10] and the ABCDE scheme [11]. In the field of resuscitation of internistic patients, the uniform European guideline of the ERC is the leading one [12].

A solution by algorithms represents an action, which leads to the goal by a search tree with several possible action sequences. The sequences form a scheme with the initial state as start. The branches are actions based on a decision and a question. Nodes correspond to the branching of options for action [13]. The first step in the search for a solution is to test whether the initial state is directly available as the target state. In order to reach the next node in the search tree, an action is taken, in the case of the ECG algorithm for example: "Heart rate between 60 and 80 per minute? All further decisions refer to the subordinate nodes. This paper is specifically concerned with finding the appropriate preclinical ECG image using an evidence-based questioning technique. For this purpose, a methodology will be developed that meets these requirements. The questioning technique should especially support disciplines that do not interpret ECG images on a daily basis. Therefore two main hypotheses are tested:

- The number of correctly interpreted preclinical ECG images increases with the help of an algorithm (H1: $\mu > \mu_0$ vs. H0: $\mu \leq \mu_0$).

- The analysis time for the preclinical ECG interpretation decreases by using the developed algorithm (H1: $\mu < \mu_0$ vs. H0: $\mu \geq \mu_0$)

Methodology for the development of the algorithm

The methodology includes four steps to develop a practice-relevant questionnaire for rescue medicine.

Definition for preclinically relevant ECG images

The definition of preclinically relevant ECG images (without resuscitation measures) is the first step. These are: Sinus rhythms (normofrequent, tachycardia, bradycardia, tachyarrhythmia, bradycardia); atrio-ventricular blocks (AV blocks I to III); intraventricular regression disorder (ST elevation or lowering); Extrasystoles (rhythmic, arrhythmic, ventricular, supraventricular); pacemaker rhythm; intraventricular conduction disorder, atrio-ventricular replacement rhythm; atrial conduction disorders (atrial fibrillation, atrial flutter). The ECG images used were generated exclusively artificially by the software "Abmu Man W".

Implementation of the source table

The second step consists of the introduction of hard interpretation criteria, which exclusively have dichotomous characteristic values (Yes or No). E. G.: "P-waves present?" to reduce subjectivity in interpretation. Table 1 shows the preclinically relevant ECG images with division according to dichotomous characteristics and the question of the characteristics. A positive answer is marked with an X. 17 different questions were necessary to distinguish the 21 images.

Development of the great primary algorithm

The starting point for the primary algorithm is the physiologically healthy heart. With eleven questions to the goal picture "sinus rhythm". The primary algorithm for all ECG images also always starts with the initial question "Does the patient have a pulse? The pathophysiological ECG target images were then inserted. Starting with the first question, the criteria and the appropriate answers were then linked to the nodes, points of view and decision directions. Common nodal points were therefore already present and were retained. Branches only arose, if the already described way with the answer "No" had to be left. This process was repeated until all ECG images from the above table of origin (ECG images with dichotomous characteristics) were displayed. The graphical representation was done with yEd-Graph-Editor. The developed primary large algorithm (see Figure 1) of the search tree consists of the account points (diamonds), answer possibilities ("Yes" and "No" as square), ECG target image (rectangle), arrows (red = physiological ECG and black = pathophysiological ECG).

Four points are to be treated specifically in the procedure:

1. If the starting question is to be answered with "No", the patient has to be resuscitated and is not part of this work.
2. A device defect represents a possible infinite loop of the primary algorithm.
3. Three questions leading directly to an ECG target image. These are "pacemaker spikes present?", "extrasystoles

Table 1. Definiton ECG Image

Number of X	ECG Image	ECG waves visible?	Pulse present?	P-wave present?	P-waves < 300/min?	Abnormal P-wave (>0.25 mV or >0.1 sec.)?	Is each P-wave followed by QRS-complex?	PQ-time increasing, until the failure of a QRS complex?	QRS-complex ≥ 0.1 sec.?	QRS-complex visible?	QRS-complex rhythmic?	Requency ≥ 60/min?	Frequency 60-100/min?	Frequency ≤ 100/min?	Extrasystoles?	ST-raising / lowering?	Pacemaker spikes?	PQ-time > 0.20 sec?
	Sinusrhythm																	
7	Normofrequency	X	X	X			X		X	X	X		X					
7	Tachycardia	X	X	X			X		X	X	X			X				
6	Tachyarrhythmia	X	X	X			X		X	X				X				
7	Bradycardia	X	X	X			X		X	X	X	X						
6	Bradyarrhythmia	X	X	X			X		X	X		X						
	AV-Blocks																	
11	AV Block I	X	X	X		x	X		X	X	X	X	X	X				X
9	AV Block II a (Wenkebach)	X	X	X				X	X	X		X	X	X				X
8	AV Block II b (Mobitz)	X	X	X					X	X		X	X	X				X
5	AV Block III	X	X	X						X		X						X
	Intraventricular excitation regression																	
10	ST-elevation	X	X	X			X		X	X	X	X	X	X		X		
9	ST-reduction	X	X	X			X		X	X		X	X	X		X		
	Extrasystoles																	
8	VES Rhythmic	X	X	X						X	X	X	X	X	X			
7	VES Arrhythmic	X	X	X							X	X	X	X	X			
9	sVES Rhythmic	X	X	X					X	X	X	X	X	X	X			
8	sVES Arrhythmic	X	X	X					X	X		X	X	X	X			
	Pacemaker																	
8	Defect	X	X	X					X	X		X	X	X				X
10	Intractness	X	X	X			X		X	X	X	X	X	X				X
	Intraventricular conduction disorders																	
6	Thigh block diagram	X	X	X			X			X	X		X					
	AV replacement rhythm																	
5	AV replacement rhythm	X	X						X	X	X	X						
	Atrial fibrillation / fluttering																	
7	auricular fibrillation	X	X	X	X				X	X	X		X					
6	atrial flutter	X	X	X					X	X	X		X					

present?" and "ST elevation or depression? In all cases the further interpretation of intermediate questions is not useful.

- The ECG target image "Unknown residual image or preclinically not relevant" was added in order to come to a conclusion also with not preclinically relevant images.
- The aim of the search tree is to successively answer all central questions with node points in order to arrive at a target image which represents the basis for further treatment. The content with the components and frequencies of the nominations in the primary large algorithm is compiled in table 2.

Compression of the large search tree into a small practical instruction for action

The interpretation aid for the preclinical interpretation of ECG images and their graphical processing should be practical and easy to understand, so that compression is necessary. The eleven most frequently asked questions for the secondary, compressed algorithm have been interlinked and linked with follow-on arrows. The questions "Frequency greater than 100

per minute?", "ST-lift?", "ST-change in at least two adjacent derivatives?" and "Increasing PQ time until failure of a QRS complex?" were not included. These are only subordinate questions for the specification of subgroups in ECG images. The compressed algorithm (see Figure 2) formed the basis of the evaluation.

Evaluation of the practical small instruction for action

The online-based survey addressed rescue medical personnel in Bavaria (Germany) with different qualifications and organisations. The invitation to participate was posted on fire brigades with rescue services, clinics and associations. The online survey was conducted in German. The primary and secondary algorithms have been subsequently translated into English for this article

The study population was guided online by a query of ECG images through a homepage. General initial questions, answers of the test persons and interpretation times were saved in a database. The Figure 3 "Online query of ECG images" shows the test setting in the group with algorithm, the ECG image to

Primary large ECG algorithm

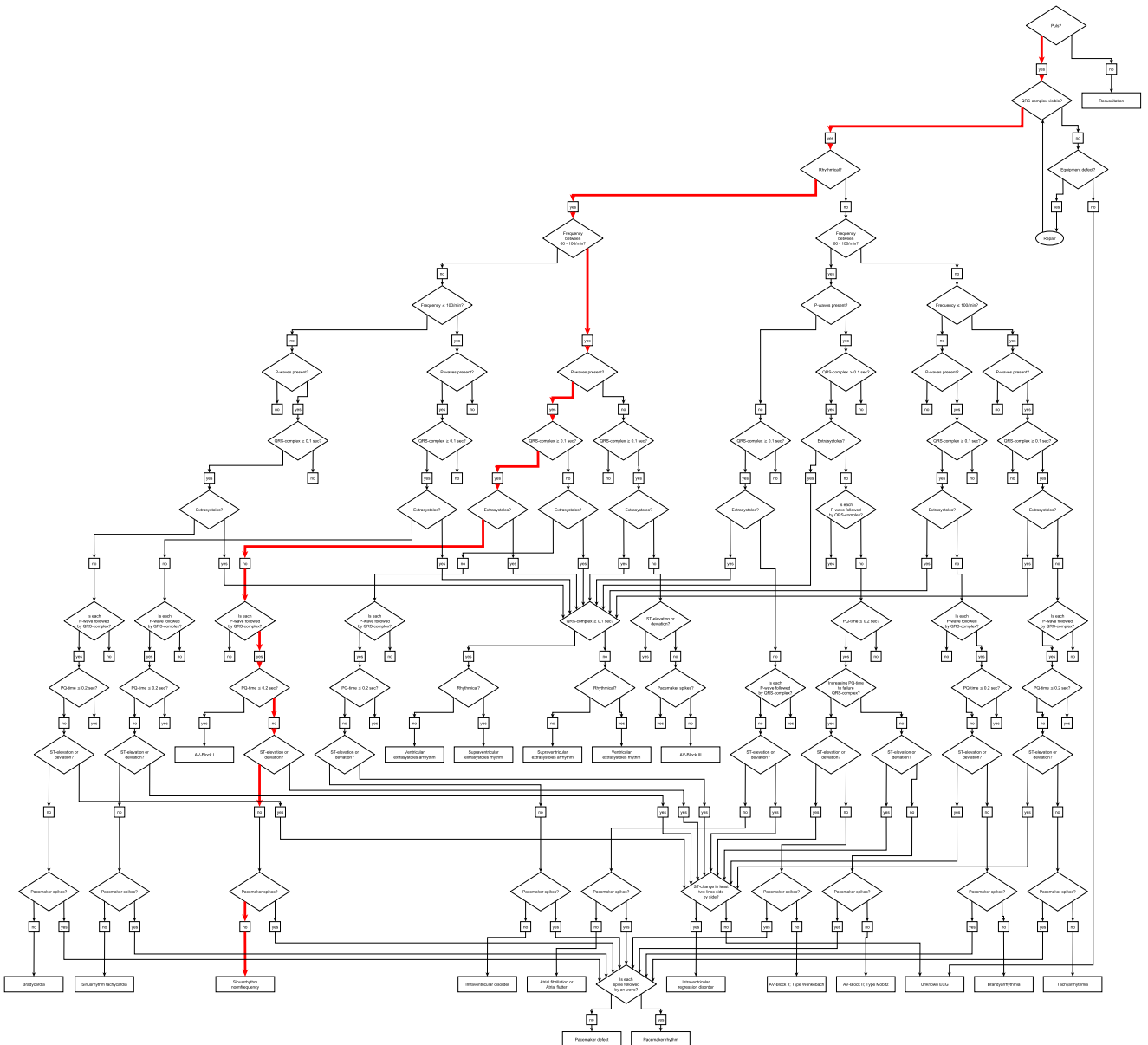


Figure 1. Primary large algorithm.

Table 2. X of questions

Question	Numbers in algorithm
Equipment defect?	1
Is each spike followed by an wave?	1
Puls?	1
QRS-complex visible?	1
ST-change in least two lines side by side?	1
Increasing PQ-time to failure QRS-complex?	1
Frequency between 60 - 100/min?	2
Frequency ≤ 100 /min?	2
Phythmical?	3
P-waves present?	6
PQ-time ≤ 0.2 sec?	7
Is each P-wave followed by QRS-complex?	8
Extrasystoles?	9
QRS-complex ≥ 0.1 sec?	9
Pacemaker spikes?	10
ST-elevation or deviation?	10

Secondary short algorithm

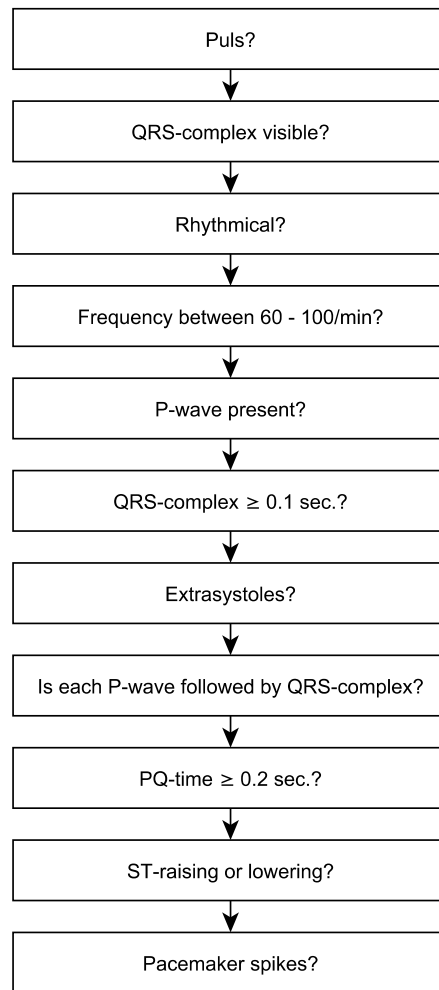


Figure 2. Secondary short algorithm.

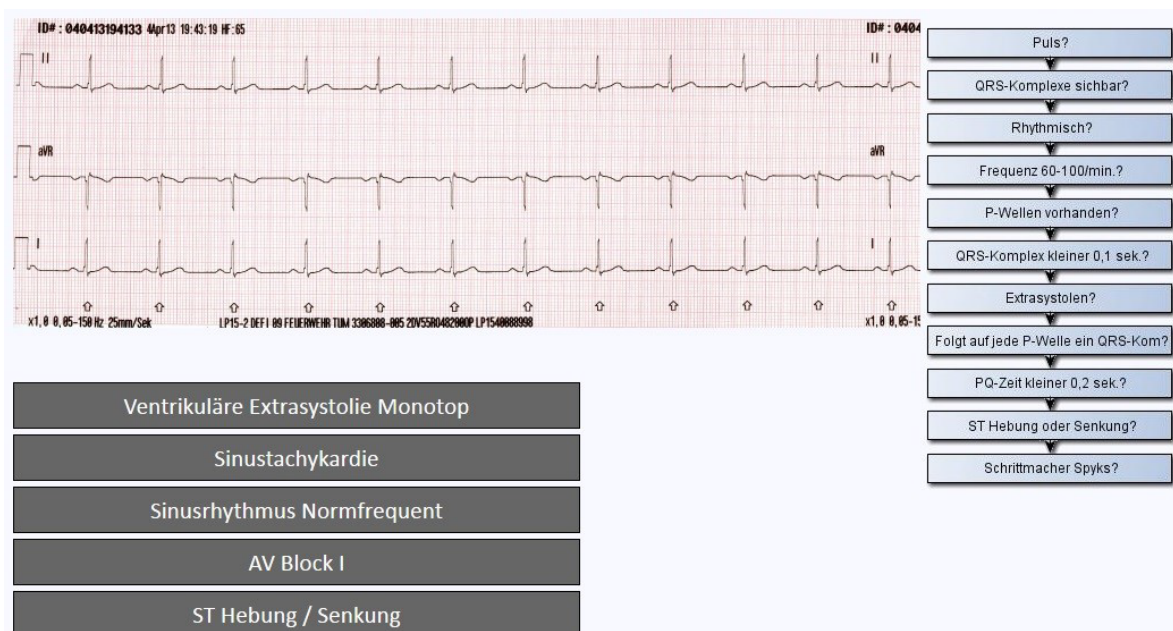


Figure 3. Online query of ECG images.

be interpreted and the possible answers. The participants were randomly assigned to the group with or without algorithm. Only in the group with algorithm the interpretation help was provided on the right side of the screen. The study included 15 ECG images, each with five similar response options.

Results of testsetting

A total of 402 people took part in the online study within three months. 357 subjects completed the complete ECG study. The group without algorithm comprises 175, those with algorithm 182 people. Mean values of the test group without algorithm (μ_0) are 392 [s] and 11.70 correct answers. The population means with the interpretation aid (μ) are 316 [s] and 12 correct answers. 62 % of the study participants stated that they are employed full-time in the rescue service. The arithmetic mean of the age was 31 years. The statistical mass includes 80 % men. The routine of the volunteers in ECG interpretation is shown in the table 3. Here it can be stated that most persons analyse an ECG 1 - 10 times per week. A good half estimate their ECG interpretation ability with four to five points out of ten. The rest was almost normally distributed. Hypothesentests. The two main hypotheses:

- The review of the first directed main hypothesis H1: $\mu > \mu_0$ vs. H0: $\mu \leq \mu_0$ "The number of correct preclinical ECG interpretations increases by using an algorithm" resulted in an assumption of the alternative hypothesis with $\alpha = 0.05$.
- The second main hypothesis H1: $\mu < \mu_0$ vs. H0: $\mu \geq \mu_0$ "The analysis time in the preclinical ECG interpretation decreases by using the developed algorithm" was rejected in favor of the null hypothesis and is therefore not valid.

From the study, directed alternative hypotheses can be generated:

- There is no correlation between gender, number of correct answers and total interpretation time.
- The degree of medical qualification influences the number of correct answers and the analysis time $\alpha = 0,05$.
- The self-assessment of the ability to interpret correlates positively with the number of correct answers $\alpha = 0.05$. The number of correct answers is also influenced by the level of medical qualification.
- There is a positive correlation between full-time employment in emergency services and the number of correct answers $\alpha = 0.05$. However, there is no correlation to be proven between analysis time and full-time employment.
- The frequency of the ECG interpretation has a positive influence on the number of correct answers when using the

algorithm $\alpha = 0.05$. The number of correct answers is not determined by the frequency of the ECG interpretation.

- The time span since obtaining the last highest medical qualification influences the number of correct answers when using the algorithm $\alpha = 0,005$.
- The algorithm has no influence on the number of correct answers in relation to the age of the test subjects.
- The lower the medical qualification of the test persons, the greater the effect of using the algorithm on the number of correct answers $p = 0.05$. The more the test persons are qualified, the greater the effect of using the algorithm on the number of correct answers $p = 0.05$. The more the test persons are qualified, the greater the effect of using the algorithm on the number of correct answers $p = 0.05$.

Discussion and outlook

This work resulted in the development of a practical algorithm for the interpretation of preclinical rele-vant ECG images in rescue operations. The interpretation time increases with the application of the specific questions, but the errors can be reduced by this measure. Especially people who seldom evaluate an ECG benefit from the interpretation aid.

A total of 357 participants completed the survey over a period of eight weeks. The great response from medical rescue personnel underlines the importance of this concern. Emergency images that require resuscitation are regularly trained - also in the watch operation - and refreshed with certified training units. However, normal internal emergencies, in which an ECG must be analysed, are the more frequent class of use. Therefore, the training should be promoted and deepened especially in this area, for example in the annual compulsory further training.

The online test setting of the algorithm proved to be a practicable means. This meant that it was only possible at all to ensure reliable recording of the time span until a decision on an answer was made. In addition, alternative hypotheses could be developed for future studies. Furthermore, when selecting an answer, the participant was forwarded directly to the next ECG image, so that a correction is not possible in order to rule out subsequent improvements. Another advantage of the Internet-based query was that the subjects could retreat to a quiet environment, which favored better concentration. On the other hand, the test subjects were able to receive uncontrolled help.

Internists and cardiologists, who regularly evaluate ECGs, have a very low error rate due to their abilities, skills and professional experience even without using the algorithm. In practice, these professional groups will not use interpretation

Table 3. Medical qualification

		Routine ECG interpretation per month						Total
		1-10	11-20	21-30	31-40	41-50	50- und mehr	
highest medical qualification	Doctor / Consultant	0	7	0	7	0	21	35
	First responder	7	0	0	0	0	0	7
	Instructor rescue medical service	42	8	14	7	7	0	77
	emergency paramedic (3 year training)	104	35	7	7	0	0	153
	emergency paramedic (0.5 year training)	50	7	7	0	0	0	64
	Basic fire department paramedic	21	0	0	0	0	0	21
Total		224	56	28	21	7	21	357

aids. In the rescue service, on the other hand, an introduction to the algorithm would be helpful for occupational groups with little routine in ECG interpretation. For practical use, the algo-rithmus would be particularly suitable as a laminated small-format aid for the ECG monitor, as it does not obstruct everyday business due to its small footprint and can be used in suitable situations without complications.

As already described, it is now common in rescue medicine to use algorithms to improve the outcome of patients. However, the analysis scheme presented here only contains an interpretation of the ECG image that is as error-free as possible. The treatment options resulting from the interpretation are not included. The link between ECG diagnosis and treatment is already described in other algorithms. However, these are always based on the ECG image, so that in the case of a misinterpretation a standardized treatment path is taken, but this leads to the wrong treatment. This is another reason why the algorithms should be used for preclinical interpretation of ECG images. How this improves the overall treatment success could be determined by a further study.

References

- [1] Bundesamt für Strahlenschutz. Methoden und Daten zur probabilistische Sicherheitsanalyse für Kernkraftwerke, Salzgitter; 2016.
- [2] Lufthansa AG. Safety Management System zur Verbesserung der Flugsicherheit, Frankfurt am Main; 2015.
- [3] Reason JT, Grabowski J. Menschliches Versagen. Psychologische Risikofaktoren und moderne Technologien. Spektrum Akademischer Verlag, Heidelberg; 1994.
- [4] Petrillo A, Zomparelli F. The Importance of Human Error and Reliability Management in Critical Conditions and Infrastructures. In: Fabio de Felice und Antonella Petrillo (Hg.): Human Factors and Reliability Engineering for Safety and Security in Critical Infrastructures. Decision Making, Theory, and Practice. Springer International Publishing (Springer Series in Reliability Engineering); 2018. P. S 1–18.
- [5] Bubb H. Menschliche Zuverlässigkeit - Ergonomische Anforderung und Methoden der Bewertung. VDI 4006 Blatt 1 und 2.
- [6] Dhillon BS. Safety, Reliability, Human Factors, and Human Error in Nuclear Power Plants. 1st ed. CRC Press; 2017.
- [7] Deutsches Institut für Normung e. V.: Informationsverarbeitung; Sinnbilder und ihre Anwendung (1983 - 12).
- [8] Demetrescu C, Sedgewick R, Tamassia R (2005) Proceedings of the seventh workshop on
- [9] Algorithm Engineering and Experiments and the second workshop on Analytic Algorithmics and
- [10] Combinatorics. Philadelphia.
- [11] Campbell JE, Kühl F. Präklinische Traumatologie. München; 2010.
- [12] Bernhardt M. Präklinisches Traumamanagement. Das PHTLS-Konzept. München; 2009.
- [13] Enke K. Lehrbuch für präklinische Notfallmedizin. Wien; 2005.
- [14] Böttinger BW, Baubin M, Mauri R, Dirks B. Leitlinien zur Reanimation 2015 des European
- [15] Resuscitation Council. Notfall Rettungsmed 2015;18:649–650
- [16] Russell S, Norvig P. Künstliche Intelligenz. Ein moderner Ansatz. In IT – Informatik. München; 2012.