Procedural Knowledge in Percutaneous Coronary Interventions

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Abstract

Percutaneous coronary intervention, PCI, is recursive process driven by decision making followed by action; the outcome is critically dependent on the *procedural knowledge and skills* of individual operators. In PCI procedural knowledge has been traditionally transferred employing the "trainee-mentor" approach. However, in number of profession including medicine, cognitive approach of procedural knowledge transfer has been shown to be superior to the conventional method. Here, we propose that the cognitive approach holds promise to improve the knowledge transfer and expertise in PCI and should be further explored.

Keywords: Percutaneous coronary interventions; Knowledge transfer; Procedural knowledge; Cognitive skills

Introduction

Expertise in percutaneous coronary interventions; PCIs, is based on two kinds of knowledge; *declarative knowledge that* and *procedural knowledge how;* concept originally introduced by Ryle [1]. Declarative knowledge is explicit, readily accessible, promptly transferred and easy to memorize; yet it may not be well suited to instruct action. In contrast, procedural knowledge is critical to instruct action, yet being mostly tacit it is difficult to access.

Declarative PCI knowledge is typically gained by study of literature and media communications; procedural PCI knowledge is largely gained by observation, imitation and practice. Although in clinical practice both types of knowledge are complementary, in the past due to the restricted access to procedural knowledge declarative knowledge has been strongly emphasized. Nevertheless, it is the procedural knowledge that appears to decide the outcomes [2].

To date, cognitive approach has been shown superior to the traditional method of knowledge transfer and expertise in a number of professions including aviation, military, sports and medicine [3]. Clearly, also in medicine the proof of the principle has been documented in number of studies focusing on acquisition of procedural expertise in performance of tracheostomy [4], basic surgical skills [5,6] and placements of central venous catheters [7]. In these studies the governing principles of explication of expert knowledge, explicit, mostly verbal instruction, deliberate practice and expert feed-back were followed.

Here, we shall briefly outline the cognitive approach to procedural PCI knowledge transfer. Psycho-motor skills are not subject of this report.

Cognition

Cognition is a biological process that based on sensory and internal stimuli provides mental representation of the real-world, fundamental to all decision making. Although at the proto-level it is shared by all living creatures, human cognition is far more complex; based on "off-line" processing of enormous fluxes of data it is capable of rational thought.

Human cognition has been traditionally portrayed by philosophers. Since the late 19th century it has become subject of scientific exploration becoming science on her own in 20th century; today, artificial intelligence, linguistics cognitive psychology and cognitive neuroscience represent the main tributaries.

In the course of the past several decades literarily hundreds of models have been proposed to anticipate human cognition. The hallmark of these empirical models is the principal use of mathematical or computer languages to allow valid interpretations and reliable predictions based on observational data. More recently, neurobiological models have been proposed based on complex hierarchical systems of neuronal networks [8] rather than on local neural structures proposed earlier [9]. While empirical models are generic, neurobiological models are detailed and specific.

The tripartite model serves as a representative example of an empirical design [10]. According to this design human cognition is organized in three fundamental levels; the pre-attentive, attentive-algorithmic and attentive-reflective. The pre-attentive System 1 level is shared by all higher vertebrates; it is fast (response times in milliseconds!), robust, reliable and largely stereotype. The attentive System 2 - algorithmic level is shared by higher primates; it oversees System 1, conducts associative and arbitrates rational thinking. The attentive System 2 - reflective level is unique to humans; it conducts rational and creative thinking, it is slower and more prone to errors, yet it is exquisitely adaptable to environmental changes (Figure 1). Although the tripartite model impressively defines the generic functions of the cognitive apparatus, to access specific cognitive functions far more detailed understanding of the underlined neurobiological processes is required [11].
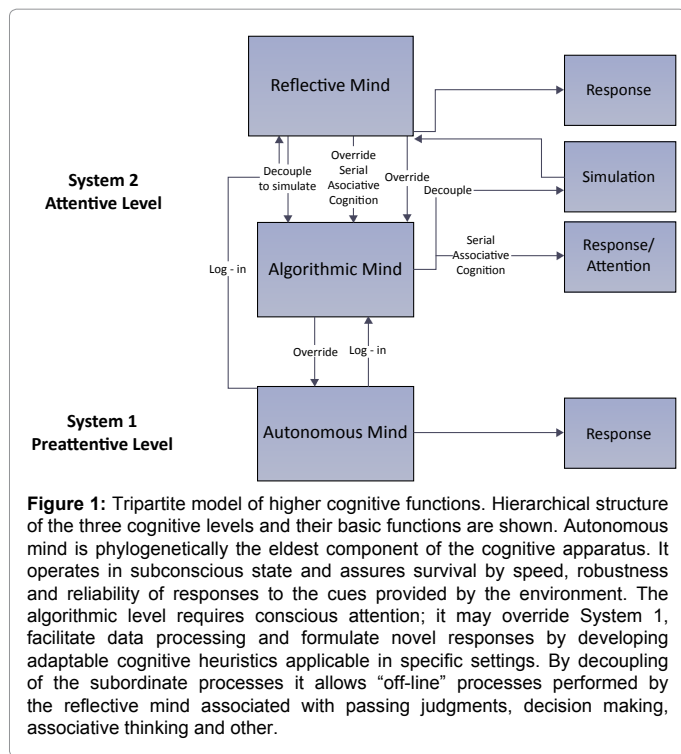
PCI Process

PCI is recursive process; it can be conveniently represented by

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Figure 1: Tripartite model of higher cognitive functions. Hierarchical structure of the three cognitive levels and their basic functions are shown. Autonomous mind is phylogenetically the eldest component of the cognitive apparatus. It operates in subconscious state and assures survival by speed, robustness and reliability of responses to the cues provided by the environment. The algorithmic level requires conscious attention; it may override System 1, facilitate data processing and formulate novel responses by developing adaptable cognitive heuristics applicable in specific settings. By decoupling of the subordinate processes it allows "off-line" processes performed by the reflective mind associated with passing judgments, decision making, associative thinking and other.

series of consecutive steps termed main interventional cycles, MIC, or rounds. Each round (except the last one) consists of two basic phases:

1. Angiographic image acquisition, interpretation, and decision upon action.
2. Performing the action, that can be either an interventional or a diagnostic step.

Each action triggers consecutive round. The decision in round N is always based on the outcome of the previous round N-1. The minimum number of rounds is N=2, e.g. direct stenting; complex interventions may consist of up to N=50 rounds, rarely more. Each round is designed to advance the intervention towards the stated goal, i.e. removal of coronary pathology. The last round lacks an action and triggers the termination of the procedure. While strategy represents the premeditated concept of specific PCI, tactics correspond to the actual execution of a given PCI. Both, PCI strategy and tactics are driven by knowledge-and skill-based decision making (Figure 2) [12].

MICs are guided by risk and benefit accounting. To assure optimum outcomes the following rules apply:
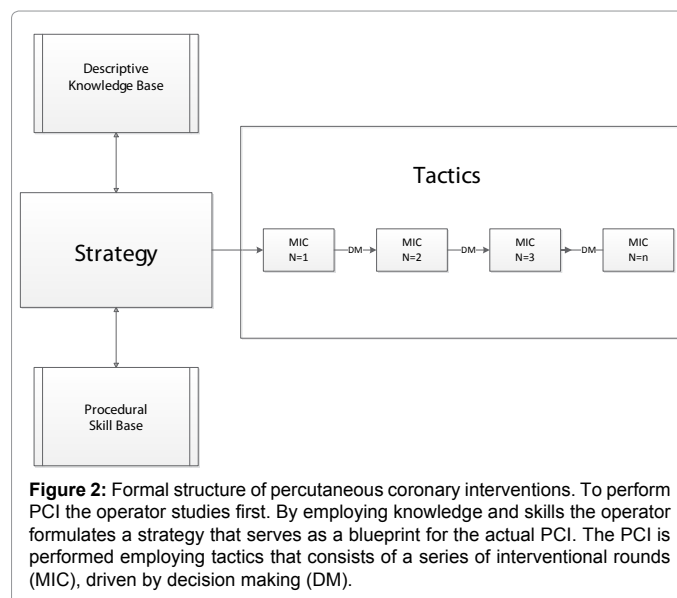
1. At each step during an intervention, the total risk should be minimized; thus all plausible actions should be considered, the actional risk incurred and the latent risk saved by each assessed and those steps with the least sum of both should be selected.
2. As long as the intervention produces overall benefits for the patient, the total risk will become smaller in each step, except for sudden changes in latent risk, e.g., due to patient instability.
3. To minimize the total actional risk the number of rounds should be kept at a minimum; rounds reducing the risk of subsequent rounds must be evaluated in light of their own actional risk.
4. To prevent escalations in procedures with increasing risk, more simple interventional strategies, or other treatment options should be considered.

Due to the recursive nature and extensive imaging documentation of each of the relevant interventional steps PCI appears to be particularly well suited to the cognitive method as shown in a number of medical non-PCI procedures (as above). To develop cognitive PCI teaching programs number of steps is required including standardized imaging documentation of cases suitable for consistent evaluation, development of "library of cases", expert panel sessions to extract expert knowledge, verbalization, definition of cognitive tasks to be mastered proceeding from standard to non-standard and from elective to emergency cases, design of practice tasks based on visual case presentation, instruction techniques, design and implementation of practice sessions and consecutive review process. Considering the complexity of each of the tasks development of cognitive PCI teaching programs may be a rather lengthy process. However, compared to the development of PCI teaching programs relying on simulation and external devices support including complex computer technology [13] cognitive method appears more favorable because it is based on real case scenarios and it is independent from external technology. In fact, to date only limited preliminary data concerning the efficacy of the computer based PCI teaching technology is available [14] and her relevance still remains to be determined.

Main Cognitive Tasks in PCI

In general, declarative PCI knowledge is represented by a compendium of cardiovascular medicine with the main focus on coronary artery disease while procedural PCI knowledge and skills represents the ability of individual operators to actually perform a PCI. According to current understanding learning includes transfer of both types of knowledge from the short-term to the long-term memory and recall in reverse [15]. Thus, it can be assumed that PCI expertise may depend partly on the "size" of stored "library of cases", and efficiency of recall by individual operators. However, it is likely that comprehensive PCI competence shall as well depend on a large number of other cognitive functions including sustained focused and divided attention, task switching and multitasking, operational modes of working, risk accounting, realistic self-efficacy, and quality of judgements as well as psycho-motor qualifications.

Inability to see the interventional sites directly causes the PCI

Figure 2: Formal structure of percutaneous coronary interventions. To perform PCI the operator studies first. By employing knowledge and skills the operator formulates a strategy that serves as a blueprint for the actual PCI. The PCI is performed employing tactics that consists of a series of interventional rounds (MIC), driven by decision making (DM).

operators to depend largely on retrieval and correct interpretation of data contained in dynamic cine and fluoroscopic images as well as static frames. It is beyond the scope of this article to review the neurobiology of visual processing [16], yet clearly rapid succession of number of specific visual tasks such as scanning, tracking, framing and speed of the visual processing, and perception of visual cues are all critical to information retrieval required for image interpretation, judgments and decision making throughout the interventional process.

Once the visual contextual information base has been established the next fundamental cognitive step is to translate this information, mostly in real-time, into the technicality of the actual coronary intervention. This translation is based on understanding of the biomechanical properties of target lesions, target sites and access pathways as well as the performance characteristics of interventional instrumentation. In essence, the operators attempt to match sites and instruments within the framework of risk, benefits and increasingly also economical considerations. Due to the enormous variety of interventional targets and multitude of performance characteristics of interventional instrumentation virtually unlimited number of possible PCI scenarios results. In summary, it appears reasonable to propose that visual skills and the abilities to translate images into technical performance factors belong to the most critical cognitive skills in the overall conduct of PCIs (Figure 3).

Development of Knowledge how

There is a general agreement that *procedural knowledge how* is attained slowly through practice. This process of practice may involve long periods of trial-and-error, in which the right knowledge eventually surfaces through a process of reinforcement. If a procedural skill is too complex, though, this trial-and-error process cannot properly discover all the necessary knowledge, and needs scaffolding in the form of declarative knowledge. As a consequence, it is generally assumed that the acquisition of complex cognitive skills starts with a declarative stage, in which knowledge guides behavior. The initial declarative knowledge can be obtained in a number of different ways, for example by observing
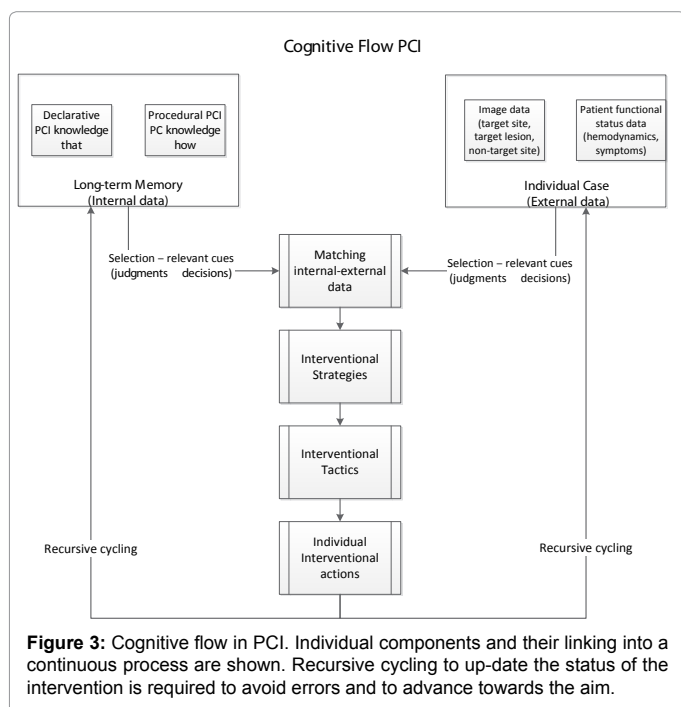
others, but most importantly for our purposes by instruction. This initial declarative stage of a skill has all the characteristics of novice behavior: using the knowledge is slow, it requires full, undivided attention, and many errors are made due to inaccuracies in the knowledge. Through practice, the declarative knowledge is gradually transformed into procedural knowledge, speeding up performance and reducing errors. This process of procedural skill acquisition is thought to be a form of knowledge compilation [17].

The following example can illustrate this process: suppose you are preparing a recipe from a cookbook. Typically a recipe consists of a number of steps that have to be taken in order to prepare the dish, and each of these steps has to be carried out in the right order. Cooking from a recipe is typically slow, because you have to consult the recipe fairly often, and have to remember where in the recipe you are. Mistakes are common, because it not always clear what the purpose of individual steps is neither is it clear what the exact and result should look (or taste) like. Even more troublesome is to try to prepare two recipes in parallel. Contrast this with cooking a well-known dish or even set of dishes, where performance is fast with few errors. In a sense, the cookbook is your externalized declarative knowledge, and becoming an expert cook means that you no longer need a cookbook, not because you have memorized the contents, but because you have internalized the art of cooking.

Anderson and Taatgen [18] assume that the transition from declarative stage can be explained by general procedural knowledge that interprets declarative knowledge (in terms of cooking: we already know how to carry out primitive steps in cooking, like boiling things, mixing ingredients and separating eggs, but we need to combine them in a coherent recipe and that is what we get from the cookbook). But if we repeatedly carry out this procedure, the knowledge from declarative memory is substituted into the interpreting procedural knowledge, creating new, specialized procedural knowledge specific to the task.

The quality of the resulting procedural knowledge depends to a large extent on the declarative knowledge that served as a basis. By quality, we refer to the robustness and flexibility: we want to be able to apply the knowledge not just in situations that are identical to the learning situation, but also in situations that are slightly different. Moreover, we want the knowledge to be robust against unknown outcomes: if an action does not produce its intended outcome, or some outside influence changes the problem, then the knowledge should enable a smooth adaptation. The key to robust and flexible skills is the right type of instruction combined with training. Instructions that are given as a list of steps to carry out without specifying the purpose of each step, and the external conditions under which they have to be carried out, tend to lead to brittle and overly specific skills. There are many examples of such instructions, for instructions manuals for electronic devices, like cameras, video equipment and computer software. More in particular they occur frequently in professional environments, like in aviation.

Instructions can be improved by supplying context to each of the individual steps. The context specifies under what condition a step should be carried out, and what the intended result of a step is. If steps are augmented with the purpose they want to achieve, it is much easier to use that knowledge in other context as well. While in a number of professions such as aviation the knowledge how has been externalized and verbalized thus being available for contextual explicit instructions the procedural PCI knowledge how has remained largely tacit. Consequently, at present in PCI transfer of knowledge how depends mostly on the quality of "trainee-mentor" interactions.

Figure 3: Cognitive flow in PCI. Individual components and their linking into a continuous process are shown. Recursive cycling to up-date the status of the intervention is required to avoid errors and to advance towards the aim.

Example: contextual knowledge how transfer - training program in aviation

A study by Taatgen, Huss, Dickison and Anderson 2008 [19] in the domain of aviation investigated whether the principles outlined hold in a highly professional environment. Large commercial airplanes are controlled by Flight Management Systems (FMS), sophisticated board computers that can carry out many aspects of a flight autonomously. Part of a pilot's training is to learn to operate the FMS. This consists of feeding the flight plan and other information about the flight into the system before the flight, and also adjusting the flight plan during flight depending on circumstances and directions from Air Traffic Control. Training on the FMS is done in two stages: a period of classroom instruction followed by training in a simulator. During classroom instruction, pilots learn approximately 100 different procedures that can be carried out on the FMS, each with a different purpose. Procedures are specified in checklists: numbered steps that have to be carried out in order. Pilots are expected to memorize the procedures before starting training in the simulator. In other words, the pilots are supplied with all the declarative information first in the classroom, after which they have to put it into practice in the simulator in order to proceduralize the skill. Unfortunately, this method often leads to poor results. Instructors in the flight simulator complain that it almost seems pilots have not learned anything during classroom instruction, and other reports compare learning the FMS to "drinking from a fire hose" [20]. Even after pilots are certified, many still have trouble carrying out less frequent procedures on the FMS.

The critical problem in the way training is organized is that pilots memorize procedures as lists of meaningless steps. Taatgen et al. [19] therefore designed an alternative representation in which every step was augmented with the context in which it had to be carried out, and also with the intended result of the step. For example, some of the procedures would start with a step that instructed pilots to press a key labeled "Legs". The purpose of this action, which was otherwise not explained, is to put a page of information on the display that shows the current flight plan (as opposed to other pages that show other flight information, like fuel, weather or communications). Obviously, this action of pressing the Legs key only needs to be carried out if the flight plan is not yet on the display, otherwise it is redundant. The augmented instruction therefore started the procedure with the instruction: "If you want to change the flight plan, and the flight plan is not yet on the display, press the Legs key to display the flight plan". This example is, of course, fairly elementary, and not very hard for pilots to discover what the function of the Legs key is. Other steps, however, were less obvious.

In their experiment, Taatgen et al. taught subjects a number of FMS procedures in either the standard form (taken from the United airlines instruction manuals), and the alternative augmented instruction. Subjects then had to solve a number of problems on a simulated FMS system. Some of these problems would require subjects to carry out the procedure exactly as they had learned it. Others required subjects to improvise. For example, the original procedure taught subjects how to change the first waypoint in the flight plan (a flight plan consists of a sequence of waypoints, which are like virtual intersections in the air). But that procedure could easily be adapted to modify any waypoint in the flight plan, and that was what subjects were asked to do.

The results of the experiments consistently showed that problems that required subjects to carry out a procedure exactly as specified were carried out equally well, regardless of the mode of instruction. But for the problems that required some improvisation, the augmented

instructions led to superior results: they both allowed subjects to learn to deal with these problems faster, but also led to a consistent advantage later in the experiment. Figure 4 shows the comparison of flight competence of pilots instructed by the conventional and cognitive approach.

Example: contextual knowledge how transfer – PCI case report

46 years old male has been admitted for severe chest pain ongoing for two hours prior to admission. 12 lead electrocardiogram showed inferior ST-elevation myocardial infarction and the patient has been taken to the catheterization laboratory. A junior cardiologist (four years clinical interventional practice, approximately 1000 PCIs) was to perform the procedure. Diagnostic coronary angiography has revealed a single vessel coronary artery disease with completely occluded right coronary artery, RCA, and PCI has been resumed. Following the placement of the 6French Judkins right guiding catheter the recanalization was attempted using the Balance Middle Weight, BMW, Boston Scientific guidewire. Following unsuccessful placement the operator has decided to increase back-up and to employ a more aggressive guidewire. 7F Amplatz, Medtronic, right 1.0 guiding catheter and Choice PT Boston Scientific guidewire were employed and successful guidewire placement has been achieved. Following two successive proximal to distal dilatations employing 2.0x20 mm dilatation catheter no antegrade coronary flow occurred. The patient experienced moderately severe chest pain with minor hemodynamic compromise; the operator has diagnosed extensive RCA dissection and decided to stop and to discuss the case with a senior cardiologist (>20 years of practice).

The case was briefly reassessed. Both operators have agreed that subintimal guidewire passage and repeated attempts of dilatation have resulted in longitudinal RCA dissection; the length of the dissection and entry points could not been determined from the available angiograms. It was also not clear whether the RCA- ostium was dissected. With
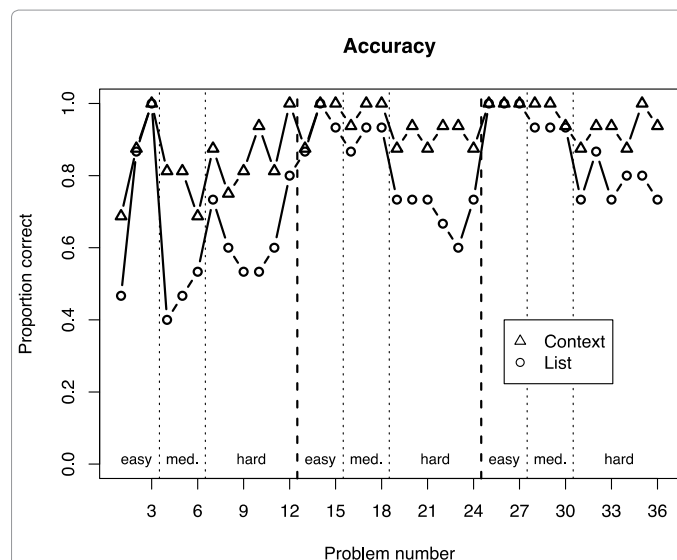

Figure 4: Comparison of flight competence of subjects instructed by the conventional (list) and cognitive (context) approach. The figure shows accuracy for 36 problems divided in 3 blocks of 12. Each block consisted of 3 easy problems (one procedure exactly as instructed), 3 medium problems (two interleaved procedures), and 6 hard problems (problem required some improvisation to solve).

the patient experiencing chest discomfort and with the onset of hemodynamic compromise expedient decisions were required. To save the case several options including stepwise withdrawal of the OTW-system with intermittent injection of contrast agent to determine the proximal flap, probing for the true lumen with different guidewires, confirmation of the guidewire position by intracoronary ultrasound, complete rewiring from the RCA- ostium, and surgical option were discussed. The junior cardiologist was ambivalent about options. The senior cardiologist suggested abandoning the initial escalating strategy with the primary aim to determine the involvement of the RCA-ostium in the dissection and secondary aim to identify the true lumen. Employing this explorative strategy 7F Amplatz right 1.0 Medtronic guiding catheter has been exchanged for 7F Judkins right 4.0 short-tip Medtronic guiding catheter and soft-tip non-aggressive guidewire, Whisper MS, Abbott, with the OTW balloon catheter were selected to carefully palpate the RCA- ostium and to search for the true lumen. The successive progress and the intraluminal position of the guidewire were repeatedly confirmed by injecting small amount of the contrast agent via the OTW balloon catheter. After securely placing the tip of the OTW balloon in AHA (American Heart Association) Segment 4 the guidewire was exchanged for a 300cm long balance middle weight, BMW, Boston Scientific guidewire and routine successive stenting of the dissected RCA- Segments was performed (Figure 5). Following the initial period of hemodynamic instability the patient stabilized and his chest pain resolved.

To provide a feed-back the case has been reviewed by both operators. Both operators agreed that the major steps towards saving the procedure have been de-escalation by deploying less dissection-prone instrumentation, careful re-exploration of the RCA- ostium for dissection and the use of the OTW- system to assure the intraluminal position of the instrumentation. Continuation or even stepping up the aggressiveness of the initial strategy would likely result in irreversible closure of the target vessel while de-escalation, re-evaluation and OTW- guided progress have provided satisfactory technical and immediate clinical outcome.

The case review showed that both operators were aware of the fact established by coronary angiography, i.e. extensive dissection. They were also aware of the fact that proceeding with the same strategy would be potentially risky and even futile. The key difference between the two operators was the absence vs. availability of procedural knowledge how to proceed in this specific setting after the initial strategy has failed. Once the main goal i.e. exploration of the RCA-ostium and the strategy, i.e. consequent use of the OTW- system to assure intraluminal position of the instrumentation the intermediate operator was in position to continue and to successfully complete the case. Although the junior cardiologist has experienced similar procedural complications in the past he has not been in position to decide upon available strategic options being unable to identify and address the key point, i.e. dissection of the RCA- ostium.

Knowledge how Transfer – Comparison between Aviation and PCI

In aviation procedural knowledge how has been over the years extensively externalized, verbalized and documented. It is verbalized in instruction manuals structured on declarative knowledge, i.e. on technical and scientific aeronautical data and it is also incorporated into virtual reality aviation simulators equipped with sophisticated board computers, FMS, programmed to mimic variety of real – life scenarios. Throughout the training pilots learn to master the knowledge how proceeding from simple to routine to unexpected scenarios. These established teaching processes assure objective assessments of achieved levels of professional competence by all trainees across the board independently from local circumstances and dispositions. Recently, based on cognitive research it has been shown that acquisition of knowledge how may be enhanced by providing the trainees with additional contextual data embedded into concrete tasks.
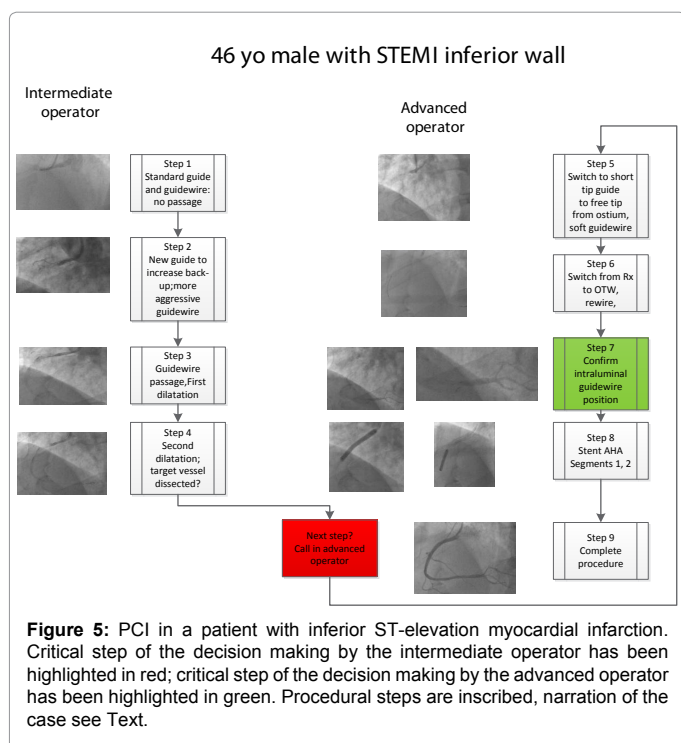
In contrast to aviation in PCI procedural knowledge has not been systematically verbalized and has remained despite over thirty years of clinical PCI practice mostly tacit. While textbooks on PCI typically beam with evidence based data derived from numerous devices driven trials the fundamental cognitive processes required for the actual PCI performance are scanty; however the "tips & tricks" seem popular to procedural skill transfer they cover only a tiny corner in the huge PCI decision space and are by far not enough to provide for the needs. The efficacy of traditional "trainee-mentor" knowledge transfer is highly dependent on ability of trainees to perceive and mentors to explain and to demonstrate; marked heterogeneity of professional PCI competence result. Development of cognitive teaching programs based on retrieval of expert knowledge appears critical to begin to close the gap between the training modus in aviation and PCI.

Conclusions

The conduct of PCI is recursive process with high demands on cognitive and technical skills of the operators. While in the past these procedural skills have been transferred mainly by mentor guided empirical approach future belong to cognitive training methods already successfully employed in number of professional fields including training of pilots in aviation. First however, professional commitment and explication of expert procedural PCI knowledge is required.

Conflict of Interest

Figure 5: PCI in a patient with inferior ST-elevation myocardial infarction. Critical step of the decision making by the intermediate operator has been highlighted in red; critical step of the decision making by the advanced operator has been highlighted in green. Procedural steps are inscribed, narration of the case see Text.

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