On Understanding Power of Judgement in Percutaneous Coronary Intervention

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Abstract

Aim: Explain how research can advance the state-of-the-practice in percutaneous coronary intervention (PCI).
Methods and results: Identifying the success factors of PCI; identifying decision-making performance (power of judgement) as the factor that could be advanced faster than it is currently the case; explaining why and how such advancement needs a different research approach than those currently pursued in medical research; presenting initial results of this approach in the form of a set of basic concepts (pivoting around *risk*) that are useful for describing the decision-making process during a PCI.
Conclusion: Building a terminology (ontology) of PCI decision-making concepts and then eliciting expert knowledge about the decision-making process itself are promising ways of advancing the teachability of PCI and hence the state-of-the-practice.

Keywords: PCI, decision-making, risk, education, training, state-of-the-practice

PCI success factors

The likelihood of success for an individual PCI (percutaneous coronary intervention) depends on four factors:

1. The condition of the patient. This refers to the patient's general as well as coronary status. For the purpose of this article we consider the initial patient status as given and beyond the influence of the operator.
2. The technical infrastructure available to the operator. This refers to all facilities of the operation environment, but particularly to the imaging, catheters, stents, and medication that can be used before, during, and after the intervention.
3. The operator's manual dexterity. This refers to the manual skill (or lack thereof) allowing the operator to perform just the intended movements and apply just the intended amount of force quickly, precisely, and reliably.
4. The operator's power of judgement. This comprises all of the operator's knowledge about factors 1 through 3 plus his or her capabilities for arriving quickly and reliably at suitable decisions about the next operational step. Such decisions take into account the portfolio of possible next interventional steps and select among them by weighing expected benefits against foreseeable risks.

PCI has become not become easier over time

Improvements in coronary imaging and the huge advances in coronary instrumentation including dilatation catheters, stents, and medication have occurred since Grüntzig's initial attempts at PCI (1). In addition, availability of evidence-based data has improved treatment judgements. Therefore, one should expect that PCI has become easier. However, it can be argued that this is not the case, because at the same time other factors have *increased* the difficulty of the typical intervention.

First, better instrumentation has enabled the operator to address far more complex cases formerly not considered suitable for PCI. The spectrum of PCI cases that are considered technically feasible has approached that of open surgery. Second, PCI is increasingly performed on aged patients presenting with more advanced CAD and multimorbidity (2). Third, PCI is increasingly performed in emergency settings or ad-hoc in single stage immediately following diagnostic coronary angiography (3). All these trends increase the risk of the intervention and hence decrease its likelihood of success.

Furthermore, since Grüntzig the PCI environment has dramatically changed. The optimistic reporting of results and needs of marketing and media representation have raised public expectation ever closer towards 100 percent success and zero complication rates (4); there is growing pressure to lower costs (5); the digital documentation of interventions provides detailed forensic evidence markedly aggravating the vulnerability of PCI operators in an increasingly litigation-charged environment (6). Taken together, these factors counteract the improvements in instrumentation and evidence-based rules of behaviour so that overall PCI has not become easier since its early days.

How to improve PCI

The difficulties described above require improving both the state-of-the-art and the state-of-the-practice of PCI. Let us consider the possibilities for doing that for each of the four factors in turn.

1. Patient condition. There is very little hope that PCI will become easier in terms of the patient conditions we have to face. On the contrary: demographic pressures may enforce us to perform PCI on increasingly difficult cases without increasing costs.
2. Infrastructure. The technical basis for PCI will likely continue to improve. Large amounts of effort and money are invested and room for improvement exists. Due to the powerful financial interests present in this area, it is not easy to evaluate and compare all innovations objectively and efficaciously, yet this is about the only critical stumble stone in this area.
3. Manual dexterity. The hand/eye skills of the operators are the most stable of the four factors. They can be learned, although only through long training and experience. There is no obvious shortcut or dramatic improvement we should expect in the next few years. In the long term, the availability of life-like computer simulations with perfect tactile feedback may shorten the learning curves of individual operators and improve the overall technical skills.
4. Power of judgement. When deciding what to do when, a master PCI operator takes into account large number of detailed parameters of patient status, interventional site and target lesions; an incredibly larger and richer set of criteria compared to the simple evidence-based advice that medical science has so far made available. We believe this factor should therefore receive much closer attention than it currently does.

How to improve power of judgement

Power of judgement can be defined as the capability of a person to regularly select a "good" option out of a set of possible options at a given time. Power of judgement is what drives the decision-process that lies at the heart of an actual PCI (7).

From a research point-of-view, improving power of judgement can be done in two rather different ways. First, by improving the state-of-the-practice, that is, the average capabilities of practicing PCI operators. Second, by improving the state-of-the-art, that is, the scientifically validated body of knowledge about how to perform PCI. We discuss each of these in turn.

Improving the state-of-the-practice

For improving the state-of-the-practice, we need to identify the set of critical factors and to focus on the conscious implementation of these factors in teaching the PCI decision-making process.

Master PCI operators exist, but we need to find better, more systematic ways how to transfer their knowledge to intermediate-level PCI operators. Currently, power of judgment in PCI is being formed in most cases in a non-rigorous (occasionally almost random) fashion based on the ability of individual operators to observe, rationalise, and implement empirical “tips and tricks” provided by angioplasty professors and on individual practical experience.

Improving the state-of-the-art

For improving the state-of-the-art, besides improving the science of mechanical and biological interactions involved in endocoronary treatments we need to find ways for externalising, objectifying, and evaluating the decision-making knowledge of master PCI operators.

From the point of view of knowledge transfer, the main problem is obviously the immense number of parameters that need to be taken into account, combined with the fact that the knowledge of these parameters is largely tacit and implicit; no PCI operator can enumerate all the things he takes into account when deciding on the next step of an intervention. However, at least intuitively, it is obvious that the repertoire of a master PCI operator is larger and better assorted when compared to intermediate- or novice-level PCI operators. It is this “library” of cases, factors, decisions, and outcomes that needs to be tapped. And while watching the work of master operators (e.g. by CCTV transmissions from catheter labs) and discussing their actions and decisions afterwards can certainly contribute, they are also certainly not enough, as we will now argue.

The immense number of parameters and their largely tacit character have a number of difficult consequences for any attempt at improving the state-of-the-art to anywhere near the level at which high-class PCI operators routinely perform.

- The large number of parameters means that tabulating the decision rules is hopeless. If a single rule takes into account a hundred tiny features of the vessel and the lesion, then not only will it be awkwardly long. Worse, there will be such a huge number of rules that nobody can ever hope to memorise, let alone apply them on an explicit, verbalised basis.
- The large number of parameters means there is no hope of validating rules by controlled experiments. No two patients or groups of patients will ever be sufficiently alike to evaluate one rule against another.
- Tacit knowledge means that no reliable method is known for eliciting the rules even if an all-knowing PCI operator was available (8).
- Tacit knowledge means that even if one could elicit a rule, no terminology is readily available to express it in a form that could be communicated intersubjectively.

Understanding power of judgement

We do therefore propose that our current focus should be on improving the state-of-the-practice rather than the state-of-the-art: Find ways to transfer the most critical PCI decision-making knowledge to less experienced PCI operators even if we are unable to validate this knowledge scientifically.

But why should it be possible to teach knowledge that we cannot express in such a form that could be validated? The reason is that human beings can share understanding of vague concepts, while science considers well-defined concepts only. For example, when a PCI operator uses a notion such as the vulnerability of a vessel (with respect to a potential balloon inflation) or the rigidity of a lesion, a second PCI operator can usually understand it, although these notions cannot easily be grasped scientifically because they consist of hundreds of different visual and tactile clues.

There are three ways how a concept can be vague. In the simplest case, the factors that form the concept are known, but the allowed values of these factors, although known, are not fixed. For instance, a lesion is not either rigid or non-rigid, but rather can be more or less rigid. Fuzzy Sets and Fuzzy Logic (9) have very successfully formalised such notions and enabled systematic reasoning about them. Note that the concepts thus defined, although they are gradual rather than strictly yes/no in nature, are still completely well-defined in a mathematical sense. Since such precise knowledge is usually not available in the PCI context (10), Fuzzy Logic will be difficult to apply, though.

In the second, more difficult case, the factors that form the concept are known, but their interplay and allowable values are not. The field of machine learning (11) describes how to handle such cases, employing techniques such as artificial neural networks and others. The basic idea here is "learning" the concepts (which themselves may be fuzzy concepts) by statistically identifying the commonalities in sets of positive and negative examples. Each example consists of a set of numerical or categorical parameter values that are assumed to be relevant in some (yet unknown) way. The learning algorithm will figure out by mathematical means which values of which parameters are relevant in which combination to indicate a certain outcome. It will be difficult to apply such methods to PCI, as we usually cannot precisely enumerate and quantify the relevant factors involved as parameters.

In the third, most difficult case, it is not known what factors form the concept. For PCI, unfortunately this is the prevalent case. The way out of this problem is known as *knowledge engineering* (12). It works by eliciting candidate factors from experts and discussing them until a useful description of the concept emerges. Such a process is required for example for describing how an expert PCI operator assesses the vulnerability of a vessel based on the available visual, tactile, and other diagnostic information.

The knowledge engineering process is almost always severely impaired by a lack of terminology. The candidate factors or the ways in which they are weighed and combined may themselves be vague concepts or at least no standardised terms exist to refer to them. The first step towards making PCI power of judgement understandable is therefore creating a suitable *ontology*, a hierarchical set of terms with defined meaning and relationships that describes the phenomena we need to talk about in order to capture how PCI experts decide. Knowledge engineering is the most promising approach to knowledge transfer in the PCI context and should be further explored.

Basic concepts for describing PCI decision-making

We have made an initial attempt at actually describing the PCI decision-making process (7) and have identified a number of basic concepts (set in *italics* below) for a PCI ontology. The most fundamental insight was that PCI decision-making is largely controlled by the notion of *risk*.

Qualitatively, a risk is an undesirable *event* that may or may not occur. Quantitatively, *risk* is the extent of *damage* incurred by the event weighed by its *probability* – even if both damage and probability are known only very roughly. PCI decision-making attempts taking the course of action with the lowest overall risk and the highest *benefit* for the individual patient. There are two fundamentally different kinds of risk, latent risk and actional risk.

Latent risk is risk that is inherent in the patient's status until actively removed; the most typical example being myocardial infarction. There are two ways of *dealing* with latent risk: one may either *accept* it and not address it, or *mitigate* it by working actively to reduce it. The two main *purposes* of PCI are mitigation of the latent risk and reduction of a patient's *symptoms*.

Actional risk, on the other hand, is the risk created by the actions of the operator. There are two ways of dealing with actional risk: one may either *avoid* it by not performing the respective action, or *accept* it and perform the action anyway. Much of PCI decision making revolves around the question of what constitutes *acceptable* actional risk. Actional risk is always accompanied by *financial costs* and by *expected benefits*. Actional risk can be partitioned into three additive components: optimum-choice actional risk, knowledge risk, and indirect risk.

Optimum-choice actional risk refers to that part of actional risk that an ideal operator acting with perfect information would intentionally accept during the production of optimum interventional results.

Knowledge risk is the part of actional risk incurred in practice because the operator's *information* about the vessel and lesion status is *incomplete* and *imprecise*, due to *limitations in imaging* and perhaps *intentional abdication* of additional diagnostic steps.

Indirect risk refers to the part of actional risk incurred by voluntarily giving up existing benefits. This is best explained by an example: Assume we have a guiding catheter in place in a vessel. If the PCI is not yet terminated, this is a benefit. Now, assume we want to exchange this catheter for another one (say, to switch from 5F to 7F). Obviously, this step involves actional risk since we may inflict damage on the patient during catheter exchange. However, even if no damage occurs, it may happen that for some reason the target vessel cannot be accessed because it proves impossible to appropriately position either this new catheter or any other one tried later. Thus, by removing a guiding catheter, we risk losing the benefit of having a well-positioned catheter (even if only 5F) in place. The possibility that this will happen is represented as indirect risk.

Conclusion

Decision-making performance appears to be the most highly modifiable factor affecting the outcome of endovascular interventions. To date the transfer of knowledge regarding the required power of judgement from expert to novice PCI operators has not been worked out systematically. Here, we provide what to our knowledge is the first attempt on a framework aiming at systematic and reproducible PCI knowledge elicitation, transfer, and acquisition based. The framework centers on risk assessment. Further work should now extend and elaborate our set of basic concepts in order to form a full PCI decision-making ontology, then elicit expert descriptions of more and more aspects of the decision process, and finally use these to educate both novice and intermediate PCI operators in order to improve the state-of-the-practice (and hence presumably the intervention results right-off-the-table as well as longer term). This process will also provide hypotheses for which we may attempt scientific validation, thus eventually also improving the state-of-the-art.

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