Failure-avoidance analysis: a brief introduction for neuroradiologists.

S T Hecht

AJNR Am J Neuroradiol 1993, 14 (5) 1094-1096
http://www.ajnr.org/content/14/5/1094.citation

Commentary

Failure-Avoidance Analysis: A Brief Introduction for Neuroradiologists

Stephen T. Hecht[1]

Neuroradiologic special procedures represent extraordinary feats of craftsmanship. To show respect for our patients, and for our teachers, we seek to bring forth the finest expression of our craft in each procedure. We all have our own little halls of fame, composed of revered individuals, who for us personify the essence of the craft. We have developed our own techniques over years, composites of what we have been taught and what we have learned by experience, often intuitively.

Neuroradiologic special procedures represent extraordinary technical accomplishments. Using a superb battery of devices, we venture almost imperceptibly into once inviolable reaches of the body, sometimes to examine, sometimes to modify. The development and deployment of those devices are exercises in engineering.

What are we? Are we craftspeople or are we engineers? Consciously or unconsciously, we have elements of both. Medicine has been, and to this day is, dominated by the tradition of craftsmanship. We are, after all, descended in part from barbers. We are familiar with the craftsperson's paradigm: if I understand the properties and capabilities of my materials, and if I have developed a rational plan for the case, and if I prepare the patient properly, and if I have everything I might possibly need, then I hope to succeed.

The engineering paradigm is somewhat less familiar to us. Engineers understand that all materials and all devices fail; they seek to define failure conditions. Physicians tend to personalize failure, and interpret it as a sign of personal shortcomings. Engineers tend to accept failure as a familiar phenomenon. They unemotionally discuss functions like the MTBF, the mean time between failures, an acceptance of the inevitability of failure. Engineers learn about the failure modes of materials and devices by testing, often by destructive testing. Destructive testing is another way of saying breaking things. By breaking things many times, in many ways, under controlled conditions, performance characteristics can be determined.

The paper by Drs. Schueler and Ruefenacht, published in this edition of the *American Journal of Neuroradiology* (1), is an engineering analysis of some devices used in interventional neuroradiology. They have measured the performance characteristics of endovascular balloons under standardized conditions in the laboratory. Since the laboratory conditions are similar to conditions found in the human body, the performance characteristics defined in the laboratory can be extrapolated to performance characteristics in living systems. In the laboratory we can learn the bursting pressures of balloons, the aspect ratios (the ratio of length to diameter) that presage rupture, and other failure conditions. Armed with an engineering analysis of the balloons, we can work within their performance envelopes, avoiding balloon failure. By making observations during procedures on human patients, it would take much longer and be far more dangerous to develop the same data, and we might never understand them with the same certitude as we can with controlled laboratory experimentation.

Engineering analysis of complex systems has been driven, in large part, by the aerospace industry. Enthusiasm for aviation has historically been tempered by concern over spectacular and appalling failures. In response to the failures, reliability theory and fault tree analysis were developed, beginning in the 1950s. Reliability theory, which originated in the engineering sciences and has been developed by mathematicians and

[1] Departments of Radiology and Neurological Surgery, University of California, Davis, 2516 Stockton Blvd, Sacramento, CA 95817.

Index terms: Catheters and catheterization, balloons; Interventional instrumentation, embolizing systems; Interventional neuroradiology, complications of; Arteries, cerebral; Animal studies; Commentaries

AJNR 14:1094–1096, Sep/Oct 1993 0195-6108/93/1405-1094 © American Society of Neuroradiology

statisticians, is based upon statistical analysis of the life lengths of materials. Fault tree analysis, developed by engineers without predominance of mathematical and statistical analysis, is based upon intimate understanding of system design and operation. Fault tree analysis takes its name from the tree-shaped diagrams that graphically portray system conditions that can result in undesired events.

Recently an analytic method called failure-avoidance analysis has been developed by Kent Stephens, a mathematician familiar with the aerospace industry (Kent Stephens, personal communication). At the root of failure-avoidance analysis is the axiom that for any event, the sum of the probability of success plus the probability of failure equals one. Decreasing the probability of failure acts to increase positive outcomes just as increasing the probability of success does.

We tend to achieve positive change by a success-driven process (eg, the craftsperson's paradigm); we attempt to satisfy all conditions required for success. For example, to perform an arteriogram successfully, we must have the best available equipment, and we must have the most highly trained personnel, and we must have an excellent power supply, and . . . The success-driven approach is subject to *and* logic dominance; there must be simultaneous satisfaction of many conditions for success to occur. *And* logic sequences are budgetarily additive, and are therefore extremely resource intensive, especially at the margin. An alternative to the success-driven approach is to seek to decrease failure potential. As failure potential decreases, it becomes increasingly worthwhile to take risks that may introduce positive change. When we analyze the determinants of failure, we find an *or*-based system. For example, if an arteriogram has an undesirable outcome, it could be the result of an equipment failure, or an error by personnel, or a power failure, or . . . Whereas complete sequences of events and conditions are required for success, single events produce failures. Identifying and eliminating individual failure-producing conditions depresses failure potential, which in turn increases the potential for positive change. The reductive approach of failure avoidance is far more cost effective than the additive, success-driven approach.

Central to the success-driven approach is the concept of achieving what should be. When we consider what should be, we gravitate toward concepts of safety and conformity, which tend to reduce creativity. At the crux of the failure-avoidance–analysis approach is the concept of defining what should not occur. The act of considering how to avoid conditions that should not occur has a releasing effect on imagination and initiative, open-ended concepts associated with increased creativity, and freedom of thought and action.

The success-driven and failure-avoidance approaches are not mutually exclusive; they are complementary. The factors that lead to success are not simply the inverse of the factors that lead to failure, and therefore success-inducing behavior complements simultaneous failure-avoidance behavior. However, as the marginal cost of the success-driven approach becomes exorbitant, the relatively more cost effective failure-avoidance approach becomes progressively more attractive.

Success augmentation and failure-avoidance analysis can be directed at the hardware level (device-device interactions), at the operator level (human-device interactions), and at the management level (human-human interactions).

How does the process of failure-avoidance analysis relate to neuroradiology? As we seek to induce success by creating increasingly complex and competent devices and techniques, we can complement the functions of that equipment and those techniques by reducing failure-encouraging behavior. Balloons do not overinflate themselves; we overinflate them. If we understand their performance characteristics better, we can do so less often. The paper by Drs. Schueler and Ruefenacht is an outstanding example of the type of work that we must see more of, the type of inquiry that will help us reduce failure during procedures because we will have a better understanding of how to avoid failure conditions.

The failure-avoidance approach is not simply restricted to destructive testing in the laboratory. Ideally, we will integrate it into our thought processes, so every time we think "what do I hope to achieve in this case" (the success-driven approach), we will also think "what must not occur, and how can we avoid it?" And if we articulate those concepts aloud, we can engage every member of our teams into the process, generating a broader spectrum of potentially beneficial ideas. The tremendous potential for positive gain of our developing armamentarium of devices can be negated by the suboptimal use of it. If, however, we carefully analyze the myriad interactions in the complex procedures we perform, we can identify critical areas in which the potential for failure is great, and seek to reduce those failure potentials. The stunning technical advances of interventional neuroradiology in recent years are the result of very careful and logical analyses of the conditions required for success. Our potential to do good could be increased by equally careful and logical analyses of the conditions at all levels that lead to failure when we use our powerful armamentarium.

So we need to embrace the paradigms of both the craftsperson and the engineer. That we are more familiar with the principles of craftsmanship than those of engineering reflects the differential evolution of our field. Just as some children walk before they speak and some do it the other way around, we have understood craftsmanship first. But we now must and will bring an understanding of engineering principles into our conscious minds. The coming years will be a time of discovery and integration for all of us.

References

1. Schueler BA, Ruefenacht DA. Risk factors leading to cerebral arterial rupture by intravascular balloon. *AJNR: Am J Neuroradiol* 1993;14:1085–1093