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Rapid Communication

Complexity and forensic pathology

Richard Martin Jones *

Wales Institute of Forensic Medicine, Cardiff University School of Medicine, University Hospital of Wales, Heath Park, Cardiff, Wales CF14 4XN, UK

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ABSTRACT

It has become increasingly apparent that nonlinearity and complexity are the norm in human physiological systems, the relevance of which is informing an enhanced understanding of basic pathological processes such as inflammation, the host response to severe trauma, and critical illness.

This article will explore how an understanding of nonlinear systems and complexity might inform the study of the pathophysiology of deaths of medicolegal interest, and how 'complexity thinking' might usefully be incorporated into modern forensic medicine and forensic pathology research, education and practice.

1. Introduction

A young man – subsequently known to have a mental illness, and found to have taken a stimulant drug – is seen behaving strangely in the street. He is partially dressed, appears to be sweating profusely, and periodically hits parked cars with a stick. Law enforcement personnel are alerted and, when they confront the man, he becomes abusive and more agitated. He refuses to drop the stick he is waving above his head, and struggles when restrained lying on his front on the ground. After a few minutes of intense physical activity, during which he is heard to complain of difficulty in breathing, he becomes quiet, and is motionless. On turning him onto his back, he is unresponsive and found to be in cardiac arrest, from which he cannot be resuscitated.

Forensic pathologists are familiar with such a complicated 'struggle against restraint' scenario, and with the questions which arise in the legal forum – a forum where the questions will seek determinative answers to what – to them – may seem simple questions of causation and/or culpability.

The role of the forensic pathologist in such cases is to endeavour to address such questions in a way which is both valid and fair, and to point out the areas where uncertainty exists – sometimes to a degree where determination of the precise part played by specific components of a scenario is not possible: in these latter circumstances, the forensic pathologist must attempt to explain what lies behind such limitations.

This is challenging, not least because of an incomplete understanding of the significance of multiple relevant factors – many of which are reviewed by Aiken et al. [1] and Barnett et al. [2] – although a schematic 'map' such as that seen in Fig. 1 can be constructed to assist the court in locating an act of legal significance (e.g. physical restraint against which the deceased struggled) within the network of multiple interrelated factors of relevance to the death.

The scientific tradition of attempting to explain a phenomenon of interest is predicated on the assumptions that explaining the individual 'components' allows one to explain the phenomenon as a whole (i.e. the 'reductionist' approach exemplified by René Descartes (1596–1650) and Sir Isaac Newton (1642–1727) [3], and that there is a linear relationship between the properties exhibited by the components and those of the 'whole'.

Whilst such an approach has been immensely successful, it has been increasingly recognized as insufficient to explain many physiological phenomena, in which **nonlinearity** is ubiquitous [3], and the output/behaviour of the phenomenon of interest is not proportional to the sum of its component inputs.

A different, but complementary, approach has emerged, exploring nonlinearity and '**complexity**' in physiological systems – in health and disease – and is increasing our understanding of how the human body responds to injurious insults, many of which are directly relevant to forensic medicine.

* Tel.: +44 2920742911.
E-mail address: jonesrm11@cardiff.ac.uk

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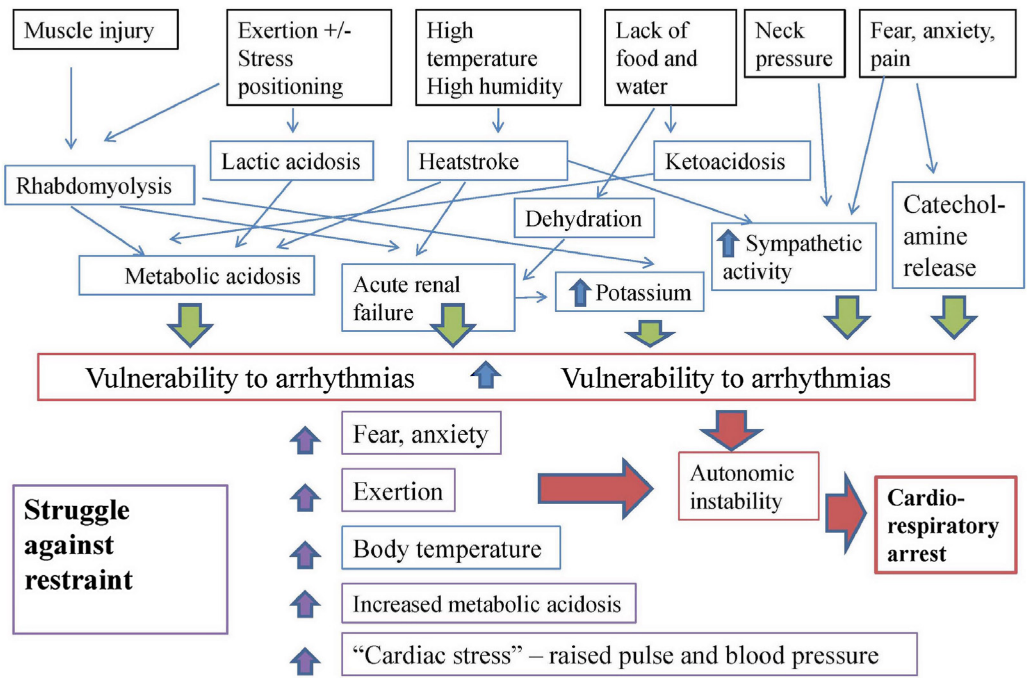

Fig. 1. An outline schematic map created to explain potentially relevant factors in a 'struggle against restraint-type death' (produced for the Baha Mousa Public Inquiry, the report of which was published in 2011 http://www.bahamousainquiry.org/linkedfiles/baha_mousa/baha_mousa_inquiry_evidence/evidence_171109/mod046705.pdf).

If we aim to make reliable decisions about the relative weight/importance of factors of relevance to a death – and the *cause* of death – we must do so with an appreciation of nonlinearity and complexity in physiological processes. A 'complexity approach' to matters of forensic pathological interest – including the use of computational modelling techniques – might help to elucidate relationships between actions of legal interest and physiological perturbations, providing the basis for reliable claims as to causation. Alternatively, such modelling might identify unforeseen perturbations relevant to death that are unrelated (or trivially related) to an action of legal significance.

This article will explore whether a complexity approach, and 'complexity thinking', might usefully be incorporated into modern forensic medicine and forensic pathology research, education and practice.

2. Complicated or complex? The significance of nonlinear system dynamics

If the behaviour or output of a **system** – an organized assembly of interacting components – is proportionate to the combined inputs of its individual components, it is linear, and amenable to linear mathematical analysis [4] and reductionism.

Physiological systems, on the whole, cannot be completely described in linear mathematical terms, however, because not only are they **complicated** (they are composed of diverse individual components), but also they are **nonlinear** and **complex** (the behaviour of the system cannot be predicted by analyzing those individual component parts in isolation).

When attempting to understand the behaviour of physiological systems, a reductionist approach is insufficient due to the rich inter-relationships between dynamically inter-connected system components [3,5–7].

'**Systems Biology**' [8,9] represents the bioscience community's focus on the application of complex nonlinear systems mathematics (informed by nonlinear dynamics, deterministic chaos theory, dynamical systems theory, complex adaptive systems theory, and complexity theory) and computer modelling/simulation to the holistic study of physiological systems, and **'Network Medicine'** is emerging as a biomedical correlate, integrating molecular data and network theory to study human disease [10–12]. Common properties of complex nonlinear systems that recur in the 'complexity' literature, are described in Box 1.

A nonlinear dynamics complexity approach is yielding valuable insights into physiological systems in health and disease, much of which has implications for clinical medicine including the management of critically ill and traumatized patients.

It is perhaps surprising that nonlinear complexity is so prevalent in physiology, but it is argued that nonlinearity facilitates internal (system–system, and sub-system–sub-system), and external (host–environment) communication [13], dynamic stability and order, and 'robustness' to perturbation (see Box 2).

Methods of identifying complexity in physiological systems utilize mathematical/computational analysis, including the determination of fractal dimensions of molecules, anatomical structures (the branching vasculature, or respiratory tract, for example), and physiological signals such as heart rate variability, systemic blood pressure, and some ion-channel kinetics [14]. Validated real-time analysis of physiological complexity, however, has been elusive.

3. Complexity and the pathophysiology of inflammation

An understanding of many deaths of medicolegal interest requires consideration of the consequences of inflammation and trauma.

The physiology of the host response to an insult is characterized by multi-system cellular, biochemical, and behavioural phenomena. 'Mapping' the diverse range of components of that host response (see http://bit.ly/1JwBb5Q for an example created for undergraduate medical teaching) reveals that it is complicated, but it is increasingly becoming apparent that it is also characterized by nonlinear complexity.

The unregulated inflammatory response can, in some circumstances, lead to the Systemic Inflammatory Response Syndrome (SIRS), Multiple Organ Dysfunction Syndrome (MODS), Multiple Organ Failure (MOF), and death. Sepsis reflects that same