Falls and frailty: lessons from complex systems

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DECLARATIONS

Competing interests
None declared

Funding
REH has received financial support from the Peel Medical Research Trust and the Fountain Innovation Fund of the Queen Elizabeth II Health Sciences Foundation

Ethical approval
Not applicable

Guarantor
REH

Contributorship
Both authors contributed equally

Acknowledgements
None

Introduction

Falls and frailty share many significant characteristics. Both are important health issues that affect older people, increase with increasing patient age and are multifactorial phenomena associated with adverse health outcomes. There are also important differences. Falls tend to be viewed by health professionals from a positivist perspective, as predictable events which they have a duty to try and prevent.[1] Falls prevention has become an important target of United Kingdom national health policy[2] and the focus of dedicated service development. Frailty, on the other hand, still lacks a precise definition[3] and is viewed by some as an inevitable consequence of age-related disease processes.[4] The prevention and treatment of frailty, while being fundamental aspirations of many researchers in the ageing field, currently remain enigmatic.

One construct for understanding frailty conceptualizes the frail older person as a complex system on the threshold of breakdown.[5] In this context, falls are more than just antecedents or associates of frailty but are a manifestation of complex system failure.[6] When complex systems fail they exhibit predictable patterns of behaviour and this can shed light on the reason why falls are frequently the 'atypical' presentation of illness in frail older adults.

In this review, the association between frailty and falls is explored. We consider how the conceptualization of frailty as a complex system failure might help us understand existing evidence regarding the aetiology and prevention of falls and, most importantly, how it might impact our clinical practice.

Frailty and geriatric syndromes

Falls, along with weight loss, incontinence, confusion and failure to thrive, were described by Professor Isaacs in the 1960s as 'geriatric giants'[7] and are now termed 'geriatric syndromes'. Geriatric syndromes have been defined as 'multifactorial health conditions that occur [due to] accumulated impairments in multiple systems'.[8] Their high prevalence has rendered 'atypical diseases' a misnomer. More than half the older people in one series presented with clinical symptoms and signs which did not directly correspond with their pathological disease process.[9] Older people defined as frail because of functional limitations were more likely to present with any geriatric syndrome[10] and there is now increasing evidence linking frailty specifically to falls.

In a large study of 6724 community-dwelling older women, frailty was an independent predictor of falls.[11] Among 111 men and women aged over 75 years, those defined as frail were 3.6 times as likely to fall as non-frail adults,[12] and frailty, measured by a lower Barthel score one month prior to hospital admission, significantly and independently predicted falls on a geriatric medicine rehabilitation unit.[13]

These studies have used different definitions of frailty. A consensus seems to have been reached in recent years that frail older people have decreased physiological reserves resulting in increased vulnerability to stressors.[14] However, how to characterize frailty in clinical practice remains controversial[3] and its measurement is an area of ongoing debate.

One construct for understanding frailty conceptualizes the frail older person as a complex system

on the threshold of breakdown.[5] The following sections explore the nature of complex systems and consider why falls may be a manifestation of complex system failure.

Characteristics of complex systems

The strength of a functioning complex system (whether biological, mechanical, political, etc.) rests in its inherent ability to withstand stresses because of the presence of multiple defences. As a result of these defences, failure of a complex system is rarely the result of a single cause but is the cumulative effect of many small insults, each of which may appear to be harmless on its own.[15] The road to failure is not abrupt because a complex system has many redundancies and as long as its reserves are not critically compromised, failing components can be replaced or circumvented and the deteriorating system may appear to function normally for some time despite the presence of defects. When system failure does occur, each small stressor that contributes to the breakdown is necessary but not sufficient to cause the failure on its own. The first processes to be compromised in the event of failure are typically higher-order functions, because they require a coordinated, integrated and precise interaction between many components of the complex system. In humans, such higher order functions include bipedal ambulation[16] and advanced cognitive processes such as divided attention.[5]

Both young and old people can be thought of as complex biological systems that are subject to various minor stresses. The distinguishing characteristic of the frail older person, however, is that the functions of many processes are already on the brink of failure so that any small stress is of more clinical significance in these individuals.[17]

Falling as a manifestation of complex system failure

Aetiology of falls

If we think about falling as a manifestation of complex system failure, it is easy to appreciate why falls in frail older people can be caused by any number of diverse precipitants. It has long been recognized that falls generally result from multiple, often inter-acting, factors. The British Geriatrics Society,[18] American Geriatrics Society,[19] Australian Commission on Safety and Quality in Health Care[20] and National Institute for Health and Clinical Excellence[21] have each issued guidelines on the management of falls which emphasize their multifactorial aetiology. Systematic reviews on falls prevention[22] or assessment[23,24] are underpinned by the attribution of falls to multiple interacting factors rather than one identifiable cause.

Yet some falls in older adults may result from a single cause. A prospective study of community-dwelling adults aged 70 years and older found that falls could be attributed to major external events in 15% of cases and to other single causes such as syncope or established neurological disease in a further 20%.[25] However, even the 'single cause' approach to falling may not be as straightforward as it appears. Syncope, for instance, is often quoted as an isolated cause of falls in the elderly but loss of consciousness may be the result of deteriorating function in several systems (e.g. cardiovascular, haematological and respiratory) in addition to defects in cerebral arterial circulation.[17,26] Therefore, it is reasonable to conclude that a substantial number of falls attributed to a single cause such as syncope may in reality arise from the interplay of various causal factors. This is consistent with the principle that complex system failure is usually due to the cumulative onslaught of several stressors.

Risk factors for falls

Older people who fall often have a profile of risk factors. Again, this is well-described in existing falls literature.[18–24] When considering risk factors it is important to keep in mind that while a particular parameter may be statistically associated with a higher risk of falling it is not always the direct cause of the fall. Instead, some risk factors (e.g. the use of an assistive device) may be markers of another serious problem (e.g. mobility deficit) that is causally associated with falling. In bivariate analysis hundreds of factors have been found to be statistically associated with falls in older adults but most are highly inter-related. The few parameters that have repeatedly been identified as independent predictors of falls in multivariate analysis include muscle strength of lower extremities, postural competence/lateral balance, impaired vision,

cognitive impairment and taking more than four medications or particular groups of drugs.[19] Polymedication is itself an indication of deficits across multiple physiologic systems and paints a vivid picture of a complex system that is on the threshold of breakdown.

A recent systematic review of 18 prospective cohort studies on falls risk factors identifiable during a clinical exam reported that the most consistent independent predictors of future falls in older adults were gait or balance deficits.[27]

The importance of balance

The prediction of falls in older people by abnormalities in gait and balance is consistent with the paradigm of complex system failure when we reflect on all that is involved in bipedal ambulation. Walking on two legs is not exceptional to humans (birds and some lizards do it too) but the complexity of this task, the kinematic features of our gait, and its dependence on central nervous system control makes human bipedalism unique and distinct from that found in animals.[28] Normal ambulation in people requires the coordination of many different muscles acting on multiple joints and is accomplished by the integration of activity in spinal neuronal circuitries with sensory feedback signals and with descending commands from the motor cortex.[28] The central nervous system coordinates this activity, adjusts it to fit environmental conditions, and refines it when required, all the while maintaining a remarkable degree of precision. For example, the position of the human foot during normal walking depends on the coordination of five joints and 15 muscles acting on the knee joint alone and yet with every step the foot is elevated by only 1–2 cm above the ground and its position varies by less than 4 mm.[29] The computational task solved by the human brain to accomplish this feat is extraordinary given the infinite number of combinations of joint and muscle positions that have to be attuned relative to each other to arrive at the desired outcome. Bipedalism is indeed a higher order function that requires a significant degree of connectivity and coordination between several interdependent components (muscular, skeletal and nervous) of the complex system that is the human body. Consequently, it should not be surprising that frail individuals who may have gait and balance deficits and who have lost the ability to integrate multiple inputs in the face of stress often present with falls.[6]

Fall and divided attention

The ability to stay upright while walking is not the only higher-order function that is compromised in frail individuals who are on the brink of failure. One group that studied fall prevention in nursing home residents reported that falls were often multitasking incidents during which a resident fell because of difficulty walking while performing another task.[30] Divided attention (the ability to process multiple stimuli or engage in several activities at once) is an executive cognitive process that requires integration of sensory input with the activity of many cortical networks. Maintaining balance while being confronted with a cognitive task is challenging even for young, healthy subjects, and multitasking has been shown to increase the incidence of falls in this population.[31] It is therefore not surprising that a frail individual with decline in multiple physiological systems may be unable to maintain advanced cortical functions such as divided attention in the face of even minimal external demand. This lack of reserve to cope with environmental exigencies is a common theme in the patterns of falls observed in frail nursing home residents. Falls often occur in the presence of external stress when a frail older person cannot rely on physical features in the surroundings to compensate for their own functional deficits (e.g. a patient with a balance deficit has nothing to hold onto in an open space). Examining this finding in light of complex system theory can shed further light on the causes of falls. One of the unique features of complex systems is their ability to maintain stability and order in the face of stress.[32] This of course depends on the overall state of the complex system, because even a small perturbation may have catastrophic effects on a malfunctioning system.[33] Against this background, falling can be viewed as a perceptible marker of failure of a complex system that was already in a dangerous state of vulnerability prior to the application of a stressor that pushed it over the edge.

Implications for clinical management of falls

Falling should be recognized as a macrostate indicator of complex system failure rather than a

specific disorder of particular organs (such as the brain or heart). This is congruent with existing clinical guidelines that falls require multifaceted assessment and holistic management.[18–21] Yet valuable time and resources are still often spent identifying the cause of a non-syncopal fall in a frail elderly patient, leading clinicians to embark on a journey of endless investigations for incidental findings.[5] If falling in the frail is truly a manifestation of complex system failure then searching for the cause of the incident is futile since this single cause does not exist. After all, failure of a complex system is the cumulative effect of multiple faults and it is only the intricate linking of these detrimental processes that leads to the overt collapse of the system. Focusing clinical management on single problems will not work when trying to salvage the vital functions of a failing complex system.

The concept of complex systems failure has implications for the prevention as well as the investigation of falls. Systematic reviews and meta-analyses evaluating the effectiveness of interventions to reduce falls in older people have reached conflicting conclusions. Multifactorial fall-prevention programmes for community-dwelling older people are reported to have limited effectiveness[34] or endorsed as beneficial.[35] Review of drugs, systematic risk factor screening and exercise are highlighted as important components of these programmes.[35] Indeed, it has recently been argued that exercise alone prevents falls in older people, with the greatest relative effect size in programmes that challenge balance.[36] In this context, exercise is a single but not simple intervention. Exercise has effects across many different cells and tissues and as such has been characterized as a pleiotropic strategy.[37] This evidence therefore supports the conceptualization of falls as a complex system failure: only complex and multifaceted interventions, if any, are effective.

Evidence regarding hospitalized older people gives further food for thought. Within the last two years, meta-analyses of the prevention of falls in older inpatients have concluded that multifaceted interventions reduce the number of falls[38] or that there is no evidence that any hospital programmes reduce falls or numbers of fallers.[39] Perhaps in frailer older people the functions of so many processes are on the brink of failure that even multifactorial interventions cannot restore normal functioning. Any small stressor continues to precipitate falls in these individuals.

Conclusion

There is a growing body of evidence enmeshing falls and frailty. This poses logistical and theoretical challenges for the effective management of falls in older people. The conceptualization of falls as a sentinel expression of the failure of a complex system helps us understand why even multifactorial falls prevention programmes are sometimes ineffective. This should not be considered justification for investigative or therapeutic nihilism but rather should stimulate further research into the aetiology and manifestations of frailty. The identification of levels of frailty at which interventions have optimal benefit, and the clear description of this frailty status in a uniformly understood language, is a tantalizing research goal.

References

1 Ballinger C, Payne S. The construction of the risk of falling among and by older people. *Ageing Soc* 2002;**22**:305–24
2 National Institute for Health and Clinical Excellence. *Falls: the assessment and prevention of falls in older people.* Clinical Guideline 21. London: NICE; 2004
3 Bergman H, Ferrucci L, Guralnik J, *et al*. Frailty: an emerging research and clinical paradigm--issues and controversies. *J Gerontol A Biol Sci Med Sci* 2007;**62**:731–7
4 Izaks GJ, Westendorp RG. Ill or just old? Towards a conceptual framework of the relation between ageing and disease. *BMC Geriatr* 2003;**19**:3–7
5 Rockwood K. Why geriatric medicine? In: Rai S, Mulley G, eds. *Elderly Medicine: A training guide.* 2nd edn. London: Taylor & Francis; 2007
6 Rockwood K. Frailty and its definition: a worthy challenge. *J Am Geriatr Soc* 2005;**53**:1069–70
7 Anderson F. A historical overview of geriatric medicine. In: Pathy MSJ, ed. *Principles and Practice of Geriatric Medicine.* Bath: Wiley; 1985
8 Tinetti ME, Inouye SK, Gill TM, Doucette JT. Shared risk factors for falls, incontinence, and functional dependence. Unifying the approach to geriatric syndromes. *JAMA* 1995;**273**:1348–53
9 Fried LP, Storer DJ, King DE, Lodder F. Diagnosis of illness presentation in the elderly. *J Am Geriatr Soc* 1991;**39**:117–23
10 Jarrett PG, Rockwood K, Carver D, Stolee P, Cosway S. Illness presentation in elderly patients. *Arch Intern Med* 1995;**155**:1060–4
11 Ensrud KE, Ewing SK, Taylor BC, *et al*. Frailty and risk of falls, fracture, and mortality in older women: the study of osteoporotic fractures. *J Gerontol A Biol Sci Med Sci* 2007;**62**:744–51
12 Nelson JM, Dufraux K, Cook PF. The relationship between glycemic control and falls in older adults. *J Am Geriatr Soc* 2007;**55**:2041–4
13 Speciale S, Turco R, Magnifico F, Bellelli G, Trabucchi M. Frailty is the main predictor of falls in elderly patients undergoing rehabilitation training. *Age Ageing* 2004;**33**:84–5
14 Walston J, Hadley EC, Ferrucci L, *et al*. Research agenda for frailty in older adults: toward a better understanding

of physiology and etiology: summary from the American Geriatrics Society/National Institute on Aging Research Conference on Frailty in Older Adults. *J Am Geriatr Soc* 2006;**54**:991–1001
15 Cook RI. *How Complex Systems Fail.* Chicago, IL: University of Chicago Cognitive Technologies Laboratory; 1998. See http://www.ctlab.org/documents/How%20Complex%20Systems%20Fail.pdf
16 de Jong BM, Leenders KL, Paans AM. Right parieto-premotor activation related to limb-independent antiphase movement. *Cereb Cortex* 2002;**12**:1213–17
17 Fairweather DS, Campbell AJ. Diagnostic accuracy. The effects of multiple aetiology and the degradation of information in old age. *J R Coll Physicians Lond* 1991;**25**:105–10
18 British Geriatrics Society Best Practice Guide. *Falls*. July 2007. See http://www.bgs.org.uk/Publications/Compendium/compend_4-5.htm (last checked January 2009)
19 American Geriatrics Society, British Geriatrics Society and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. Guideline for the prevention of falls in older persons. *J Am Geriatr Soc* 2001;**49**:664–72
20 Australian Commission on Safety and Quality in Health Care Guidelines. 2008. See http://www.safetyandquality.gov.au/internet/safety/publishing.nsf/Content/FallsGuidelines-2008Downloads (last checked January 2009)
21 National Institute for Health and Clinical Excellence. *Clinical practice guidelines for the assessment and prevention of falls in older people.* London: NICE; 2004
22 Kannus P, Sievänen H, Palvanen M, Järvinen T, Parkkari J. Prevention of falls and consequent injuries in elderly people. *Lancet* 2005;**366**:1885–93
23 Gates S, Fisher JD, Cooke MW, Carter YH, Lamb SE. Multifactorial assessment and targeted intervention for preventing falls and injuries among older people in community and emergency care settings: systematic review and meta-analysis. *BMJ* 2008;**336**:130–3
24 Scott V, Votova K, Scanlan A, Close J. Multifactorial and functional mobility assessment tools for fall risk among older adults in community, home-support, long-term and acute care settings. *Age Ageing* 2007;**36**:130–9
25 Campbell AJ, Borrie MJ, Spears GF. Risk factors for falls in a community-based prospective study of people 70 years and older. *J Gerontol* 1989;**44**:M112–17
26 Lipsitz LA, Pluchino FC, Wei JY, Rowe JW. Syncope in institutionalized elderly: the impact of multiple pathological conditions and situational stress. *J Chronic Dis* 1986;**39**:619–30
27 Ganz DA, Bao Y, Shekelle PG, Rubenstein LZ. Will my patient fall? *JAMA* 2007;**297**:77–86
28 Nielsen JB. How we walk: central control of muscle activity during human walking. *Neuroscientist* 2003;**9**:195–204
29 Winter DA. Foot trajectory in human gait: a precise and multifactorial motor control task. *Phys Ther* 1992;**72**:45–56
30 Templer J, Connell BR. Geriatrics: Environmental and behavioural factors in falls among the elderly. *Rehabilitation* 1994;**30**:92–3
31 Barra J, Bray A, Sahni V, Golding JF, Gresty MA. Increasing cognitive load with increasing balance challenge: recipe for catastrophe. *Exp Brain Res* 2006;**174**:734–45
32 Seely AJ, Christou NV. Multiple organ dysfunction syndrome: exploring the paradigm of complex nonlinear systems. *Crit Care Med* 2000;**28**:2193–200
33 Kauffman S. *At Home in the Universe: The Search for the Laws of Self-Organization and Complexity.* New York, NY: Oxford Press; 1995
34 Gates S, Fisher JD, Cooke MW, Carter YH, Lamb SE. Multifactorial assessment and targeted intervention for preventing falls and injuries among older people in community and emergency care settings: systematic review and meta-analysis. *BMJ* 2008;**336**:130–3
35 Gillespie LD, Gillespie WJ, Robertson MC, Lamb SE, Cumming RG, Rowe BH. Interventions for preventing falls in elderly people. *Cochrane Database Syst Rev* 2003;**4**:CD000340
36 Sherrington C, Whitney JC, Lord SR, Herbert RD, Cumming RG, Close JC. Effective exercise for the prevention of falls: a systematic review and meta-analysis. *J Am Geriatr Soc* 2008;**56**:2234–43
37 Inouye SK, Studenski S, Tinetti ME, Kuchel GA. Geriatric syndromes: clinical, research, and policy implications of a core geriatric concept. *J Am Geriatr Soc* 2007;**55**:780–91
38 Oliver D, Connelly JB, Victor CR, *et al*. Strategies to prevent falls and fractures in hospitals and care homes and effect of cognitive impairment: systematic review and meta-analyses. *BMJ* 2007;**334**:82
39 Coussement J, De Paepe L, Schwendimann R, Denhaerynck K, Dejaeger E, Milisen K. Interventions for preventing falls in acute- and chronic-care hospitals: a systematic review and meta-analysis. *J Am Geriatr Soc* 2008;**56**:29–36