Unintentional Falls in Older Adults: A Methodological Historical Review

Mark Speechley
The University of Western Ontario

RÉSUMÉ
PubMed fournit plus de 6,000 références (700 critiques) sur les chutes accidentelles des personnes âgées. Cet article retrace les jalons principaux et méthodologiques dans l'application de méthodes épidémiologiques depuis les premières publications dans ce domaine, à la fin des années quarante. Dans le contexte des avances faites en définition des cas médicaux, échantillonnage, mesure, conception de la recherche et l'analyse statistique, l'article passe en revue les estimations de fréquence d'apparition, les associations de facteurs de risque, les conséquences de la morbidité et de la mortalité, la démonstration de la théorie des facteurs multirisques à l'aide des interventions sur la prévention des chutes et les défis de modèles de prédiction des risques de chutes. Les explications méthodologiques sont fournies pour les hétérogénéités observées et le cas médical est présenté en faveur d'aller au-delà des listes indifférenciées des facteurs de risque, en mettant l'accent sur l'équilibre et la démarche comme les facteurs par lesquels on peut mieux comprendre les effets mécanistes des facteurs de risque distaux. En outre, l'affaire est faite pour faire avancer nos analyses statistiques en examinant les interactions parmi les facteurs de risque intrinsèques et entre les facteurs intrinsèques, extrinsèques et environnementaux.

ABSTRACT
PubMed lists over 6,000 references (700 reviews) on unintentional falls in older adults. This article traces key methodological milestones in the application of epidemiologic methods since the earliest publications in the late 1940s. Within the context of advances in case definition, sampling, measurement, research design, and statistical analysis, the article reviews estimates of frequency of occurrence, risk factor associations, morbidity and mortality consequences, demonstration of the multiple risk factor theory of falls using fall prevention interventions, and the challenges of fall risk prediction models. Methodological explanations are provided for observed heterogeneities, and the case is presented for moving beyond undifferentiated lists of risk factors by focusing on balance and gait as the factors through which the mechanistic effects of distal risk factors can be understood. Moreover, the case is made to advance our statistical analyses by looking at interactions among intrinsic risk factors and between intrinsic, extrinsic, and environmental factors.

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Correspondence and requests for offprints should be sent to / La correspondance et les demandes de tirés-à-part doivent être adressées à:
Mark Speechley, Ph.D.
Dept. of Epidemiology & Biostatistics
Room K201, Kresge Bldg.
The University of Western Ontario
London, ON N6A 5C1
(mark.speechley@schulich.uwo.ca)

> The fact that old people are liable to tumble and hurt themselves is a matter of common knowledge … Not only may the injuries resulting from these falls be of great severity, but in really old people a fall may have the effect of precipitating a senile decay. Apart altogether, however, from its social importance, the liability of old people to fall presents problems of the greatest clinical interest. It is odd that this has attracted so little curiosity, and it is greatly to be hoped that a more intensive study of the question may be made in the future.
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> J.H. Sheldon, 1948, p. 96

Introduction

Falling by older adults is a frequent occurrence and can have devastating consequences, making it a major clinical and public health problem. Applying

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epidemiologic methods to this problem has several challenges: many older adults fall repeatedly; many falls are unwitnessed; older people can forget or under- or over-report their falls, and may interpret the word "fall" differently. Falls have a multifactorial etiology, and many of the known risk factors are at least moderately intercorrelated. A fall can cause a physical injury or a fear of falling, either (or both) of which can then operate as risk factors for subsequent falls. Thus, we face an unreliably defined and measured, multifactorial, recurrent condition that, over time, can cause its own risk factors. What we know about a health problem depends on the tools we have used, and the tools we are able to use at any given time depend on what is already known. In addition to providing an overview of the core findings on the epidemiology of falling in older adults, a primary focus of this article is the development and refinement of research methods from the first studies of falls in older adults, the earliest of which date to the 1940s.

Background

Although falling unintentionally is ubiquitous across the life course, many falls in healthy younger people are readily explained by one or two major causal factors. In small children, these are intrinsic factors such as basic developmental level (Agran et al., 2003) sometimes in combination with environmental factors such as using wheeled walkers near stairs (Khambalia et al., 2006). In adolescence and young adulthood, many falls are readily explained by participation in sports and other activities that deliberately challenge the balance system. As participation in highly active sports declines during the middle years ("Statistical Report on the Health of Canadians," 1999), many falls are readily attributable to single factors such as alcohol intoxication (Kool, Ameratunga, Robinson, Crengle, & Jackson, 2008) or highly hazardous environments such as slippery surfaces. Occupational falls in especially hazardous environments such as construction sites are also frequent in this age range (Rivara & Thompson, 2000). At some point in the aging process, however, due both to normal age-related declines in physiologic systems (e.g., musculoskeletal, neurological, and sensory) as well as to limitations caused by specific diseases and injuries, people begin to fall more frequently. While older adults can still fall in the same circumstances as younger people, the etiology of many individual fall events shifts from simple to more complex causal models.

As the number of intrinsic risk factors increases, so does the frequency of some key extrinsic factors, particularly multiple medications that are often prescribed in response to age-, injury-, or disease-related intrinsic factors. Environmental features such as stairs and door thresholds that were navigated safely for decades can suddenly become fall hazards. These precipitating environmental factors interact with predisposing factors related to age, injury, or disease, resulting in a clear increase in both the proportion of older people who fall and, for those who fall, the frequency of their falls (Tinetti, 2003; Rubenstein & Josephson, 2006; Rubenstein, 2006). Thus, three descriptive aspects that distinguish "geriatric syndrome" falls from those that occur across the life course are that they occur (a) repeatedly during routine (non-athletic) activities, (b) in people with multiple intrinsic and extrinsic risk factors, and (c) under environmental circumstances that would not have resulted in a fall at younger ages.

An interested researcher, health care professional, or caregiver conducting a PubMed search in 2011 for studies on "accidental falls" in "humans" "aged 65 or older" will identify nearly 6,000 references. Limiting the search to "review papers" reduces the haul to slightly over 700. By any reasonable standard, these are valid indicators that the academic study of falling in older adults has matured, but perhaps so successfully that those just beginning their interest in the topic now face information overload. Fortunately, it is possible for the initiate to locate quickly the core set of findings by consulting review papers written by the leading authors in the field such as Tinetti (2003) and Rubenstein (Rubenstein & Josephson, 2006; Rubenstein, 2006), by consortia such as the American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons (2001), the comprehensive reviews done in Europe under the auspices of the ProFaNE network (Skelton & Todd, 2007), and the recently updated Cochrane Collaboration reviews of interventions, by Gillespie et al. (2009) in community dwellers and by Cameron et al. (2010) for those in institutions. Knowledge translation beyond the peer-reviewed article has been partially successful, as shown by governmental websites that distill the main findings for public consumption (e.g., Public Health Agency of Canada; http://www.phac-aspc.gc.ca/index-eng.php; in the United States, the Centers for Disease Control and Prevention; http://www.cdc.gov/).

The epidemiologic study of a health topic ideally progresses through stages during which topic-specific issues and problems are identified, and methodological solutions are tested. The first stage is an awareness of the clinical or public health magnitude of a health problem in terms of its frequency of occurrence and the morbidity and mortality consequences. This is followed by tentative case definitions, which are applied in prevalence studies to estimate the overall frequency of the problem, and in uncontrolled case series to identify putative risk factors for falling. These are then examined in quick and relatively inexpensive retrospective

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(e.g., case-control) studies, followed by more costly and time-consuming prospective cohort studies. This methodological progress enables the identification of confounding variables and successively greater control over their effects, resulting in increased precision of the estimated effects of specific risk and protective factors. Ideally, over time we would also see (a) advances in sampling to minimize selection biases, (b) refinements in the measurement of exposure and outcome variables to minimize information biases, (c) the identification of important subgroups as a means of explaining heterogeneities in main effects observed across previous studies, and (d) continual refinement of statistical analytic procedures. Accordingly, the second major objective of this article is to outline the key methodological advances in design, sampling, measurement, and analyses of unintentional falls in older adults.

The replicated identification of a risk factor set enables the development of prediction models to identify individuals or groups at varying levels of risk. The subset of risk factors that are potentially modifiable can then be treated in randomized risk factor modification studies. If a relative reduction in fall risk is observed in the treatment group, and is associated with a relative reduction in risk factor prevalence in that group, the cycle is complete as we have now definitively confirmed that the risk factors are true causes of the outcome. The third major objective of this article is briefly to review progress in risk prediction models and in fall prevention in experimental multifactorial risk modification interventions.

Many fall risk factors are shared between those living in the community and those in institutional care, and these settings in some sense reflect different stages in the natural history of the problem. However, falls in the two settings differ in terms of (a) risk factor prevalence and modifiability, (b) the frequency of occurrence and outcome probabilities, (c) the health professionals who are involved with care, and (d) the interventions that can be delivered. While the key methodological issues related to research design, measurement, and analysis are largely transferable between settings, these important differences remain.

Overview of the Epidemiology of Falling

Case Definition

Numerous definitions have been used in fall studies and have been reviewed (Kellogg International Work Group on the Prevention of Falls by the Elderly, 1987; Hauer, Lamb, Jorstad, Todd, & Becker, 2006; Zecevic, Salmoni, Speechley, & Vandervoort, 2006). The multiplicity of definitions undoubtedly accounts for some of the heterogeneity seen in prevalence and incidence estimates, as well as in the strength of associations with risk factors noted across various studies (e.g., American Geriatrics Society, British Geriatrics Society, & American Academy of Orthopaedic Surgeons Panel on Falls Prevention, 2001). It is not surprising and is in fact appropriate that the earliest studies relied on a tacit understanding of the term "fall", rather than attempt a formal operational definition. For example, in one of the earliest published studies, by Droller (1955), a sample of older people was simply interviewed on "the question of falling". Only by using a broad definition could the early authors catalogue the range of events that older adults identify as falls, which in turn informed the first attempts at typologic classification (e.g., Droller, 1955; Sheldon, 1960). This early work formed the basis for operational definitions in later studies that allowed greater specificity of "geriatric syndrome" falls, (e.g., by excluding falls due to overwhelming external forces that would cause a fall in a young healthy person (Nevitt, Cummings, Kidd, & Black, 1989; Tinetti, Speechley, & Ginter, 1988) and by focusing the analysis on those who fell repeatedly over the period of follow-up (Nevitt et al., 1989).

Occurrence

Fall occurrence can be expressed in numerous ways, and the resulting proliferation can make it difficult to compare estimates across studies. If the unit of analysis is the person, then the proportion experiencing at least one fall during a specified time interval indicates the fall *risk* of the observed group. In spite of differences in sampling and measurement (i.e., fall case definition), three seminal prospective cohort studies published between 1988 and 1993 produced similar annual fall risk estimates of 29 per cent (O'Loughlin, Robitaille, Boivin, & Suissa, 1993), 32 per cent (Tinetti et al., 1988), and 35 per cent (Campbell, Borrie, & Spears, 1989). Interestingly, Droller's non-prospective 1955 study produced a risk estimate of 35 per cent (Droller, 1955).

Among those who fall, many are repeat fallers. The recurrent nature of falling means that either falls or fallers can be treated as the unit of analysis. Early case series such as Sheldon's (1960) study sampled on the basis of 202 fallers but the analysis was based on 500 falls. The analysis of falls clustered with variable frequency within persons is problematic because they are not statistically independent events. As well, the highly right-skewed distribution of the number of falls suggests that means, and parametric statistics such as t-tests, are inappropriate.

Because the number of falls is a discrete variable, one valid approach to the recurrent nature of falling has been a simple dichotomy of one-time versus recurrent (two or more) fallers. Tinetti et al. (1988) reported that

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14.8 per cent fell once and 17.3 per cent fell two or more times. In a sample on average about four years younger, O'Loughlin et al. (1993) reported that 17.6 per cent fell once and 11.5 per cent fell two or more times. Another use of this dichotomy has been to restrict the sample to those with a recent fall history, and the analysis to recurrent fallers (≥ 2 falls) ascertained prospectively, as done by Nevitt et al. (1989).

Another main occurrence measure used for recurrent events is cumulative incidence rate, defined as the total number of events divided by the total person-time at risk. O'Loughlin reported an annual incidence rate of 41.4 falls per 1,000 person-months, compared to 56.8 falls per 1,000 person-months calculable from data reported by Campbell et al. (1989). Both fall risk and fall rate increase with age, and are higher in those in long-term care and other institutional settings (Rubenstein, 2006).

The challenges of analyzing fall data were well summarized 20 years ago by Cumming, Kelsey, and Nevitt (1990). Recent statistical contributions to the literature include more-sophisticated methods to analyze both recurrent falls and person-time at risk using Poisson regression for discrete count variables, and variants of Cox proportional hazard survival analysis, either for the study of risk factors (Gill, Zou, Jones, & Speechley, 2009) or in fall prevention trials (Robertson, Campbell, & Herbison, 2005).

Causes of Falls I: Contributory Conditions and Typologies

Some early studies placed a heavy emphasis on understanding falls using a typology approach. For example, Droller (1955) distinguished between clinical conditions such as vertigo (by far the most common single factor he observed), and environmental conditions such as loose rugs. Droller also distinguished between "liability to fall" and "opportunity to fall" (now predisposing and precipitating factors) and clearly recognized that the causes of a particular fall were "frequently multiple and difficult to unravel". Another early author (Sheldon, 1960) found it "surprisingly easy" to categorize 500 falls. For example, Sheldon reckoned that 171 (34%) were "accidental falls" that happened on stairs, due to slipping, and so on. Sheldon also recognized that his categories were not "self-contained": vertigo was judged the main cause of 37 of the "non-accidental" falls as well as 12 of the 171 "accidental" falls.

By 1978, Isaacs had pointed out the limitations of using a mixture of descriptive terms (e.g., slips and trips, dizziness, drop attacks) and pathological terms (e.g., postural hypotension) and pointed out that attributing a fall to a "loss of balance" is a tautology, not an etiology (Isaacs, 1978). Nonetheless, the tradition of classifying falls by type continues. Rubenstein's summary (2006) of several such studies is interesting for several reasons. For example, overall the most likely cause was "accident" or environment related, with a mean attributed percent of falls across studies of 31 per cent, but with a range among studies of 1 to 53 per cent. Second most frequent was gait or balance disorders or weakness, at 17 per cent (range: 4 to 39), followed by dizziness or vertigo (13%, 0 to 30%); drop attack (9%, 0 to 52%); confusion (5%, 0 to 14%); postural hypotension (3%, 0 to 24%); visual disorder (2%, 0 to 5%); syncope (0.3%, 0 to 3%); other specified causes (15%, 2 to 39%); and unknown (5%, 0 to 21%).

Although potentially useful for explaining some falls, the enormous ranges in the proportions across studies further underscores the difficulties of accurate retrospective causal attribution in a multifactorial condition, much less the valid differentiation (e.g., among syncope, orthostatic or postural hypotension, and dizziness or vertigo) obtained from self-report. As with previous authors, Rubenstein (2006) has emphasized that many of the falls classified as "accidents" are actually the result of the interaction between environmental hazards and individual susceptibility.

Causes of Falls II: Individual Risk Factors

Although some researchers have noted that more than 400 fall risk factors have been reported (Masud & Morris, 2001), a critical epidemiology would urge that a distinction be made among mere associated variables, risk markers, and truly causal risk factors that can be understood within a theoretical framework. Many fall researchers have come to support the multifactorial risk factor theory of falling, which posits that most falls in older adults are the result of the gradual accumulation of both normal age-related and specific disease-related declines in the key systems underlying postural stability (Tinetti, 2003; Rubenstein & Josephson, 2006; Rubenstein, 2006; American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention, 2001). First mentioned by the early authors (Droller, 1955; Sheldon, 1960), quantitative evidence for this theory came from prospective cohort studies that observed a gradient of increasing fall risk across strata of increasing numbers of baseline risk factors (Tinetti et al., 1988).

This theory in turn gained support from advances in biomechanical and physiological understanding of human balance (Carter, Kannus, & Khan, 2001; Lord, Menz, & Tiedemann, 2003). Although frail (or intoxicated) people can fall from a bed or a chair, the first geriatric syndrome falls often occur from a standing height. Each fall from a standing height requires two factors: an initial perturbation that displaces the body's center of mass, and the failure rapidly to regain balance using the trunk, hips, feet, hands, or arms. Walking, an important feature of independent mobility, involves deliberately transferring balance from one foot to the other. Given the centrality of balance and the challenges posed by walking, it is not surprising that balance and gait problems have been repeatedly identified as fall risk factors (e.g., American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention , 2001; Tinetti et al., 1988). However, rather than be analyzed alongside age-, injury-, and disease-related factors, perhaps balance and gait should be considered the key proximal systems through which the distal "upstream" factors combine to produce many geriatric falls.

Human balance is extremely complex; however, a simple physiological model gives prominence to three physiological systems: (a) the visual, (b) the somatosensory, and (c) the vestibular (Lord et al., 2003). Each system automatically sends signals to the brain to help maintain balance. In young healthy people, redundancy among the systems compensates for temporary limitations in any one system (e.g., walking in darkness). With age, injury, and disease, however, redundancy is reduced such that balance is not as easily maintained when presented with a challenge.

This physiological model with balance at its core, and assessments that directly assess various aspects of balance and associated physiologic systems (Lord et al., 2003), provides a clear conceptual basis for understanding the causal role of intrinsic risk factors such as muscle weakness, foot problems, and visual deficits (American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention , 2001). The causal role of other identified risk factors such as arthritis can be understood with reference to effects on balance through decreased range of motion, and on safe mobility via effects such as antalgic gait. Similarly, the causal role of factors such as activities of daily living (ADL) and other physical functional limitations is probably via numerous pathways such as muscle weakness, sensory limitations, and specific diseases. Similar causal interpretations can be made for factors such as advanced age and female gender, in which sarcopenia might cause leg weakness and balance and gait problems. A balance-and-gait–centric model provides a mechanistic interpretation of many causal risk factors for most geriatric syndrome falls, although by definition it excludes those due to sudden loss of consciousness.

Given the observation of compromised balance and gait through myriad mechanisms, we can then understand how precipitating factors (e.g., dimly lit monochromatic stairs with no handrail) interact with predisposing factors (e.g., visual deficit, heavily callused feet, tranquilizers) to cause individual falls. This in turn helps us understand the absence of a simple main effect of the number of environmental hazards present. Specifically, Tinetti et al. (1988) found that, on average, people who fell actually had *fewer* baseline environmental hazards (13.6) than those who did not (14.4).

Another supportive finding is that the risk of serious injury posed by situational factors is very low in those with no intrinsic risk factors, but mounts rapidly when both factors are present (Tinetti, Doucette, & Claus, 1995). A potential tripping hazard such as a raised doorsill between rooms will not cause a fall as long as the occupant has the memory to recall it, the eyesight to see it, and the ankle dorsiflexion and hip flexion to step over it. It is only when the internal balance mechanisms are compromised that previously benign environmental features become fall hazards. This interpretation also explains why environmental modifications have minimal effects in general populations of older adults, but dramatic effects in those with severe visual impairment (Gillespie et al., 2009). By considering how each age-, injury-, and disease-related limitation can mechanistically cause falls via balance-and-gait systems, we can move beyond simple "lists of risk factors" (e.g., American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention , 2001) that make no distinction about the temporal position of the various factors in the causal pathways of individual falls.

Another advance in the study of intrinsic risk factors is an awareness of the distinction between increasing fall risk resulting from normal physiologic aging (e.g., decreased visual acuity, muscle strength, reaction time, range of motion) and those due to specific conditions such as Parkinson's disease. The early community-based risk factor studies typically had very few, mostly pragmatic, exclusion criteria (e.g., severe cognitive impairment) but otherwise attempted to enroll representative cohorts of older adults. But because both the frequency of falling and the role of many risk factors in Parkinson patients who fall are likely to be somewhat specific to that condition, it is now appropriate for studies to enroll cohorts of patients with the same fall risk-increasing condition. In addition to Parkinson's disease (Latt, Lord, Morris, & Fung, 2009), studies of people with stroke (Weerdesteyn, de Niet, van Duijnhoven, & Geurts, 2008) and dementia (Härlein, Dassen, Halfens, & Heinze, 2009) have been recent examples of the use of sample restriction, a very strong design stage (as opposed to analysis stage) method of enhancing signal detection by increasing sample homogeneity.

We can appreciate the importance of this advance by examining past practice. For example, one review of fall risk factors showed that cognitive impairment or dementia was detected in only four of the 11 studies that examined it, with the largest odds or risk ratio equal to 2.3 and the lowest one equal to the null (American Geriatrics Society, British Geriatrics Society, & American Academy of Orthopaedic Surgeons Panel on Falls Prevention, 2001). It is highly likely (and, with the null result, virtually certain) that these figures substantially underestimate the true causal effect of cognitive problems on falls at the population level. As well, these values highlight the fallacy of basing fall prevention policies and practices on the size of odds or risk ratios. Specifically, it is a fallacy to interpret the size of an odds or risk ratio as indicative of a risk factor's biological causal potency in individuals. In fact, the size of an estimate represents the prevalence of the risk factor in the causal complements of the individual causal models present in the sample. In other words, the routine exclusion of people with severe cognitive impairment from community studies has introduced a selection bias that would in turn reduce the prevalence of this risk factor in the causal models of the individual fallers in these studies, resulting in a biased estimate towards the null of the true population effect.

Some psychological fall risk factors such as depression (American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention, 2001) can also be understood mechanistically through a balance-and-gait–focused model. For example, reviews of longitudinal studies have shown that baseline depression levels are associated with reduced physical activity (Roshanaei-Moghaddam, Katon, & Russo, 2009), which in turn could increase fall risk partly through deconditioning and muscle weakness. Other psychological factors, such as fear of falling, might be similarly posited to increase fall risk through a deconditioning mechanism, although recent studies suggest that reduced gait velocity in those with fear of falling is adaptive to optimize balance, rather than a sign of balance impairment (Reelick, van Iersel, Kessels, & Rikkert, 2009).

Of all of the characteristics that have been associated with falling, fear of falling is probably the best example of a factor that is both a cause and an effect of falls. Prospective studies suggest that fear of falling can arise due to factors other than recently experiencing a fall, and that falling and fear of falling share many risk factors in common (Murphy, Dublin, & Gill, 2003; Friedman, Munoz, West, Rubin, & Fried, 2002). Understanding a factor with bidirectional effects that is also correlated with other risk factors is challenging and is an excellent example of the power of prospective designs over retrospective designs. As well, because fear of falling is observed in older adults who have fall risk factors but have not themselves had a recent fall, the possibility that fear of falling could be an adverse event of programs that seek to prevent falls purely by "increasing fall risk awareness" (e.g., pamphlets full of frightening statistics about sequelae) should receive more attention.

Some of the other previously identified fall risk factors are probably better understood as risk markers. For example, a recent fall history is one of the most consistently identified factors associated with fall risk, and is used appropriately as one of two entry points (the other being emergency room admission for a fall) to a fall prevention algorithm (American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention, 2001). To call it a risk factor is, however, misleading, because recent fall history is merely an occurrence of the outcome of interest a year earlier in a natural history. Put another way, people who fall in Year 2 and who reported having fallen in Year 1 are simply recurrent fallers observed over a two-year risk window.

Many of the remaining 400 "risk factors" identified in studies probably have little or no true causal role in most individual fall models, and arose in studies due to chance sampling variability and by confounding through their association with true causal factors. But pursuing this line of thinking raises another methodological issue: what is the logic of using multivariable statistical models to estimate the independent effects of single factors on a multifactorial recurrent outcome in which many factors are at least moderately intercorrelated and in which the outcome can cause its own risk factors? The concern goes beyond the statistical nuisance of multicollinearity and the limitations of stepwise regression models. Specifically, is it logical to try to estimate the independent effect of, say ADL limitations, adjusted for the effects of weakness in the legs (or vice versa)? If intrinsic risk factors interact both with each other and with situational factors to cause falls, perhaps our analytic emphasis should shift to the study of effect measure modification, rather than adjusted main effects of collinear variables. Bellinger (2000) argued that the study of neurotoxicants in children's health had reached the point where the next advances would come from studying effect measure modification, and the fall literature may have now reached a similar situation.

As mentioned, the epidemiologic cycle is complete when the causal theory is demonstrated by experimental

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modification of putative risk factors that are correlated with changes in outcome probabilities. The multiple risk factor theory of falling reached this stage in 1994 when Tinetti et al. (1994) were able to explain the positive result of their FICSIT trial by demonstrating relatively more risk factor changes in the treatment group (Tinetti, McAvay, & Claus, 1996). That the pooled estimate of efficacy observed in the 2003 Cochrane review (Gillespie et al., 2003) was weaker in subsequent reviews (Gates, Fisher, Cooke, Carter, & Lamb, 2008) is more readily explained by interventions of insufficient intensity (Tinetti, 2008) than by the sudden invalidity of the theory.

Injurious Falls and Other Outcomes

Because most falls in older adults do not result in injury (Tinetti, 2003; Rubenstein & Josephson, 2006; Rubenstein, 2006; American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention, 2001; O'Loughlin et al., 1993), falling is a necessary but insufficient cause of a fall injury (just as serious injury is necessary but insufficient for other outcomes such as hospitalization and institutionalization). Most early studies placed greater emphasis on detecting falls, and less on injurious falls. Because injurious falls can also be recurrent events, all of the statistical challenges of analyzing falls are present with injurious falls. However, because only a minority of fallers experiences an injury, the precision of the statistical estimates from cohort studies of a set sample size will be lower because the outcome is rarer. Added definitional challenges are that injuries differ in terms of the nature of the injury and anatomic site and severity, and a single fall can produce multiple injuries.

Together, these challenges may partly explain heterogeneities in occurrence estimates and risk factors identified across studies. For example, Nevitt, Cummings, and Hudes (1991) reported serious injuries (fracture, dislocation, or laceration requiring suture) in 6 per cent of 539 falls among recurrent fallers whereas O'Loughlin et al. (1993) reported serious injury in 3 per cent of 197 falls, including one-time fallers, using a similar definition of serious injury. Tinetti et al. (1988) reported serious injuries (fractures as well as soft-tissue injuries that required medical attention) in 11 per cent of 272 falls. As noted with falls, different units of analysis (e.g., 23 to 24% serious injurious falls among fallers; Tinetti, Doucette, Claus & Marottoli, 1995; Tinetti et al., 1988) cannot directly be compared to figures with falls in the denominator.

Using hospitalization or emergency room visit data to estimate occurrence will introduce further selection biases due to referral, admission, and access-to-care factors. Hip fracture is perhaps one exception where hospitalizations will approximate population incidence; however, hip fractures are seen in only 1 per cent (Rivara & Thompson, 2000) to 1.5 per cent (Tinetti et al., 1988; O'Loughlin et al., 1993) of falls from prospective series.

The March of Methods

The textbook description of the progression of epidemiologic methods broadly describes the study of unintentional falls in older adults.

Case Definition

The earliest published studies in the 1940s (Sheldon, 1948) and 1950s (Droller, 1955) used a tacit definition which could include "near falls". For example, Sheldon's data came from a health survey of a representative sample of older English adults. Amazingly, a question on falls was added only after the study began, when the researchers realized the importance of falling (Sheldon, 1948). Interestingly, Sheldon reported a figure of 36.2 per cent of the subjects being "liable to falls", including 10 "near fallers" but excluding all cases of a "genuine slip such as might happen to anyone" (Sheldon, 1948, p. 96). Despite these limitations, if the 10 "near falls" are excluded, Sheldon's estimate of 32.6 per cent is squarely in the range of the estimates from the later prospective cohort studies (29 to 35%) that also excluded near falls (Tinetti et al., 1988; O'Loughlin et al., 1993; Campbell et al., 1989).

Sampling

The early authors were clearly aware of the differences between community-dwelling and institutionalized older adults, and sampled accordingly. For example, Droller's study (1955) was set in the community whereas Fine's study (1959) was set in hospital. The legacy of this distinction can be traced to the present day, and to the decision to produce separate Cochrane systematic reviews of fall prevention programs in the two settings (Gillespie et al., 2009; Cameron et al., 2010). Whereas Sheldon in 1960 was aware of the "heavy pathological bias" of studying hospitalized people, his sample consisted of fallers seen in the emergency room, hip fracture patients, and fallers reported by family physicians, which probably introduced a selection bias due to injury severity (Sheldon, 1960). The authors of an early longitudinal study of falling in a home for the aged (Gryfe et al., 1977) argued that residents with the highest levels of independence living in such a setting might be generalizable to older adults in the wider community. Indeed, their estimated rate of 668 falls per 1,000 person-years (55.7 per person-month), while higher than the 41.4 falls per 1,000 reported by

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O'Loughlin et al. (1993), is very close to the 56.8 per 1,000 figure calculable from data reported by Campbell et al. (1989).

Another early study sampled on the basis of injury and included both community and institutional subjects (Lucht, 1971). Interestingly, this 1971 study is the earliest publication on falling in older adults that appears in PubMed, and was also among the first papers to address the potential for falls to be prevented. In this comprehensive prospective case series of 472 people over 60 years of age who had been treated in hospital after falling in their homes or institutions, Lucht estimated the annual incidence of serious injury due to a fall at 14 per 1,000 population. This same study noted that three times more injured fallers were women than were men, and that fall frequency increased sharply at age 75. In the discussion, Lucht directly addressed the potential for fall risk reduction through a combination of medical treatment and environmental modification. In another early study that used a mixed sampling approach of community, residential care, and hospital residents, Campbell, Reinken, Allan, and Martinez (1981) retrospectively estimated a fall risk of 34 per cent, again squarely in the range of the prospective cohort estimates in community populations, probably because their sample was overwhelmingly of community origin.

Research Designs

The descriptive case series was gradually replaced by the first controlled investigations, but surprisingly this did not really occur in the community setting until the early 1980s (Prudham & Evans, 1981). A common approach has been to identify recent fallers and non-fallers from a single sample, and then to compare these two groups with respect to potential risk factors. Although this resembles the case-control design, it is properly called a backward prevalence design (Kleinbaum, Kupper, & Morgenstern, 1982). The first assumption is that people who have recently fallen and those who have not form two distinct groups, and that differences in prevalence of certain characteristics indicate potential risk factors. Underlying this assumption is that the risk factors identified existed prior to the fall. While immutable factors such as age and gender meet this assumption, other characteristics such as balance, gait, sensory deficits, and functional limitations clearly do not. This design is particularly problematic with falls because "risk factors" can in fact be outcomes of falls in some cases (e.g., gait abnormality due to fall injury), or both risk factors and outcomes in others (e.g., fear of falling).

The limitations of this design were noted in the early 1990s (Cumming et al., 1990) coincident with the seminal prospective cohort studies previously mentioned (Nevitt et al., 1989; Tinetti et al., 1988; O'Loughlin et al., 1993). These cohort studies ensured that factors present at baseline existed prior in time to falls measured over the follow-up period. The possibility that some baseline factors were actually caused by falls occurring before the study can be partially controlled by including fall history as a covariate in multivariable models.

With the temporality of previously identified risk factors confirmed in the cohort studies, it was appropriate to move on to experimental manipulations of modifiable risk factors in randomized trials. The recent Cochrane reviews summarized the results of 111 trials involving more than 55,000 community residents (Gillespie et al., 2009) and of 41 trials involving more than 25,000 residents in institutions (Cameron et al., 2010).

These reviews are invaluable in identifying which interventions seem to work, and how well, in which populations. Many interventions have stronger effects when rate ratios, as opposed to risk ratios, are analyzed, and in many cases the former is statistically significant and the latter is not. This pattern suggests that many interventions are more effective in reducing the average number of falls among fallers than they are in reducing the proportion of people who fall. In community dwellers (Gillespie et al., 2009), tai chi, individually prescribed multi-component home exercise, and multi-component group exercise fit this pattern, as do multidisciplinary multifactorial interventions among long-term care residents (Cameron et al., 2010).

These results also provide important clues about which interventions do not appear to be effective, and help address the issues of high-risk versus general-population approaches, and multifactorial versus single-factor interventions. For example, home safety interventions reduce fall rate by 41 per cent among those with severe visual impairment, and vitamin D supplementation reduces fall rate by 43 per cent among those with deficiency, yet neither intervention has a statistically (or clinically) significant effect in unselected community populations (Gillespie et al., 2009). Moreover, multifactorial risk factor assessment coupled with active intervention results in a 30 per cent reduction in pooled fall rate, compared to a 16 per cent reduction if the intervention stops at referral or recommendations for treatment. Multifactorial interventions in long-term care residents with cognitive impairment, and single exercise modalities, appear to be ineffective (Cameron et al., 2010).

It is hoped that future studies will be designed to build systematically on these results (e.g., by using fall rate as the primary outcome measure). One possible explanation for heterogeneity in effect sizes across intervention studies in institutions is that "usual care" differs across institutions and within them over time. Although the routine clinical care of complex patients can never be standardized as can be done in placebo-controlled drug trials, careful descriptions of the control condition and of steps taken to prevent conscious or subconscious enhancements of "usual care" during a study will improve the estimates of the efficacy of specific interventions and ease the interpretation of future meta-analyses.

Individual Fall Risk Prediction

Because falling is so profoundly multifactorial, falls among individuals, as well as different falls by an individual, can be the result of different sets of risk factors as they combine to produce minimal causal sufficiency. Researchers who have attempted to predict individual fall risk actually faced the same problem encountered by earlier researchers who attempted to categorize falls by "type". Consider two people each with the same five baseline risk factors: (a) leg weakness, (b) weak grip strength, (c) severe foot calluses, (d) poor vision, and (e) the same nine prescription medications. The first person has four falls over the next year. The first fall is caused primarily by the first three risk factors; the second one by factors unknown or unmeasured; the third is caused by interaction among three of the medications and two of the other factors; and the fourth is caused in part by injuries sustained in the first three. The second person does not fall over the next year. A third person, with no known risk factors, does fall. Each of these contingencies is possible, and this complexity is not present in most health outcomes we wish to predict. It is probably for this reason, in addition to the use of backward prevalence designs and the effects of chance sample variability, that most scales to predict individual fall risk perform poorly (Gates, Smith, Fisher, & Lamb, 2008).

Conclusion, and the Road Ahead

It was possible for the fourth edition of a textbook on the care of the geriatric patient published as recently as 1971 to have no chapter, or even an index entry, for "falls" (Cowdry & Steinberg, 1971). Despite this textbook time lag, the presence of nearly 6,000 published works on falling in older adults in one bibliographic database has met Sheldon's hope, expressed more than 60 years ago, for "a more intensive study".

The application of epidemiologic methods to the study of unintentional falls in older adults revealed methodological challenges in case definition, sampling, and analysis. Early descriptive studies, necessarily atheoretical, enabled subsequent progress towards a coherent multifactorial theory that at least partially explains many "geriatric syndrome" falls. The causal plausibility of many age-, injury-, and disease-related risk factors has been strengthened by a mechanistic interpretation centered on balance and gait. That some risk factors are truly causal seems undeniable when interventions reduce both their relative prevalence and fall risk.

Although we do not yet have a definitive answer to the question of the optimal intensity of intervention needed to produce an effect, it does seem increasingly clear that interventions that stop short of actively modifying risk factors are less effective than those that deliver active interventions (Gillespie et al., 2003, 2009; Tinetti, 2008). More research is required into the relative merits and trade-offs of the high-risk versus general population, and multifactorial versus single-intervention approaches to fall risk reduction (Campbell & Robertson, 2009). Modern risk factor studies are moving beyond replications of well-established risk factors to investigate risks posed by lifestyle factors and by specific prescription drugs; these studies are more sophisticated than previous approaches by considering interactions and by calculating population-attributable risks for specific risk factors (Faulkner et al., 2009). Knowledge translation researchers are exploring the barriers to putting prevention knowledge into practice in falls (Tinetti et al., 2008; Fortinsky et al., 2008; Murphy, Tinetti, & Allore, 2008) and associated conditions (Levinson & Clay, 2009).

Pooled estimates based on tens of thousands of randomized participants have strongly suggested that we can immediately reduce the incidence of falling by at least 25 per cent with knowledge already in hand (Gillespie et al., 2009; Cameron et al., 2010). Proof of efficacy in preventing serious injuries is more difficult to obtain due to sample size requirements and other reasons, but to the extent that injury risk increases with fall frequency, there is every reason to expect that an intervention that reduces fall rate will also reduce fall injury rate.

But changing practice is difficult (Tinetti et al., 2008; Fortinsky et al., 2008; Murphy et al., 2008), and there are many other yawning gaps in evidence-based care for providers and policy makers to address. Regrettably, most Canadian provinces do not have special funding envelopes that would pay appropriate health professionals for detailed fall risk assessment and treatment of modifiable risk factors that the evidence clearly suggests would reduce fall incidence. This is probably the greatest single step Canadians need to advocate in order to have a comprehensive evidence-based fall prevention strategy. While waiting for this policy oversight to be corrected, older adults and their caregivers and providers can hopefully squeeze some fall prevention under the radar by identifying and treating fall risk factors as part of "usual care" (Tinetti & Kumar, 2010).

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