MIKA PALVANEN

Upper Body Fractures in Older Adults

Epidemiology and Injury Mechanisms

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ACADEMIC DISSERTATION
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LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following original publications, referred to as I-VI in the text:

I. Kannus P, Palvanen M, Niemi S, Parkkari J, Järvinen M, Vuori I (1996): Increasing number and incidence of osteoporotic fractures of the proximal humerus in elderly people. BMJ 313:1051-1052.

II. Palvanen M, Kannus P, Niemi S, Parkkari J (1998): Secular trends in the osteoporotic fractures of the distal humerus in elderly women. Eur J Epidemiol 14:159-164.

III. Palvanen M, Kannus P, Niemi S, Parkkari J, Vuori I (1998): Epidemiology of minimal trauma rib fractures in the elderly. Calcified Tissue Int 62:274-277.

IV. Kannus P, Palvanen M, Niemi S, Parkkari J, Natri A, Vuori I, Järvinen M (1999): Increasing number and incidence of fall-induced severe head injuries in older adults. Nationwide statistics in Finland in 1970-1995 and prediction for the future. Am J Epidemiol 149:143-150.

V. Kannus P, Palvanen M, Kaprio J, Parkkari J, Koskenvuo M (1999): Genetic factors and osteoporotic fractures in elderly people: prospective 25 year follow up of a nationwide cohort of elderly Finnish twins. BMJ 319:1334-1337.

VI. Palvanen M, Kannus P, Parkkari J, Pitkäjärvi T, Pasanen M, Vuori I, Järvinen M (2000): The injury mechanisms of osteoporotic upper extremity fractures among older adults: A controlled study of 287 consecutive patients and their 108 controls. Osteoporosis Int 11:822-831.

ABBREVIATIONS

BMD	Bone mineral density, g/cm^2
CI	Confidence interval
DZ	Dizygotic
ICD	International Classification of Diseases
MZ	Monozygotic
NHDR	National Hospital Discharge Register
OR	Odds ratio
SD	Standard deviation

INTRODUCTION

Osteoporosis and osteoporotic fractures (also known as minimal-trauma, age-related or low-energy fractures) are a major, continuously increasing public health problem worldwide, especially in contemporary Western societies with aging populations (Cummings et al. 1985, Riggs and Melton 1988, Jones et al. 1994). As the number of older adults continues to increase, the number of osteoporotic fractures will also increase. In Western societies, a 50-year-old white woman has a greater than 50 per cent chance of suffering at least one osteoporotic fracture during her remaining lifetime (Chrischilles et al. 1991, Nevitt 1994).

Typical sites of osteoporotic fractures are ankle, knee, hip, pelvis, vertebrae, ribs, proximal and distal humerus, and distal forearm (Cummings et al. 1985, Johnston and Slemenda 1995, Sambrook 1996). Hip fractures, the most serious of the osteoporotic injuries, are associated with more deaths, impairment, disability and costs than all other osteoporotic fractures combined (Phillips et al. 1988, Chrischilles et al. 1991, Nevitt 1994). In the USA, hip fractures account for more hospital days than any other musculoskeletal injury, representing more than two-thirds of all hospitalization time due to fractures (American Academy of Orthopaedic Surgeons 1993), causing estimated annual costs of over 7 billion USD (Cummings et al. 1990b). In Europe, the number and incidence of hip fractures have increased steadily during recent decades (Alffram 1964, Nilsson and Obrant 1978, Jensen 1980, Lewis 1981, Swanson and Murdoch 1983, Wallace 1983, Johnell et al. 1984), this alarming trend being observed in Finland as elsewhere (Lüthje 1985, Kannus et al. 1996a, Kannus et al. 1999a). Between 1970 and 1997 the number of hip fractures among Finnish people aged 50 years and over more than tripled (Kannus et al. 1999a).

Besides hip fractures, increasing secular trends have been also seen in many other types of osteoporotic fractures. Epidemiologic studies have concentrated on the distal forearm (Falch 1983, Solgaard and Petersen 1985, Lauritzen et al. 1993), spine (Melton et al. 1989, Cummings et al. 1989, Cooper et al. 1992a), pelvis (Melton et al. 1981, Parkkari et al. 1996), knee (Bengnér et al. 1986a, Kannus et al. 1997), and ankle (Bengnér et al. 1986b, Daly et al. 1987, Kannus et al. 1996b), whereas those occurring at the proximal or distal humerus, elbow and ribs have been almost neglected, although their treatment is also demanding and expensive. Thus, more information concerning long-term secular trends in this latter context is also needed for assessment of future fractures and for effective fracture prevention.

The exact reasons for the increasing age-specific incidence of osteoporotic fractures in older adults are largely unknown. A common view is that an increase in the incidence of age-related bone loss or osteoporosis could be one of the most important factors implicated (Wasnich et al. 1987, Melton et al. 1993a, Johnell 1995), but convincing evidence regarding any secular trend in the age-adjusted bone strength of older adults is lacking. On the other hand, the incidence of fall-induced injuries sustained by frail older persons is increasing (Rubenstein et al. 1994, Kannus et al. 1999b) and many recent investigations have shown that falls and associated risk factors are even more important predictors of fractures than osteoporosis. This has been especially clear in the case of hip fractures (Hayes et al. 1993, Greenspan et al. 1994, Greenspan et al. 1998, Schwartz et al. 1998), although falling and fall mechanics are equally likely to be significant determinants in other osteoporotic fractures such as upper extremity fractures (Kelsey et al. 1992, Nevitt and Cummings 1993, O'Neill et al. 1996b).

It has been estimated that about 95 per cent of fractures of the proximal humerus, elbow and wrist are the result of a fall, but that only about 5% of all falls result in fracture (Cummings and Nevitt 1994, Nevitt 1994). It has thus remained unclear precisely which fall-related factors are important and critical in the etiology and pathogenesis of upper extremity fractures. The few risk factor studies made of these fractures have focused on the first phase of the fall only, i.e., the instability phase which results in loss of balance due to host and environmental factors (Tinetti and Speechley 1989, Kelsey et al. 1992, Nevitt and Cummings 1993, O'Neill et al. 1996b, Luukinen et al. 1996), while the other three phases in the fall of a patient with an upper extremity fracture, that is, the descent phase, impact phase, and the post-impact phase during which the subject comes to rest (Hayes et al. 1993, 1996), have attracted no major interest. Nevertheless, exact knowledge of these three latter phases of falling (i.e., fall mechanics) is essential for any reliable insight into the etiology and pathogenesis of upper extremity fractures and thus for fracture prevention.

REVIEW OF THE LITERATURE

1. Definition of osteoporosis and osteoporotic fractures

Osteoporosis is a bone disease characterized by low bone mass and microarchitectural deterioration of bone tissue leading to enhanced bone fragility and a consequent increase in fracture risk (Nevitt 1994, Consensus Development Conference 1996). A more detailed definition of osteoporosis has been devised by an expert panel convened by the World Health Organization (1994); bone mineral density (BMD) from 1.0 to 2.5 SD (standard deviation) below the mean value for the healthy young reference population is defined as osteopenia (or low bone mass), BMD more than 2.5 SD below this young mean value is defined as osteoporosis, and BMD below 2.5 SD with a history of one or more fragility fractures is defined as "established" or severe osteoporosis. Characteristic of osteoporotic (or "age-related", "minimal-trauma", or "low-energy") bone fractures is that their number and incidence increase sharply with age, they are more common in women than in men, they occur at sites which contain substantial amounts of trabecular bone, and they are associated with minimal or moderate trauma only (typically a fall on the floor from standing height or less) (Melton 1988, Jones et al. 1994, Kannus et al. 1996b). The most common and well-known forms of these fractures occur at the hip, spine and distal forearm.

2. Epidemiology of osteoporotic fractures

Osteoporotic fractures in older adults constitute today a worldwide epidemic and the number of such injuries is increasing rapidly with the aging of the world population (Cummings et al. 1985, Cooper et al. 1992b, Lauritzen et al. 1993, Jones et al. 1994, Riggs and Melton 1995, Gullberg et al. 1997). The true incidence of osteoporotic fractures is, however, difficult to assess because high-quality population studies are few (Muscat Baron et al. 1994). It has been estimated that in the U.S. alone some 1.5 million osteoporosis-related fractures occur annually (Peck et al. 1988, Nevitt 1994). Hip, distal forearm and vertebral fractures each comprise about one sixth of this total (Jones et al. 1994, Nevitt 1994). The problem of osteoporotic fractures is both qualitatively and quantitatively more or less the same in Europe and in other developed countries (Cummings et al. 1985, Riggs and Melton 1995).

Osteoporotic fractures are a major cause of disability, functional impairment and death in older people (Melton 1996, Kannus et al. 1999b). Excess mortality among a group of relatively healthy older women is especially associated with clinical vertebral and hip fractures (Cauley et al. 2000).

2.1. Spine and lower extremity

The number and incidence of *vertebral fractures* have increased considerably concomitant with the aging of the populations (Kanis and McCloskey 1992). The true incidence of vertebral fractures is not known; it has been estimated that less than half of these injuries come to clinical attention since many osteoporotic vertebral fractures are spontaneous and not symptomatic enough to result in medical consultation (Cooper et al. 1992a, Kanis and McCloskey 1992). Moreover, probably no more than 10% of subjects with a vertebral fracture come to inpatient hospital attention (Kanis and McCloskey 1992). Thus, the true figures for vertebral fractures may be considerably higher than reported (Riggs and Melton 1995, Rungby et al. 1995).

Because women live longer, the lifetime risk of a vertebral fracture from the age of 50 onward is about 16% in white women as against about 5% in white men (Melton 1997). However, despite the widespread belief that osteoporosis is a disorder of women, recent studies from different countries indicate that the age-specific prevalence of vertebral fracture is as high in men as in women, affecting approximately one fourth of each group, depending on the definition of vertebral fracture (O'Neill et al. 1996a, Andersson et al. 1997, Burger et al. 1997). In the most comprehensive study to date, the prevalence rate of vertebral fracture was identical (20%) in European men and women (O'Neill et al. 1996a). In Rotterdam, the Netherlands, the prevalence of moderate-to-severe vertebral deformities was similar in women and men (15% vs. 12%) (Burger et al. 1997). In the European Vertebral Osteoporosis Study, the fracture prevalence in Western Europe was found to be 19% in older women and 21% in older men, and in Scandinavia, 26% and 24%, respectively (O'Neill et al. 1996a). In Australia, the prevalence of vertebral fractures was approximately 25% higher in men than in women (Jones et al. 1996).

In addition to data on the incidence and prevalence of vertebral fractures, importance attaches equally to their secular changes. Such studies have been very few. In Malmö, Sweden, the age-adjusted incidence of vertebral fractures increased substantially between 1950 and 1983 (Bengnér et al. 1988a), and in our own recent study of fall-induced, fracture-associated spinal cord injuries in older adults, the age-adjusted injury incidence per 100 000 person-years, clearly increased from 1970 to 1995: in women from 5 to 29, and in men from 7 to 17 (Kannus et al. 2000a).

The majority of *pelvic fractures* seem to be of osteoporotic origin, and they usually occur as a consequence of moderate or minimal trauma only (Melton et al. 1981, Ragnarsson and Jacobsson 1992, Lüthje et al. 1995, Parkkari et al. 1996). Melton and associates (1981) found that in Rochester, Minnesota, USA, during the period 1968-1977 the incidence of pelvic fractures increased markedly with age in both sexes, was greater for women than for men at all ages over 35 years, and reached a maximum in women 85 years old or older. The overall whole-population incidence was 37/100 000 persons per year. Ragnarsson and Jacobson (1992) examined the features of pelvic fractures in Skaraborg County, Sweden, between 1976 and 1985 and likewise found a rising incidence by age, especially among women. Their overall whole-population incidence was 20/100 000 persons per year. In Finland, Kannus and associates (2000b) observed a considerable increase in the overall number and incidence of 60-year-old or older persons hospitalized with an osteoporotic pelvic fracture in 1970-1997, the increase being most pronounced in the oldest age groups. The overall fracture incidence per 100 000 persons was 20 in 1970 and 92 in 1997.

During recent decades the number and incidence of *hip fractures* have increased in the developed countries in Europe (Nagant de Deuxchaisnes and Devogelaer 1988, Obrant et al. 1989, Boereboom et al. 1992, Dretakis et al. 1992, Anderson et al. 1993, Kanis 1993, Nungu et al. 1993, Parkkari et al. 1994, Thorngren 1995, Kannus et al. 1999a), North America (Melton et al. 1987, Cummings et al. 1990a, Martin et al. 1991, Cooper et al. 1992b), Oceania (Cooper et al. 1992b, Lau 1993), and Asia (Maggi et al. 1991, Lee et al. 1993, Rowe et al. 1993). Demographic changes are expected to lead to further large increases in the elderly population of the world, and future projections indicate that the annual number of hip fractures in the world will rise from 1.66 million in 1990 to about 6.26 million by the year 2050 (Cooper et al. 1992b). Hoffenberg and colleagues (1989) calculated that population aging alone will raise the annual number of hip fractures in England and Wales by about 30% between 1985 and 2015, but if the age-adjusted and sex-adjusted incidence rates continue to rise as they did before 1985, the increase in the number of hip fractures will be as high as 150%. In Finland, the number of hip fractures in people aged 50 years or more almost quadrupled between 1970 and 1997, and if this trend in fracture incidence and population aging continues, the number of fractures will be three-fold higher in the year 2030 than in 1997 (Kannus et al. 1999a). It is, however, well to note in this context that in the USA the rise in the incidence of hip fracture has been reported to be levelling off (Melton et al. 1996).

Many recent epidemiologic studies indicate that not only the number but also the age-specific incidence of hip fracture has increased (Obrant et al. 1989, Maggi et al. 1991, Boereboom et al. 1992, Dretakis et al. 1992, Kanis 1993, Lee et al. 1993, Rowe et al. 1993). In both absolute and relative terms the age-specific incidence increases have been most pronounced in the oldest age groups (Kannus et al. 1999a).

Throughout the world, the age-specific and age-adjusted incidences of hip fractures are about two times higher in women than in men (Kanis 1993, Melton 1993 and 1996). The over-representation of women in these statistics has been explained by women's lower bone mass and density and higher frequency of falling (Winner et al. 1989, Melton 1993). Differences in fall characteristics between men and women may also explain women's higher risk of hip fracture (O'Neill et al. 1994). However, there would appear to be a greater difference in the incidence of hip fractures between countries than between men and women from the same country (Johnell et al. 1992, Kanis 1993, Elffors et al. 1994).

Epidemiologic information on osteoporotic *knee fractures* is scant and as far as we know there has been only one study to date investigating secular trends in minor trauma knee fractures. Kannus and associates (1997) reported that in Finnish women aged 60 years or more the number and incidence of hospitalized patients with a knee fracture clearly increased during the period 1970-1994, while among Finnish men the number and incidence of minor trauma knee fractures showed no consistent trend changes over time. The same trend was seen in the age-adjusted and age-specific incidences of these fractures — in women the incidences clearly increased while in men no rise could be observed.

The incidence of osteoporotic *ankle fractures* is increasing, especially in elderly women (Bengnér et al. 1986a, Daly et al. 1987). Kannus and associates (1996b) reported that in Finnish older adults 60 years of age or older the number and incidence of hospitalized patients with an osteoporosis-related ankle fracture increased considerably between 1970 and 1994, the number and incidence being 370 and 57 in 1970, and 1243 and 130 in 1994.

2.2. Upper extremity

Many studies have been made of the epidemiology of distal radius (Buhr and Cooke 1959, Knowelden et al. 1964, Matkovic et al. 1979, Owen et al. 1982, Melton and Riggs 1983, Falch 1983, Kaukonen 1985, Solgaard and Petersen 1985, Lauritzen et al. 1987, Hove et al. 1995, Jónsson et al. 1999, Hagino et al. 1999) and proximal humerus fractures (Knowelden et al. 1964, Rose et al. 1982, Lauritzen et al. 1987, Bengnér et al. 1988b), although only a few of them have included information on secular trends in fracture incidence. However, fractures of the distal forearm are as common as hip fractures, and all upper extremity fractures together comprise about one third of all osteoporotic fractures (Jones et al. 1994). A knowledge of secular trends in these fractures is thus essential for the planning of effective fracture prevention.

In Rochester, Minnesota, Owen and colleagues (1982) found no secular change in the incidence of *distal radius fractures* between 1945 and 1974, whereas data from Malmö, Sweden, showed a substantial age-adjusted increase in this type of fracture (Bengnér and Johnell 1985). A more recent study from Malmö shows that in women the increase in incidence of wrist fractures appears to have been interrupted, when comparing the years 1980-1981 to the years 1991-1992 (Jónsson et al. 1999). Among men, in turn, the incidence of wrist fractures appears to be increasing, even since the 1980s (Jónsson et al. 1999). In Japan, the observations have been the opposite; there, the age-adjusted incidence of distal radius fracture for women showed a significant increase between 1986 and 1995, while no increase was observed among men (Hagino et al. 1999). Melton (1988) reported that the distal radius fracture incidence rose between the ages of 50 and 65 and has remained fairly stable thereafter. On the other hand, Jones and colleagues (1994) demonstrated an exponential increase in distal forearm fractures with increasing age.

There is some seasonal variation in the occurrence of distal radius fractures (Mallmin and Ljunghall 1992, Hove et al. 1995). Among Danish and Norwegian women the number of wrist fractures has been reported to be highest in the winter (Solgaard and Petersen 1985, Hove et al. 1995). Likewise in Rochester, Minnesota, distal forearm fractures were more frequent in winter than summer among men and women 35 years of age or older (Jacobsen et al. 1999).

Epidemiologic information on osteoporotic *elbow fractures* is very scarce. The proportion of these fractures constitutes about 5% of all osteoporotic fractures in persons aged 65-74 years. This proportion decreases to 2% in 80-year-old and older people (Nevitt 1994).

Over 70 per cent of patients with a *proximal humerus fracture* are 60 years of age or older, and three fourths of them are women (Kristiansen et al. 1987, Lind et al. 1989, Lauritzen 1993). The accidents leading to fracture of the proximal humerus occur fairly evenly throughout the year, although a peak has been reported to occur in January (Merrild and Bak 1983, Lind et al. 1989).

The incidence of osteoporotic fractures of the proximal humerus was on the increase in both men and women in Malmö, Sweden, between the 1950s and the 1980s (Bengnér et al. 1988b). From the age of 40, the incidence begins to increase exponentially (Kristiansen et al. 1987). Lind and colleagues (1989) reported that in Danish women the highest incidence for osteoporotic fractures of the proximal humerus was 409/100 000 (women aged 71-80). In the Study of Osteoporotic Fractures (Kelsey et al. 1992), the incidence was 648/100 000 in 80-year-old or older persons. No nationwide study of the incidence of osteoporotic fractures of the proximal humerus has previously been reported and data on the time trends in this type are scarce.

Rib fractures are among the most common fractures among older adults (about 10% of all), being as common as humeral fractures, and the incidence increases with age (Mayo et al. 1993, Jones et al. 1994, Ziegler and Agarwal 1994).

The long-term and nationwide secular trends in osteoporotic fractures of the distal humerus, proximal humerus or ribs have not previously been reported. The epidemiologic part of this thesis was planned to obtain this information.

3. Risk factors for osteoporotic fractures

There is solid evidence to indicate that osteoporosis predisposes to fracture, at least at the hip, vertebrae, distal forearm, humerus, and pelvis (Alffram and Bauer 1962, Alffram 1964, Arnold 1973, Melton et al. 1981, Rose et al. 1982). However, osteoporosis is only one of the several important determinants of fracture risk and the wide range of risk factors reflects the fact that these injuries result from a complex interplay of trauma (typically a fall) and bone strength (Cummings and Nevitt 1989, Nevitt 1994). In other words, fractures are due to a combination of the fragility of the bone tissue (osteoporosis) and a force applied on the bone, this usually as a result of a fall (Thorngren 1995).

3.1. Risk factors for osteoporosis

Many factors predisposing to osteoporosis have been identified. These include genetic factors, family history, white race, female sex, aging, earlier traumas and osteoporotic fractures, late puberty, premature menopause, hormonal disorders (e.g. hypogonadism, hyperthyroidism, hyperparathyroidism and anorexia), inadequate nutrition (e.g. low calcium intake), low body mass, smoking, intake of medication (long-term corticosteroid use), pollution, prolonged immobility, physical inactivity and alcohol abuse (Kelsey 1989, Obrant et al. 1989, Seeman and Allen 1989, Lips and Obrant 1991, Consensus Development Conference 1993, Cummings et al. 1995, Slemenda and Lips 1996, Lips 1997).

3.2. Risk factors for falls

The pathophysiology of falling is complex and a variety of risk factors have been identified, including female sex, aging, gait and balance impairment, muscle weakness, impaired vision, poor health and nutrition, cognitive impairment, depression, dizziness, fear of falling, medications (sedatives, psychoactive agents), a poor pulse rate rise 30 seconds after standing up, a positive history of falls, living in an institution, and exposure to environmental hazards (Tinetti et al. 1988, Tinetti and Speechley 1989, Nevitt et al. 1989, Nevitt 1990, Rubenstein et al. 1994, Luukinen et al. 1996, Ross 1998, Whooley et al. 1999, Nurmi 2000). Several of these factors may interact at one time and persons with multiple risk factors run an especially high risk of falls. Some of the risk factors are only temporary, whereas others may be related to a chronic condition.

3.3. Risk factors for fractures

The precise reasons for the increase in the age-adjusted incidence of osteoporotic fractures in older adults are largely unknown. As noted above, one of the most important risk factors is decreased bone strength (Johnell 1995). It is possible that the occurrence of osteoporosis has increased during recent decades, although evidence of a secular decrease in age-adjusted bone strength in older adults is lacking. On the other hand, fall-induced injuries sustained by frail older persons are on the increase (Rubenstein et al. 1994, Kannus et al. 1999b) and many recent investigations have shown that falling and risk factors for falls are even more important predictors of fracture than osteoporosis (Hayes et al. 1993, Greenspan et al. 1994 and 1998, Heaney 1998, Schwartz et al. 1998). The higher the kinetic energy involved in the fall (slips, stair falls, falls from an upper level), the higher is also the risk of sustaining a fracture (Luukinen et al. 2000). About 70-80% of all osteoporotic fractures, except vertebral fractures, and over 90% of osteoporotic hip and upper extremity fractures are the result of a fall (Nevitt 1994, Cummings 1996). Thus, factors which increase the risk or severity of falls are likely to increase the risk of fractures.

Previous non-spinal fractures and prevalent vertebral fractures are reported to be independent risk factors for new *vertebral fractures* and other osteoporotic fractures in general. Women with vertebral fractures are 4-5 times more likely to suffer a new vertebral fracture and twice as likely to experience hip fracture than women without vertebral fractures (Ross et al. 1991, Wasnich et al. 1994, Black 1997). Depression is also associated with a substantially increased risk of vertebral fractures in women (Whooley et al. 1999).

Most risk-factor studies of osteoporotic fractures have examined and included in analysis only a small number of risk factors and have concentrated mainly on *hip fracture*. The risk factors underlying hip fractures can be divided into those which are treatable and to those which are not. Treatable factors are low bone density, smoking, alcohol consumption, poor vision, medication (long-acting sedatives), high caffeine consumption, tea consumption (protective), low calcium intake, physical inactivity, muscle weakness, poor health, low body mass index, low exposure to sunlight, and previous falls (Cummings et al. 1995, Johnell et al. 1995, Cummings 1996, De Laet et al. 1997, Jacqmin-Gadda et al. 1998). Untreatable factors, in turn, comprise age, history of maternal hip fracture, previous fractures, height, dementia, late menarche and length of the femoral neck. The more risk factors an individual carries, the higher is the risk for sustaining a hip fracture (Cummings et al. 1995). The risk is doubled when an individual is unable to rise from a chair without using his/her arms (Nevitt et al. 1989). Greenspan and associates (1994) reported that in both sexes significant and independent risk factors for hip fracture are direction of fall, femoral neck BMD, potential energy of fall, and body mass index. Falling to the side and direct impact on the hip region have also elsewhere been reported to be the most prominent sources of risk (Hayes et al. 1993, Greenspan et al. 1998). Further, other independent risk factors are reported to be slower gait, difficulty in doing a tandem (heel-to-toe) walk, reduced visual acuity and small calf circumference (Dargent-Molina et al. 1996).

In *wrist fractures*, factors associated with falling are as important as bone density (Nevitt and Cummings 1993). Especially falling backwards and onto an outstretched arm substantially increases the risk of wrist fracture (Nevitt and Cummings 1993). Brisk and frequent walking exercise trebles the risk of sustaining a wrist fracture (O'Neill et al. 1996b). Other liabilities are poor vision, low calcium intake, low body weight, previous falls and a previous wrist fracture (Kelsey et al. 1992, O'Neill et al. 1996b, Honkanen et al. 2000).

Risk-factor studies of osteoporotic *fractures of the proximal humerus* are few. Factors apparently independently associated with an increased rate of fracture of the proximal humerus include a recent decline in health status, insulin-dependent diabetes mellitus, infrequent walking, and several indicators of neuromuscular weakness such as inability to stand with feet in a tandem position for more than a few seconds (Kelsey et al. 1992).

4. Injury mechanisms in osteoporotic fractures

Over 80% of combined non-spinal fractures among older white women, the group at highest risk of fracture, are associated with falls (Nevitt 1994). As noted above, the sources of risk in older adults are many and widely reported, but the studies in question have focused mainly on the first phase of a fall, i.e. the instability phase which results in loss of balance due to host and environmental factors. In other words, these studies have clarified *why* older adults fall. In fact, however, a fall also includes a descent phase, an impact phase, and a post-impact phase during which the subject comes to rest (Hayes et al. 1993, 1996). Very little is known of these latter phases of falling or fall mechanics, i.e. *how* the falls occur, although they may include important clues for fracture prevention.

4.1. Spine and lower extremity

Vertebral fractures occur under a heterogeneous set of circumstances. Falling is a less predominant cause of vertebral fractures than of hip fractures, although 25-50% of acute symptomatic vertebral fractures among older adults are related to falls and controlled activities such as lifting (Cooper et al. 1992a, Myers et al. 1996, Myers and Wilson 1997). On the other hand, approximately half of vertebral fractures are not attributable to a known loading activity. Such spontaneous fractures may be the result of fatigue damage from loading during normal activities (Andersson et al. 1997).

Most *hip fractures* are the result of falling (Alffram 1964, Johnell and Obrant 1983, Parkkari et al. 1999), but only about 1% of all falls among older women result in hip fracture

(Nevitt and Cummings 1992). Falling is much more likely to cause a hip fracture if the subject falls to the side and lands on or near the greater trochanter, if the fall has high impact energy (as initiated from a greater height), if the faller does not land on, or use, her hand to diminish the energy of the fall, and if she lands on a hard rather than a soft surface (Grisso et al. 1991, Nevitt and Cummings 1993, Greenspan et al. 1994, Parkkari et al. 1999).

4.2. Upper extremity

Wrist fractures are closely associated with falling onto an outstretched arm, which may explain why their incidence does not increase significantly after the age of 60, when people become more sedentary and unable to use their arms to reduce the falling energy (Rungby et al. 1995). However, falls to the side are unlikely to result in wrist fractures (Melton et al. 1988, Nevitt and Cummings 1993), while falling backwards on an outstretched arm with the wrist hyperextended may in many cases be the cause of wrist fractures (Nevitt and Cummings 1993). Kelsey and associates (1992) reported that in the USA 71% of fractures of the distal forearm occurred as a result of a fall from standing height or less. Correspondingly, in Norway, Hove and colleagues (1995) reported a figure of 81%, and in Denmark, Solgaard and Petersen (1985) reported that 87% of women's, and 64% of men's wrist fractures occurred in a similar manner. Reliable studies on the detailed injury mechanisms of wrist fractures have not, however, been published.

Reliable and detailed studies concerning injury mechanisms in *fractures of the elbow area* are also lacking. Aho (1991) reported that the most typical injury mechanisms in cases of fracture of the distal humerus were direct impact associated with falling and traffic accidents.

Almost 80% of the *fractures of the proximal humerus* in 18-year-old or older people are the result of a fall (Lind et al. 1989). In older women, the figure is even 95% (Nevitt 1994). About 75% of falls leading to a fracture of the proximal humerus occur from standing height or less in women aged 65 years and older (Kelsey et al. 1992). It has been suggested that these fractures come more easily in individuals who walk slowly, fall sideways, and are not able to slow down the fall with an outstretched arm, but so far, no reliable studies have been published concerning the injury mechanisms involved in fractures of the proximal humerus.

The orientation of the fall and the site of impact are presumably of significance in determining the type of fracture which will result from the fall. However, none of the previous studies on injury mechanisms in upper extremity fractures and fall characteristics of patients with such fractures have taken into account *all* of the important issues in fracture mechanics; i.e., seeking to clarify the mechanisms of injury to the upper extremities in a large prospective study using a design in which (1) the time delay between the fall and the interview is minimized, (2) the interview is composed of open questions and then structured questions and schematic drawings of possible fall characteristics, (3) the results are controlled by an appropriate control group (fallers without a fracture, or with another type of fracture), and (4) collection of objective evidence such as hematoma at the fracture site is included in data acquisition.

AIMS OF THE STUDY

The aims of this study were:

1. to determine time trends for the absolute number and incidence of 60-year-old or older hospitalized patients with an osteoporotic proximal humerus, distal humerus or rib fracture, or a severe fall-induced head injury in Finland over the period 1970-1995. The head injuries were selected to represent a nonosteoporotic injury category, a category reflecting the time trends in the number and severity of falls among older Finnish adults.

2. to determine whether genetic factors play a role in explaining variation in risk of osteoporotic fracture, the true endpoint of the entire osteoporosis problem. The question was held to be of special importance since many previous studies had shown that genetic factors largely explain the interindividual variation in risk of osteoporosis, while no previous study had used fractures as the endpoint.

3. to clarify the injury mechanisms involved in osteoporotic upper extremity fractures among older adults and to compare these mechanisms with those in control fallers, and thus to obtain an insight into the etiology and pathogenesis of upper extremity fractures with an eye to fracture prevention.

MATERIALS AND METHODS

1. Epidemiologic studies (I-IV)

1.1. Proximal humerus fractures (I)

Osteoporotic fracture of the proximal humerus was defined as a fracture occurring in individuals aged 60 years or more as a consequence of a minimal trauma only, i.e., a fall from standing height or less. Thus, all patients aged 60 years or more who were admitted to Finnish hospitals in the periods 1970-72, 1974-75, 1978-80, 1983-85, 1988-89 and 1991-93 for primary treatment of a first fracture of the proximal humerus were selected from the National Hospital Discharge Register (NHDR). The unique personal identification number made it possible to focus the analysis on this first recorded admission. The NHDR contained data on age, sex, place of residence, hospital number and department, patient's admission and discharge days, place and etiology of injury and place of secondary treatment. Traffic and other transportation accidents and other types of high-energy trauma causing fracture of the proximal humerus were excluded. The Finnish NHDR is the oldest nationwide discharge register in the world, and the data it provides are well suited to epidemiologic purposes. In a patient-file-controlled study of the accuracy of Finnish hospital discharge data, the NHDR injury diagnosis was found to be correct in 96% of cases (Aro et al. 1990, Keskimäki and Aro 1991). Correspondingly, Lüthje and colleagues (1995), in their study of pelvic fractures, checked 10 per cent of patient files and found the percentage of correct NHDR diagnoses to be 97%. The annual coverage of injuries in the Finnish NHDR is, in turn, 95% and over (Salmela and Koistinen 1987, Aro et al. 1990, Honkanen 1990), and that of the injury mechanism 94% (Lüthje et al. 1995).

Fractures were recorded by both the main (first) and secondary diagnoses. According to directives issued by the Finnish National Board of Health, the first diagnosis described the main reason for the patients' hospital stay. The second, third and fourth diagnoses indicated other possible diseases or injuries.

The diagnoses were coded with a five-digit code according to the eighth and ninth revisions of the International Classification of Diseases (ICD) indicating the type of the fracture. Between 1970 and 1986, the eighth revision of ICD and its two codes for fractures of the proximal humerus (81200 and 81210) were used. After 1987, the following five-digit codes were used: 8120A and 8121A.

The study material comprised the whole Finnish population, that is, about 5 million persons. In other words, the given absolute numbers and incidences of fracture of the proximal humerus were not cohort-based estimates but complete population results, and for this reason, the study did not use the statistical analyses characteristically needed in cohort or sample-based estimations.

Age adjustment was made by means of direct standardization using the mean population between 1970 and 1993 as standard. The annual midyear populations in each five-year age group in the period 1970-1993 were obtained from the Official Statistics of Finland (1970-1993). The fracture incidences were calculated for both sexes and expressed as the number of cases/100,000 persons/year. To establish age-specific incidences for the selected age groups (60-69, 70-79, 80-), the yearly numbers of fractures were divided by the midyear population for each age and sex group. The rates were expressed as the number of cases/100,000 persons/year, by sex and by age group.

The figures for fracture incidences observed in the different age groups over the study period (1970-1993) were used to predict the absolute number of osteoporotic fractures of the proximal humerus and their age-specific incidences in the population in the years 2000, 2010, 2020 and 2030. The regression lines were first calculated for both sexes and for each age group (60-69, 70-79, 80-) and were then used to determine the age- and sex-specific fracture incidences in women and men 60 years of age and over till the year 2030. Thereafter, within each age and sex group, the estimated absolute number of fractures was obtained by multiplying the above-mentioned incidence by the estimation of the number of inhabitants, the latter being obtained from "Population Projections in Finland in 1993-2030" (Official Statistics of Finland 1993).

1.2. Distal humerus fractures (II)

The definitions and methods used in the epidemiologic study of osteoporotic distal humerus fractures were the same as those mentioned above in chapter 1.1. with the exceptions that Finnish men were not included (too few fracture cases available) and the follow-up covered all years between 1988 and 1995. Between 1970 and 1986, the NHDR codes used for the distal humerus fractures were 81242 and 81252, and from 1987 onwards, the codes 8124A and 8125A.

1.3. Rib fractures (III)

The definitions and methods used in the epidemiologic study of minimal-trauma rib fractures were the same as those mentioned in the proximal humerus study (chapter 1.1.) with the following exceptions: First, besides the study group, the figures were also studied in younger patients aged 20-49 years to determine whether possible changes in the study group occurred specifically in the elderly population, or were merely more general trends in all age groups. Second, this study involved one follow-up year more (year 1994) than that of the proximal humerus. Third, prediction of the absolute number of minimal-trauma rib fractures in the future was also made for the younger patient group.

1.4. Fall-induced head injuries (IV)

A severe fall-induced head injury to an older adult was defined as a head injury occurring in a person 60 years of age or older as a consequence of a fall from standing height (1m) or less and resulting in hospitalization of the victim. Thus, all patients 60 years of age or older, and from the four remaining adult 10-year age groups (20-29, 30-39, 40-49, and 50-59 years) as a randomly selected younger reference group, all patients aged 30-39 years who were admitted to hospitals in Finland for primary treatment of a fall-induced head injury in 1970-1995 were selected from the National Hospital Discharge Register. The Finnish NHDR and its contents are described in greater detail in chapter 1.1.

Fall-induced acute head injuries were recorded by evaluating the primary and secondary diagnoses and the cause of injury (E-code). Between 1970 and 1986, the eighth revision of the ICD and its following codes were used: 80000-80410 (skull fractures), 85000-85110 (head injuries without fracture), and 85200-85411 (head injuries causing intracranial bleeding). In 1987 and after, the following codes from the ninth revision of the ICD were used: 8000A-8033A (skull fractures), 8500A-8519X (head injuries without fracture), and 8520A-8541X (head injuries causing intracranial bleeding).

The study was based on the entire Finnish population and the annual midyear population figures for each 5-year age group (60-64, 65-69, 70-74, 75-79, 80-84, 85-89, ≥90 years) between 1970 and 1995 were taken from the Official Statistics of Finland (1970-1995). Age adjustment and predictions for the future were made in same way as set out in chapter 1.1.

2. Hereditary susceptibility (V)

In this prospective 25-year follow-up of a nationwide cohort of elderly Finnish twins, osteoporotic fractures were defined as described for the other epidemiologic studies (I-IV), but the age limit was set at 50 years or more. Thus, all 50-year-old or older twin cohort members admitted to Finnish hospitals (1972-1996) for primary treatment of an osteoporotic fracture were selected from the National Hospital Discharge Register.

The Finnish twin cohort comprises all Finnish same-sex twin pairs born before 1958 with both co-twins alive in 1975. An extensive questionnaire was mailed to the twins in 1975 to confirm twinship, determine zygosity and obtain data on health-related variables. The overall response rate was 89% (Kaprio et al. 1978, Sarna et al. 1978).

Twin zygosity was determined by examining the responses of both members of each twin pair to two questions on the similarity of appearance at school age, items similar to those employed in other large twin samples (Cederlöf et al. 1961, Jablon et al. 1967, Magnus et al. 1983). A set of decision rules was then applied to classify the twin pairs as monozygotic (MZ), dizygotic (DZ) or undetermined zygosity. The validity of the zygosity was studied in a subsample of 104 pairs, and the agreement in classification from the questionnaires and 11 blood markers was 100% (Sarna et al. 1978). The estimated probability of misclassification was 1.7%.

The total number of MZ and DZ twin pairs born before 1946 was 7549 at the beginning of the prospective follow-up of the cohort. Of these, 2308 were MZ, and 5241 DZ pairs. Among the MZ pairs, 1221 pairs were female and 1087 male, while among the DZ pairs, 2618 pairs were female and 2623 male. The approximately 2:1 DZ to MZ ratio reflects the high rate of twinning in Finland during the first half of the 20th century.

Twin similarity in respect of osteoporotic fractures was summarized by estimates of concordance. Concordance could be assessed in two types (termed pairwise and probandwise), each calculated separately for MZ and DZ pairs (Falconer 1981). The 95% confidence intervals (95% CI) for concordance of fractures were also computed.

Pairwise concordance is the relative number of twin pairs in whom disease (osteoporotic fracture) has affected both twins in a pair, and it is calculated by the formula C/C+D, in which C is the number of concordant pairs and D is the number of discordant pairs (Emery 1976). Probandwise concordance is defined as an individual's risk of disease (the conditional probability that one twin is affected, given that his/her cotwin is affected) and, as such, can be compared with the probability of disease for an individual in the general population. Probandwise concordance is calculated by the formula 2C/(2C+D) (Emery 1976).

The overall cumulative risk of fracture (with 95% CI) was calculated by dividing the number of fracture cases by the total number of individuals. The relative fracture risk (with 95% CI), in turn, was calculated by dividing the above-noted probandwise concordance by this overall cumulative fracture risk.

3. Injury mechanisms in upper extremity fractures (VI)

3.1. Study design

The design of this study was case-control. Between September 1995 and December 1997, 287 consecutive case subjects and 108 randomly selected controls were recruited from the two main emergency rooms in the city of Tampere, Finland, these being located in Tampere University Hospital and Tampere Community Health Center. An additional 46 case subjects (14% of the total number of 333) and 12 controls (10% of the total number of 120) were eligible but could not be recruited for the following reasons: 8 cases and 4 controls could not be contacted; 4 cases and 1 control could be contacted, but they did not find suitable time for interview; 22 cases and 4 controls could be contacted but refused participation; and 12 cases and 3 controls could be contacted but lived too far away.

3.2. Subjects

The case subjects were 112 patients with a fresh fracture of the proximal humerus, 65 with a fresh elbow fracture [i.e., fracture of the distal humerus (n = 31), proximal radius (n = 10) or proximal ulna (n = 17), or their combination (n = 7)], and 110 with a fresh wrist fracture [i.e., fracture of the distal radius (n = 90), distal radius and ulna (n = 7), navicular bone (n = 1) or metacarpal bone (n = 1), or other type of wrist fracture (n = 11)]. The inclusion criteria for the case subjects were that the patient had to be 50 years of age or older and that the fracture had occurred as a result of a low-energy trauma only (typically a fall from standing height or less). In the great majority of the patients, the injury had occurred less than 24 hours before admission. All high-energy traumas such as traffic accidents were excluded.

The control subjects were also to be 50 years of age or older, with the same kind of acute low-energy trauma as the case subjects but without a fracture, or with a fracture other than the case fractures. Of the control subjects, 57 experienced no fracture in their accident, while 51 had sustained a fracture other than a proximal humerus, elbow or wrist fracture. These fractures and their numbers were: hip 14, ankle 11, tibia and/or fibula 6, rib 4, humeral shaft 3, pelvis 3, clavicle 2, patella 2, lumbar spine 1, calcaneus 1, orbita 1, scapula 1, distal femur 1, and cervical spine 1. The basic characteristics of the case and control subjects are presented in Table 1.

3.3. Interview and examination of the subjects

All subjects included in the study first provided verbal or signed informed consent. Characteristics of the accident were then determined by personal interview (MP) of the patients and any eye-witnesses within a week (mean three days) after the injury. In 31% of cases the interview was conducted within 48 hours, in 58% within 72 hours and in 75% within 96 hours after the injury. Seven subjects were interviewed by telephone.

At the beginning of the interview, each subject's basic characteristics were determined (Table 1). The functional capacity of the subject immediately prior to the accident was assessed using a 4-point scale: excellent (completely independent in all daily activities), good (some problems, but does not need external help), fair (needs other people's help daily), and poor (almost entirely dependent). This scaling was based on studies measuring activities of daily living (ADL activities) (Katz et al. 1970, Lawton 1971, Lammi et al. 1989). Mental status was assessed by the Minimental Test classifying the status with a 4-point scale (normal, slightly impaired, moderately impaired, severely impaired). This scaling was based on the Mental Status Questionnaire (MSQ) (Lawton 1971). Subjects' vision was recorded as "good", "fair" or "poor" as they subjectively experienced it. Preinjury medical conditions were requested in detail, including heart disease, hypertension, diabetes, pulmonary disease, gastrointestinal disease, cerebrovascular disease, osteoarthrosis and rheumatoid diseases. Use of any psychotropic agents and alcohol at the time of the accident, and the number of previous falls and fractures were also recorded. Preinjury ambulatory ability was categorized as ability to walk "independently", "with an assistive device (cane, walker)", or "with others' help", "able to move by a wheelchair", "able to sit only", and "bedridden". All case subjects and controls, except one in the elbow fracture group, could walk independently or with the aid of an assistive device before the accident.

Characteristic	Patients with a proximal humerus fracture (n = 112)	Patients with an elbow fracture (n = 65)	Patients with a wrist fracture (n = 110)	Controls (n = 108)
Women (%)	80	86	94	74
Mean age (years)	74±9	68±12	71±10	70±12
Weight (kg)	70±16	70±16	67±12	71±16
Height (cm)	163±8	164±9	162±7	165±9
BMI (kg/m²)	26±6	26±5	26±4	26±5
Functional capacity (%)[1]				
excellent	63	63	84	68
good	22	20	12	22
fair	15	17	4	9
poor	0	0	0	1
Mental status (%)[2]				
normal	82	85	94	84
slightly impaired	11	11	4	11
moderately impaired	7	1	1	4
severely impaired	0	3	1	1
Vision, subjectively (%)				
good	16	17	24	25
fair	53	54	46	50
poor	31	29	30	24
not known	0	0	0	1
Most common medical conditions (%)[3]				
Heart disease	29	28	26	26
Hypertension	30	23	29	28
Diabetes	12	12	7	9
Pulmonary disease	11	6	7	7
Gastrointestinal disease	6	6	3	3
Cerebrovascular disease	8	6	1	4
Osteoarthrosis	6	3	3	2
Rheumatoid arthritis	7	9	3	8
Psychotropic agents (%)[3]				
Nerve or sleep[4]	30	19	18	19
Alcohol	9	8	2	9
Previous fracture (%)	63	72	64	50
Falling during the preceding month (%)	6	5	3	16

[1] At the time of the accident. Excellent: completely independent in all daily activities; Good: some problems, but not requiring external help; Fair: needs other people's help daily; Poor: almost entirely dependent.
[2] Classified by the Minimental Test.
[3] At the time of the accident.
[4] The medicine taken less than 24 hours before the accident.

Table 1. Basic characteristics of patients with a proximal humerus fracture, elbow fracture and wrist fracture, and controls, mean ± SD

The interview was then continued with open questions on the characteristics and circumstances of the accident, the subjects thus being given an opportunity to tell in their own words "what happened", "where it happened", "when it happened" and "how the accident occurred", and, intentionally, only after this open interview were they asked more specific and precise questions. The exact date (month and day), time (one hour precision) and place of the accident (indoors/outside, room, kitchen, corridor, staircase, bathroom, garden, street etc.) were recorded. The falling height was graded as follows: "a fall in horizontal position from a bed", "fall from seated position", "fall from standing height", "height of one step", "height of two steps", and "height greater than two steps". Landing surface was graded on a 9-point scale according to the hardness of the surface, from very hard (e.g. ice, stone) to very soft (e.g. thick grass, thick carpet) and the evenness of the surface was divided into "uneven" and "even". The number of layers of clothing worn at the time of the accident was also registered.

As above, the first specific questions regarding injury mechanisms and fall characteristics were intentionally open-ended and only after them was a structured questionnaire used. Activity at the time of the fall was divided into "lying down", "sitting", "standing still", "turning around", "reaching forward/to the side", "walking straight ahead", "taking a backward step", "taking a step to the side", "running", "jumping", "walking up stairs", "walking down stairs", "riding a bike or sledge, or related activities", "pulling/pushing", "throwing/striking something", "changing from one activity to another", and "doing something else". The subject's own opinion on the main reason for the fracture/accident was classified as "tripping", "slipping", "dropping", "feeling dizzy", "getting ill/attack", "sudden strength loss in the legs", "external factor (push, pull, impact)", "sudden gesture (throw)", and "something else". Direction of fall was recorded as "forward", "obliquely forward", "sideways", "obliquely backward", "backward", or "other direction".

Finally, the subjects were shown schematic drawings of different kinds of falls (Figs 1-3 in paper VI), and each was asked to choose the figure which best represented his/her fall. The part of the body which took the main impact during the fall (impact location) was recorded as "head", "shoulder/upper arm", "elbow/forearm", "hand", "chest/ribs", "back", "hip/thigh", "buttocks", "knee/lower leg", "foot/heel", "other part of the body", or "not known". Breaking of the fall was scaled as: "yes, with an outstretched arm", "yes, in some other way", "no", "not known", or "no fall".

After the interview the subjects were examined and all their injuries were recorded by the examining physician (MP). Special attention was paid to the occurrence of fresh subcutaneous hematomas and bruises on the patient's body as a clear indication of an acute impact at that particular site.

3.4. Statistical methods

As descriptive statistics, means and standard deviations were used for continuous variables, and percentage distributions for classified or noncontinuous variables. The differences in the noncontinuous outcome variables between the case and control groups, adjusted for age, gender and functional capacity, were subjected to logistic regression analysis or polychotomous logistic regression analysis (Dixon 1992), and odds ratios (OR) with 95% confidence intervals were calculated.

RESULTS

1. Epidemiologic studies (I-IV)

1.1. Proximal humerus fractures (I)

In the population aged 60 years and over, both the annual total number and the overall incidence of hospitalized patients with an osteoporotic fracture of the proximal humerus increased steadily during the study period, the number from 212 in 1970 to 844 in 1993 (an average increase of 13% a year) and the incidence (per 100 000 persons) from 33 to 89. The Finnish population aged 60 years and more increased 46% (from 652 000 to 951 000) during this 23-year period (Figure 1).

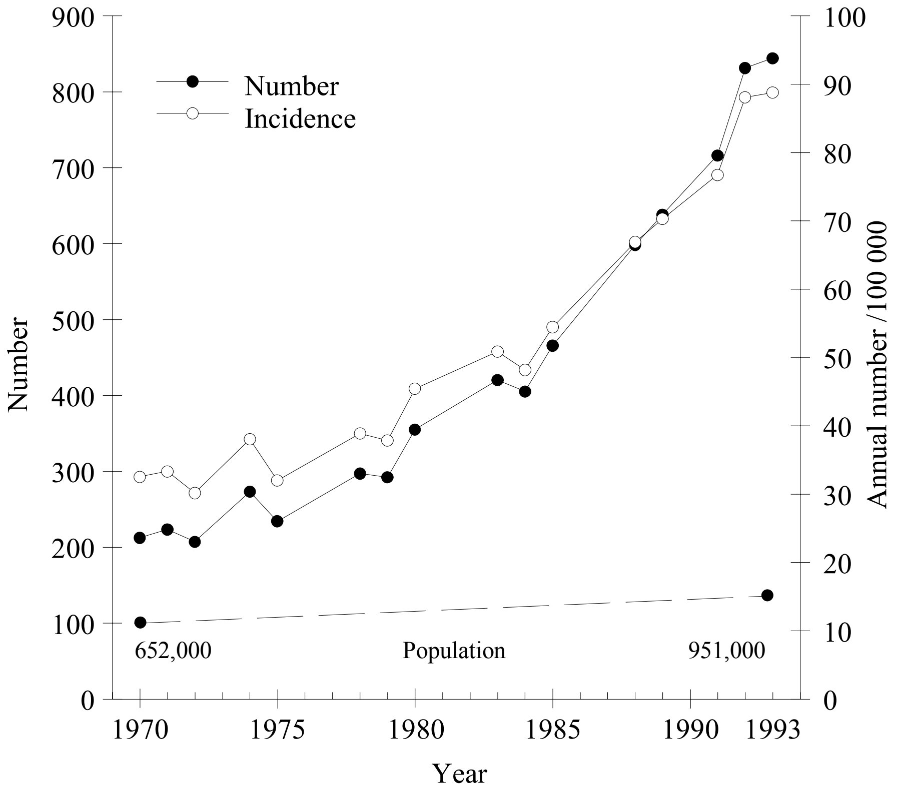

Figure 1. Number and incidence of 60-year-old or older hospitalized patients with an osteoporotic fracture of the proximal humerus in Finland over the period 1970-1993.

The age-adjusted incidence (per 100 000 persons) of osteoporotic fractures of the proximal humerus increased from 50 to 106 in women and from 14 to 41 in men during the same time period (Figure 2). The mean age of patients increased from 72.1 years (1970) to 76.2 years (1993).

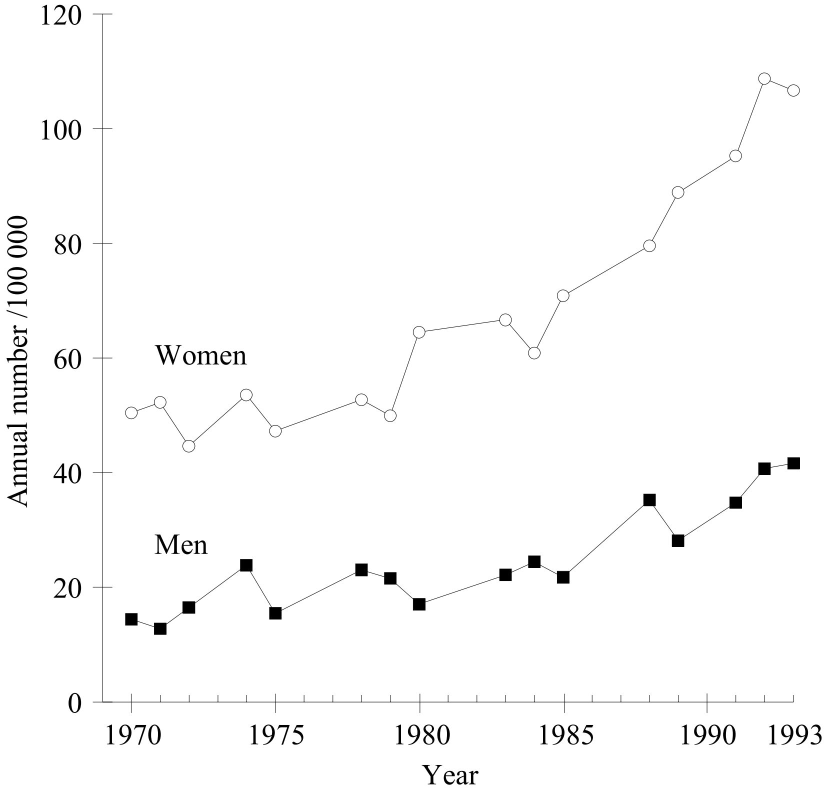

Figure 2. The age-adjusted incidence of hospital-treated osteoporotic fractures of the proximal humerus in 60-year-old or older people in Finland over the period 1970-1993.

In both sexes, the age-specific incidence (per 100 000 persons) of osteoporotic fractures of the proximal humerus increased considerably in all age groups over the study period. For example, in women aged 80 years or more the fracture incidence was 92 in 1970 and 256 in 1993, and in men, correspondingly, 32 in 1970 and 96 in 1993.

If the incidence of fractures continues to increase at the same rate the total number of first osteoporotic fractures of the proximal humerus in Finland is predicted to be about 1000 in the year 2000, and correspondingly 1400, 2000 and 2600 in the years 2010, 2020 and 2030 (Figure 3).

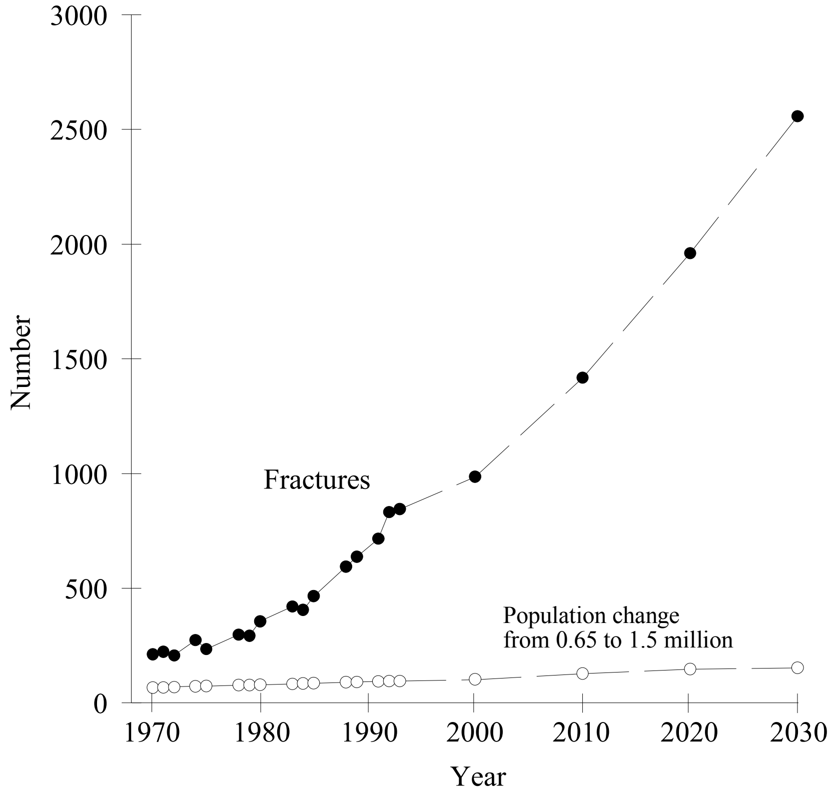

Figure 3. Prediction of the number of the Finnish population aged 60 years or more and the number of their osteoporotic fractures of the proximal humerus up to the year 2030.

1.2. Distal humerus fractures (II)

The annual total number and overall incidence of hospital-treated osteoporotic fractures of the distal humerus among Finnish women aged 60 years or more increased during the study period, the number from 42 (1970) to 175 (1995) (an average increase of 13% per year) and the incidence (per 100 000 women) from 11 to 30. The Finnish female population aged 60 years and more increased 48% (from 396 000 to 586 000) during this entire 25-year period (Figure 4).

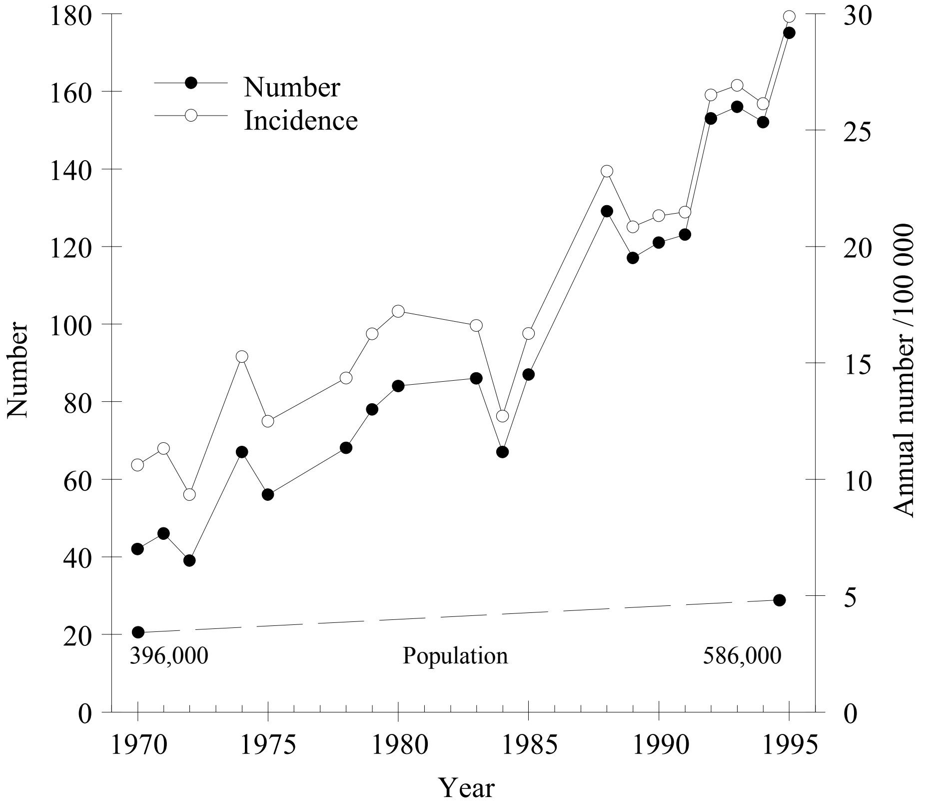

Figure 4. Number and incidence of hospital-treated osteoporotic fractures of the distal humerus among Finnish women aged 60 years or more over the period 1970-1995.

The age-adjusted incidence (per 100 000 women) of these fractures also increased, from 12 to 28, a relative increase of 133% (Figure 5). The mean age of the female patients with an osteoporotic fracture of the distal humerus also increased during the study period, from 71.8 years (1970) to 76.0 years (1995).

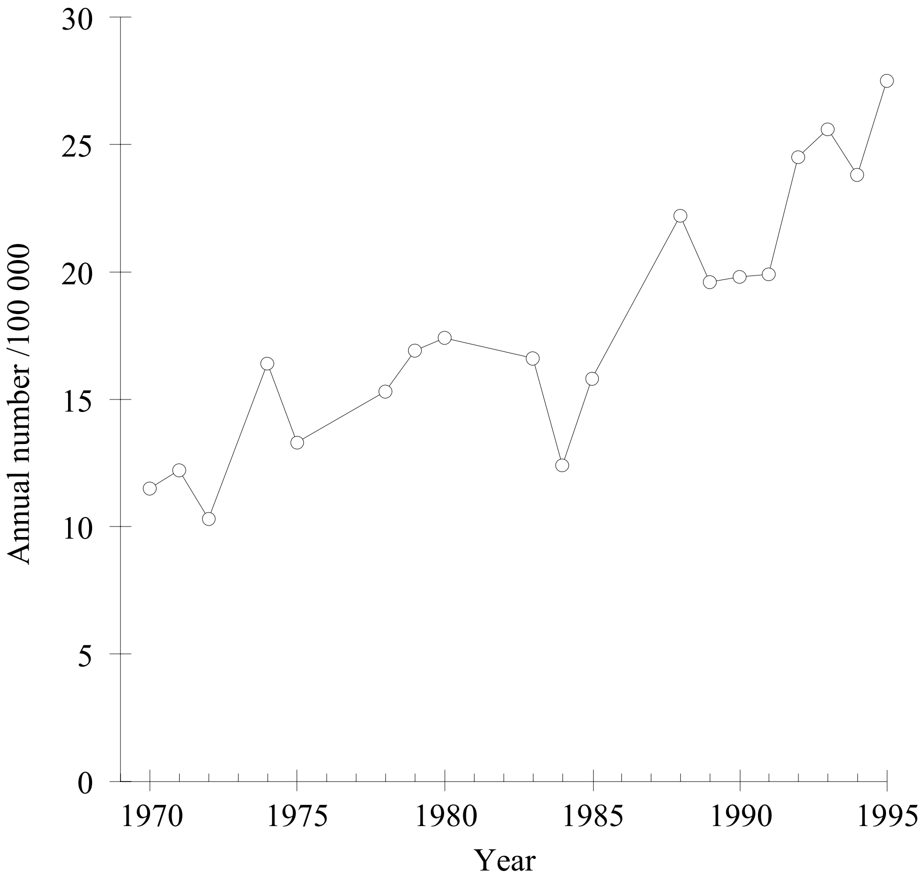

Figure 5. The age-adjusted incidence of hospital-treated osteoporotic fractures of the distal humerus in 60-year-old or older women in Finland over the period 1970-1995.

The age-specific incidence (per 100 000 women) of osteoporotic fractures of the distal humerus in Finnish women rose over the study period in all age groups. The increase was most pronounced in the oldest age group (patients 80 years of age and over), their age-specific incidence being 8 in 1970 and 54 in 1995 (sevenfold increase). In other groups (60-69 and 70-79), the increase was about twofold.

If the above-mentioned incidence development continues, the total number of osteoporotic fractures of the distal humerus in Finnish women will be approximately 180 in the year 2000, and correspondingly, 250, 340 and 440 in the years 2010, 2020 and 2030 (Figure 6).

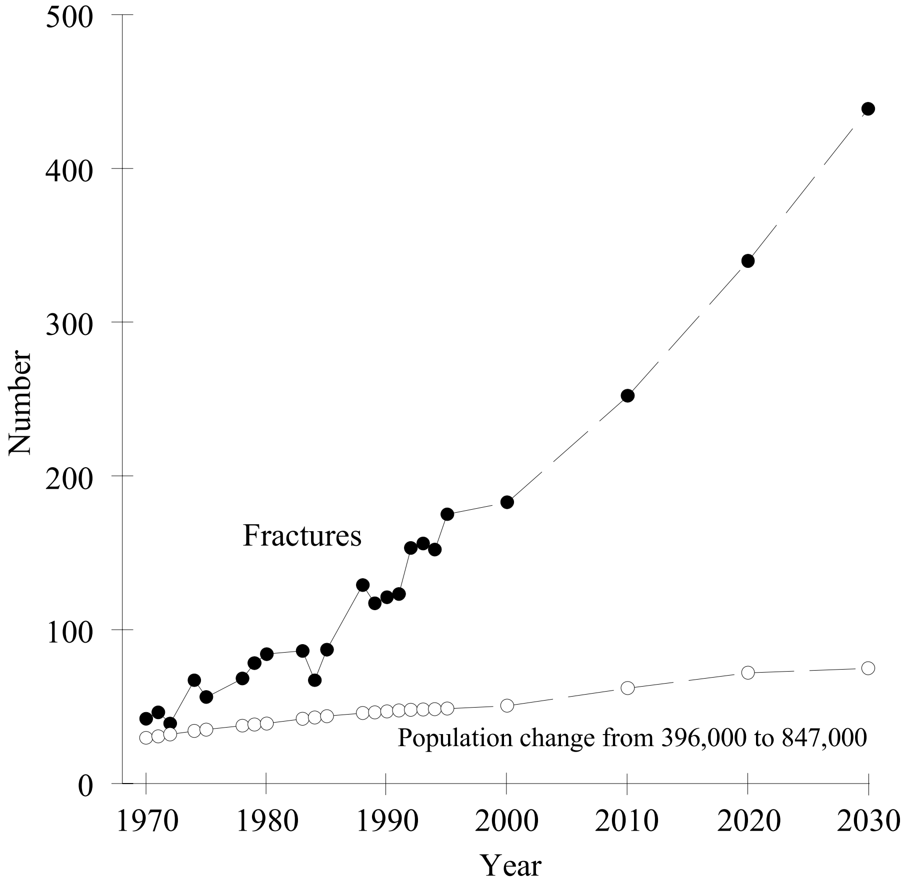

Figure 6. Prediction of the number of the Finnish female population aged 60 years or more and the number of their osteoporotic fractures of the distal humerus up to the year 2030.

1.3. Rib fractures (III)

1.3.1. Study group

The annual total number of Finnish older adults aged 60 years and older hospitalized with a minimal-trauma rib fracture rose steadily during the study period, from 270 in 1970 to 576 in 1994. The average increase was 5% per year. The overall incidence of these fractures also increased during this 24-year period, from 41 to 60, although the population of older Finnish adults 60 years and more increased 47% (from 652 000 to 958 000) (Figure 7). However, the age-adjusted incidence in women changed slightly (36 in 1970, 41 in 1980, and 40 in 1994). In men, the corresponding incidences were 63, 91, and 71. The mean age of patients increased from 74.3 (1970) to 81.5 (1994) in women and from 69.6 to 73.2 in men.

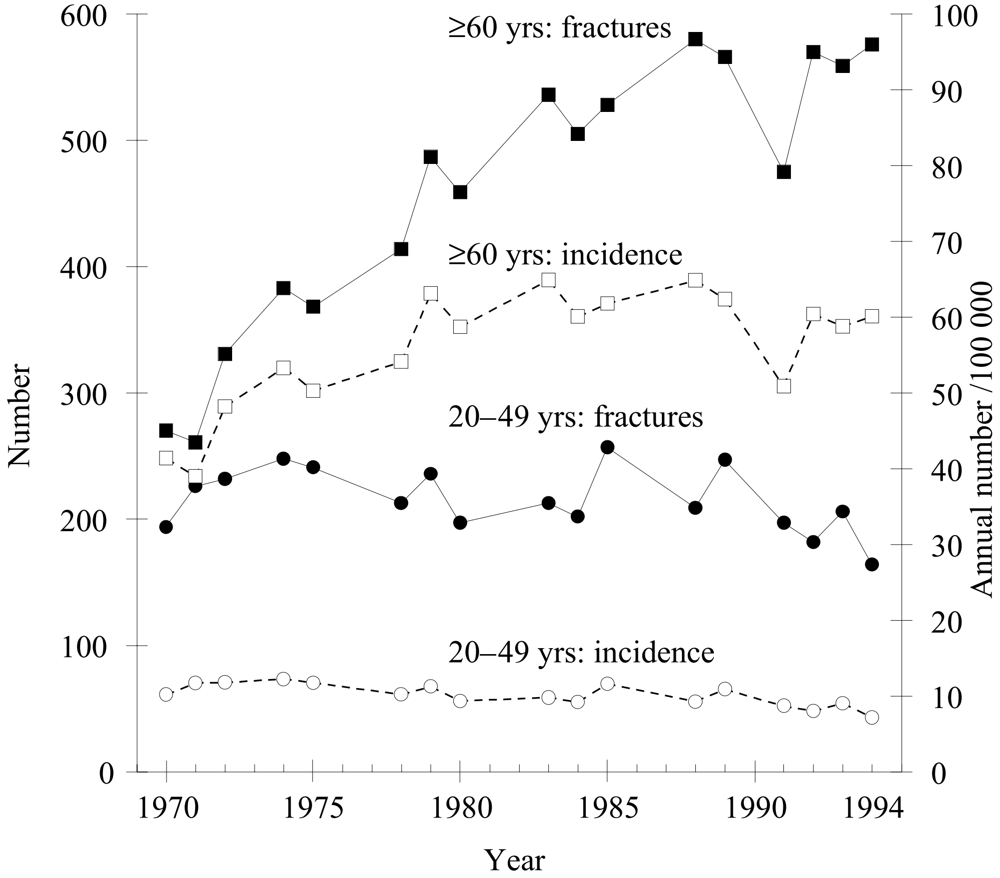

Figure 7. Number and incidence of hospital-treated minimal-trauma rib fractures in Finland in 60-year-old or older persons (black squares indicate the number and open squares the incidence), and in younger patients aged 20-49 years (black circles indicate the number and open circles the incidence) during the period 1970-1994.

The age-specific incidences of minimal-trauma rib fractures (per 100 000 persons) showed no notable trend over time except in women aged 85 and over. In this group, the age-specific incidence increased from 108 (1970) to 251 (1994).

If the increasing trend in the overall fracture incidence continues, the annual number of first minimal-trauma rib fractures can be calculated to be approximately 1000 in the year 2010.

1.3.2. Younger patients

In younger patients, the annual total number and incidence of hospital-treated minimal-trauma rib fractures showed no increasing trend over time; in fact, the trends seemed to be decreasing although the population aged 20-49 years increased by 19% (from 1 908 000 to 2 275 000) during the study period. The number and incidence of these fractures were respectively 194 and 10 in 1970, and 164 and 7 in 1994 (Figure 7). The age-adjusted incidence was 10 in 1970, 10 in 1980, and 6 in 1994. The number of minimal-trauma rib fractures in younger patients (20-49 years) can be calculated to be approximately 110 in the year 2010.

1.4. Fall-induced head injuries (IV)

1.4.1. Older adults

In persons 60 years of age or older, the total annual number of hospitalized patients with a fall-induced severe head injury rose considerably during the study period, from 554 in 1970 to 1393 in 1995. The average increase was 6% per year. In general, the incidence curve for injuries also showed an increasing trend, although the Finnish population of persons 60 years of age or older increased by 48% (from 652 000 to 968 000 persons) during this 25-year period. The overall incidence (per 100 000 persons) of fall-induced severe head injuries in persons 60 years of age or older was 85 in 1970 and 144 in 1995 (Figure 8). The corresponding age-adjusted incidences were 80 and 125 for women, and 102 and 147 for men. The mean age of older persons sustaining fall-induced severe head injuries also increased during the study period, from 69.6 years in 1970 to 75.0 years in 1995.

For all severe head injuries in Finland (i.e. all age groups and all causes of severe head injuries included), the proportion of the 60-year-old or older persons' fall-induced severe head injuries showed a steady increase, from 5% in 1970 to 18% in 1995. In the population aged 60 years or older, the proportion of fall-induced severe head injuries (of all severe head injuries in this age group) also rose, from 41% to 63%.

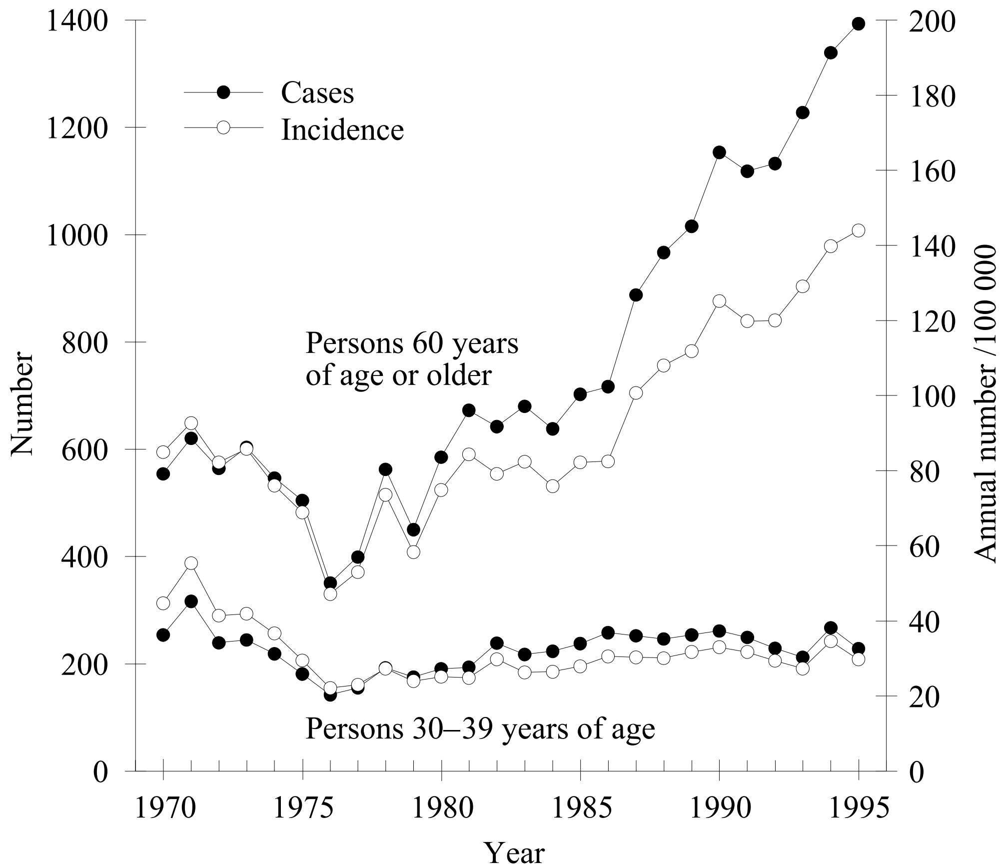

Figure 8. Number and incidence of fall-induced severe head injuries in Finland in persons 60 years of age or older and persons 30-39 years of age between 1970 and 1995.

In the youngest age groups of elderly women and men (60-64 and 65-69 years), the incidence of fall-induced severe head injuries evinced no consistent trend changes over time, while in the older age groups, especially in those 80 years of age or older, the injury incidence clearly increased.

If this increase in the injury incidence continues, the total number of older persons' fall-induced severe head injuries in Finland can be calculated to be approximately 1420 in the year 2000, and correspondingly, 2050, 2800 and 3650 in the years 2010, 2020, and 2030.

1.4.2. Reference group

In the group aged 30-39 years, the annual number and incidence of hospitalized patients with a fall-induced severe head injury showed no increasing trend over time. Early in the 1970s, the number and incidence of these injuries somewhat decreased, after which no notable changes occurred (Figure 8).

2. Hereditary susceptibility (V)

Between 1972 and 1996, 786 twin-cohort members sustained an osteoporotic fracture requiring hospital treatment. The overall cumulative risk of fracture was similar in monozygotic (all 5.4%; men 4.1%; women 6.6%) and dizygotic twins (all 5.1%; men 3.5%; women 6.8%).

The pairwise concordance for fractures was 9.6% (95% confidence interval, 6.2% to 14.2%) in monozygotic pairs and 5.9% (4.0% to 8.4%) in dizygotic pairs, the observed difference of 3.7% having a confidence interval of -0.6% to 8.1%. By sex, this concordance was 9.9% in monozygotic male pairs (9.5% in women) and 2.3% in dizygotic male pairs (7.9% in women). In hip fractures, the pairwise concordance was 7.8% (3.4% to 15.0%) in monozygotic and 6.7% (3.5% to 12.0%) in dizygotic pairs, the difference of 1.0% having a confidence interval of -5.3% to 7.4%.

The probandwise concordance for fractures was 17.6% (11.2% to 24.0%) in monozygotic pairs and 11.2% (7.5% to 14.9%) in dizygotic pairs. By sex, this concordance was 18.0% in male monozygotic pairs (17.4% in women) and 4.4% in male dizygotic pairs (14.6% in women). In hip fractures, the probandwise concordance was 14.4% (5.5% to 23.0%) in monozygotic and 12.6% (6.2% to 19.0%) in dizygotic pairs.

Among men, the relative risk of fracture was 4.39 (2.70 to 7.16) in monozygotic pairs and 1.28 (0.64 to 2.56) in dizygotic pairs; the corresponding risks among women were 2.64 (1.83 to 3.81) and 2.16 (1.65 to 2.83), respectively. In the case of hip fractures, the relative fracture risk was 5.99 (3.68 to 9.78) in monozygotic pairs and 6.97 (4.67 to 10.4) in dizygotic pairs.

3. Injury mechanisms in upper extremity fractures (VI)

3.1. The circumstances of the injury

The injury was a result of a fall in 109 cases of proximal humerus fracture (97%), in 63 patients with an elbow fracture (97%), and in all patients with a wrist fracture (100%). In the control group, correspondingly, the injury was a result of a fall in 100 patients (93%).

Most of the upper extremity fractures occurred outdoors; 54% in the proximal humerus group, 57% in the elbow group, 62% in the wrist group, and 47% in the control group. In all groups the main activity at the time of the accident was walking straight ahead, the percentages being 61%, 52%, 59% and 48%, respectively. The proportions of all other activities at the time of the accident were less than 10% each in the fracture groups and less than 16% each in the control group. Almost all the patients fell on even ground (88-91%). According to the patient's own judgement the main reason for the injury was tripping or slipping, these reasons being reported for 72% of the proximal humerus fractures, 82% of the elbow fractures, 85% of the wrist fractures, and 58% of injuries in the control group. All other causes were involved clearly less frequently (less than 13% each).

3.2. Fall mechanics and directions

Fall mechanics in patientcases and controls are presented in Table 2. In logistic regression analysis, the number of patients sustaining a "fall from standing height or less" did not differ statistically significantly between the groups ($p = 0.15$), the group comparison being adjusted for gender, age and functional capacity. Nor were there any significant differences when comparing the "hardness of the landing surface" between the groups ($p = 0.71$). However, patients with a wrist fracture (48%) managed to break the fall e.g. with an outstretched arm more frequently than those in the other groups (7-21%) ($p<0.001$). The odds ratio (OR) when comparing these patients to the controls was 3.9 (95% confidence interval (CI), 2.0 to 7.3). By contrast, patients with a proximal humerus fracture managed to break the fall clearly less frequently than controls (OR 0.33; 95% CI, 0.14 to 0.80) (Table 2).

	Patients with a proximal humerus fracture (n = 112) %	Patients with an elbow fracture (n = 65) %	Patients with a wrist fracture (n = 110) %	Controls (n = 108) %	*p* value*
Fall from standing height or less	90	91	90	81	0,15
Hard landing surface	75	74	81	79	0,71
Managed to break the fall	7 [a]	11	48 [b]	21	<0.001
Main impact					
on the shoulder/upper arm	76 [b]	3	0	8	<0.001
on the elbow	1	69 [b]	3	4	<0.001
on the hand/wrist	3	6	76 [b]	9	<0.001
Hematoma					
on the shoulder/upper arm	68 [b]	2	2	2	<0.001
on the elbow	5	62 [b]	3	0	<0.001
on the hand/wrist	5 [c]	6 [c]	58 [b]	18	<0.001

* Logistic regression analysis; results adjusted for gender, age and functional capacity.
Pairwise comparisons ($p<0.05$):
a Differs from controls and patients with a wrist fracture.
b Differs from controls and all other groups.
c Differs from controls.

Table 2. Fall mechanics in cases of proximal humerus fracture, elbow fracture and wrist fracture, and controls

Concerning the main impact sites and hematomas, the differences between upper extremity fracture groups and controls were clear and statistically significant (Table 2). In 76% of the patients with a proximal humerus fracture, the main impact of the fall was direct to the shoulder or upper arm, while in the other groups this percentage was 8% or less ($p<0.001$). As an objective sign of this impact, a subcutaneous shoulder hematoma was observed in 68% of the patients with a proximal humerus fracture, while such a finding was rare in the other groups (2% in each) ($p<0.001$).

In 69% of the patients with an elbow fracture, the main impact was direct to the elbow, and in 62% of these patients a fresh subcutaneous hematoma was observed in the elbow area. In other groups, the corresponding figures were 5% or less ($p<0.001$ for both). In the wrist fracture group, patients reported that the main impact was straight to the hand or wrist in 76% of cases (other groups 9% or less, $p<0.001$), and the hematoma was found in 58% of these patients in that area (other groups 18% or less, $p<0.001$) (Table 2).

Fall directions in cases of proximal humerus fracture, elbow fracture, wrist fracture and controls are presented in Table 3. In polychotomous logistic regression analysis, the intergroup differences in fall directions (adjusted for gender, age and functional capacity) were statistically highly significant (χ^2=43.6, df=15, p<0.001). Most of the patients with the proximal humerus or elbow fracture reported that they had fallen obliquely forward (43% and 38%) or to the side (29% and 26%). In the wrist fracture group, the main fall direction was also obliquely forward (34%), although other fall directions were also fairly frequently and equally represented (13-19%). In controls, the main fall direction was to the side (32%). Backward falls occurred in only 4% of all falls in the proximal humerus group, 8% in the elbow group, 13% in the wrist group and 14% in the controls. The odds ratio for an obliquely forward fall resulting in a proximal humerus fracture was 3.5 (95% CI, 1.4 to 9.2), as compared to fall directions among the controls and the "obliquely backward fall direction". Compared with other subjects, patients with an elbow fracture were not likely to have fallen straight forward (OR 0.21; 95% CI, 0.05 to 0.92) and patients with a wrist fracture were not likely to have fallen straight to the side (OR 0.37; 95% CI, 0.15 to 0.91). In this analysis, the obliquely backward direction was used as the "reference fall direction" because in this direction the differences between the groups were smallest (Table 3).

	Patients with a proximal humerus fracture (n = 112) %	Patients with an elbow fracture (n = 65) %	Patients with a wrist fracture (n = 110) %	Controls (n = 108) %
Fall direction				
Forward	10	5 [a]	16	19
Obliquely forward	43 [a]	38	34	16
To the side	29	26	16 [b]	32
Obliquely backwards	11	17	19	16
Backwards	4	8	13	14
Not known/No fall	4	6	2	4

*In polychotomous logistic regression analysis the intergroup differences in fall directions (adjusted for gender, age and functional capacity) were statistically highly significant (χ^2=43.6, df=15, p<0.001).
Pairwise comparisons (p<0.05) ("obliquely backwards" as a reference category):
a Differs from controls.
b Differs from controls and patients with a proximal humerus fracture.

Table 3. Fall direction in cases of proximal humerus fracture, elbow fracture and wrist fracture, and controls*

The above-described distribution of the main fall directions associated well with the distribution of the patients obtained by the (subsequently and separately introduced) falling pictures, pictures visually depicting the fall characteristics the subject might have experienced (the pictures and their detailed results are presented in paper VI).

DISCUSSION

Osteoporotic fractures are coming to constitute an increasingly important problem in the developed countries by reason of the continuing growth of the elderly population (population at risk) and age-adjusted incidence (average individual risk) of fractures. Consequently, this expensive medical condition will be exacerbated in terms of both human suffering and financial burden (Muscat Baron et al. 1994). Nevertheless, precise numbers and incidences of osteoporotic fractures in the future have been difficult to assess since the number of population-based studies has been low.

The present series (papers I-IV) reported secular trends among hospitalized patients with a fracture of the proximal or distal humerus, or ribs, or a fall-induced severe head injury, in the entire elderly Finnish population. We showed that not only the number but also the incidence of these fractures and injuries in older Finnish adults have increased during the last three decades and is still increasing. The aging of the population explains a great part of the numerical increase; however, the age-adjusted figures reveal that the increase, especially in humeral fractures and head injuries, is even more rapid than can be accounted for by demographic changes alone. This would imply that the number of such patients requiring treatment in the future may be greater than demographically expected.

The precise reasons for this development in fracture and injury incidences are not known. The explanations most commonly offered have been that the bones of older adults are weaker today than in the past; i.e., deterioration in age-adjusted bone quality caused by decreased mineral density and bone strength, and / or that older persons fall more often and more seriously than before, e.g. because of impaired balance, coordination, proprioception, reaction time and muscle strength (Obrant et al. 1989, Melton 1993, Greenspan et al. 1994, Thorngren 1994). In other words, it has been suspected that, on average, older persons are less healthy and functionally less capable today than in the past.

Osteoporosis is one of the main risk factors for fractures among older adults (Riggs and Melton 1982, Johnston and Slemenda 1987, Wasnich et al. 1987, Meltzer et al. 1989, Sinaki 1989, Kanis et al. 1990, Myburgh et al. 1990, Ross et al. 1990, Melton et al. 1993b, Cummings et al. 1995, Johnell 1995), but there has so far been no clear evidence to support the conception of a deterioration in the average strength of elderly people's bones during the last decades. Further, in fall-induced severe head injuries among older adults (paper IV) deterioration in bone quality cannot explain the rising injury trends, since head injuries represent a non-osteoporotic injury category. Rather the findings (paper IV) suggest that older adults' tendency to fall has increased during recent decades, and many other investigations have shown that falling and risk factors for falls are the main determinants of fracture (Nevitt and Cummings 1993, Cummings et al. 1995, Dargent-Molina et al. 1996, Marshall et al. 1996, Nguyen et al. 1996, De Laet et al. 1997) and that they seem to be even more important markers of fracture risk than osteoporosis (Greenspan et al. 1994 and 1998, Heaney 1998, Schwartz et al. 1998).

Genetic factors have a substantial role in explaining age-specific variations between individuals in bone mass and density (Smith et al. 1973, Pocock et al. 1987, Evans et al. 1988, Seeman et al. 1989, Krall and Dawson-Hughes 1993, Flicker et al. 1995), but no previous study has directly evaluated whether they can explain some of the variation in the risk of osteoporotic fracture, the true end point of the entire osteoporosis problem, in older people. The results here (paper V) would indicate that genetic factors are not strongly related to the likelihood of osteoporotic fracture, and this was particularly clear in older women.

Thus, against the above-noted background, we extended our views on the prevention of osteoporosis. As prevention of fractures in older people is the ultimate goal in the prevention and treatment of osteoporosis, the traditional strategy in prevention of osteoporotic fractures — increasing peak bone mass and prevention of age-related bone loss — should include serious efforts towards a diminution of the number and severity of falls in older persons and protection of the critical anatomical sites of the body when a fall occurs.

In the case of upper extremity fractures, it had been estimated that about 95 per cent of fractures of the proximal humerus, elbow and wrist are the result of a fall, but only about 5% of all falls result in fracture (Nevitt 1990, Nevitt and Cummings 1993, Cummings and Nevitt 1994). It thus remained unclear which fall-related factors are important and critical in the etiology of upper extremity fractures. The few risk factor studies made in this context have focused on the first phase of the fall only, i.e., the instability phase which results in loss of balance due to host and environmental factors (Tinetti and Speechley 1989, Kelsey et al. 1992, Nevitt and Cummings 1993, Luukinen et al. 1996, O'Neill et al. 1996b). Consequently, the other three phases of the fall in the case of an upper extremity fracture (the descent phase, impact phase, and the post-impact phase during which the subject comes to rest) received no major attention (Hayes et al. 1993 and 1996, Nevitt and Cummings 1993, Cummings and Nevitt 1994). For our own part we considered precise knowledge of these three latter phases of falling (i.e., fall mechanics) in patients sustaining an upper extremity fracture to be essential in obtaining a reliable insight into the etiology and pathogenesis of upper extremity fractures and hence for fracture prevention. Research in this area has in fact been recommended to determine how rather than why people fall (Consensus Development Conference 1996, Hayes et al. 1996).

Following the above-noted guidelines, a controlled study of fall mechanics in 287 consecutive cases of upper extremity fracture and 108 controls was conducted (paper VI). The study showed each of the most typical osteoporotic upper extremity fractures among older adults (proximal humerus, elbow and wrist fractures) to have its own specific injury mechanisms. The great majority of these fractures are the result of a fall, the most typical fall direction being obliquely forward, and the main impact in the great majority of patients being direct to the fractured site. This means that effective prevention of these fractures could probably be achieved by minimizing the obvious risk factors for falling and by reducing the fall-induced impacting force with injury site protection.

There were two notable strengths in our epidemiologic studies. First, the source of data, i.e. the Finnish National Hospital Discharge Register, is the oldest nationwide discharge register in the world and its accuracy and coverage have been shown to be good, especially in the context of severe injuries such as fractures (Salmela and Koistinen 1987, Honkanen 1990, Aro et al. 1990, Lüthje et al. 1995). Second, the study was based on the whole Finnish population (5 million). In other words, the given absolute numbers and incidences of injuries are not cohort-based estimates but complete population results.

A limitation of our epidemiologic studies is that the numbers, incidences and secular trends elicited cannot be directly generalized to other populations in the world, although it is likely that the incidences and trends of upper body fractures are similar in other Western countries with predominantly white populations. Further studies are required to bring out precise details for each population. In addition, our database on fractures and injuries did not include information on comorbidity, medications and lifestyles of patients. In other words, our findings of increasing incidences among older adults in Finland are presented without explanatory speculations. Further, in Finland a great proportion of patients with a fracture of the proximal humerus or ribs are treated as outpatients, while most with a fracture of the distal humerus are probably admitted to hospital. This means that the final total numbers of these fractures are difficult to assess accurately.

Our findings on proximal humerus, distal humerus and rib fractures, and fall-induced severe head injuries among elderly persons are alarming for two reasons. First, not only is the incidence of these injuries among older adults increasing, but the population at risk is constantly expanding and will expand more rapidly in the near future. As a result, the largest age group in Finland (the 15-year cohort born after World War II) will reach the average age of older adults with upper body fractures and injuries between the years 2020 and 2030. Second, the increasing mean age of patients is likely to involve greater difficulties in the treatment of these injuries (longer times for fracture healing, longer rehabilitation periods, and more treatment failures such as nonunions and loss of stability of the osteosynthesis) as well as increasing rates of general morbid conditions and, indirectly, mortality.

Although the data in the study of hereditary factors (paper V) were collected from hospital admissions only, which represent in some fracture types (such as wrist and vertebral fractures) only a proportion of fractures sustained in the population as a whole, it was unlikely that the persons admitted to hospital were selected according to zygosity. We would thus assume that the results and conclusions of this study are unbiased and valid. One limitation was that the number of pairs concordant for fractures was small, especially among men. Clearly, more incident case material is necessary to increase the statistical power of the study and thus make for more definitive conclusions. This will be especially important for different fracture types, as family history studies seem to suggest that a positive family history of a specific fracture (wrist, hip) increases the risk of sustaining that specific fracture (Cummings et al. 1995, Fox et al. 1998). Only the coming years will show the true fracture development in our Finnish twin cohort.

The study of the injury mechanisms involved in osteoporotic upper extremity fractures (paper VI) has some obvious strengths. For the first time, the direct injury mechanisms of upper extremity fractures among older adults (i.e., the descent, impact and post-impact phases of falls resulting in proximal humerus, elbow or wrist fracture) were investigated in detail. Second, the number of the patients in each fracture group and the number of controls were fairly high (287 patients and 108 controls), thus giving a reasonable possibility to examine the fall mechanics and directions in each fracture group and between the groups. Third, the cases and controls were interviewed and examined according to a prospective study plan, thus keeping the delay between injury and examination short. This design also allowed reliable recording of the fresh hematomas and bruises and analysis of their connection to the fall mechanics.

There were also limitations in the study of injury mechanisms. Interview and examination of persons who have just experienced an injury will never be 100% reliable. In other words, we cannot be sure how well elderly fallers can describe the fall characteristics and circumstances. However, this study showed that falling mechanics in patients with a proximal humerus, elbow or wrist fracture were clearly and significantly different from those among the controls and this difference cannot be explained by possible uncertainties in the methods of data acquisition, especially when all the subjects and controls were interviewed and examined in a same way and the objective sign, a fresh subcutaneous hematoma on the upper extremity, could frequently be found in patients with a proximal humerus, elbow and wrist fracture but rarely in the controls. Continuous, 24-hours a day video monitoring of elderly persons living in long-stay geriatric facilities would yield the most reliable data on the fall mechanics related to osteoporotic upper extremity fractures, but for this purpose a relatively large number of older adults would have to be recruited, with coverage of the entire facility by video cameras, including toilets, corridors and rooms, and the ethical problems of video control would render such a study difficult to carry out.

The present results are in accordance with the few previous studies which have reported the circumstances of injuries resulting in proximal humerus or wrist fractures. Kelsey and associates (1992) reported that over 70% of these fractures are the result of a fall from standing height or less. In our study the figure was 90%. Likewise, Solgaard and Petersen (1985) reported that 87% of wrist fractures in women and 64% in men result from a fall from standing height or less. Nevitt and Cummings (1993) reported that nearly all women with wrist fractures (88%) fell on the hand or wrist, compared with 46% of falls without fracture. In our study 76% of the patients with a wrist fracture reported that the main impact was directed straight to the hand or wrist, while the figure was only 9% in the controls.

Since most upper body fractures seem to be related to the fall and direct trauma at the fracture site, prevention of such falls would seem a feasible means of reducing the number of these fractures. The risk factors for injurious falls are well described. They include low body weight, increasing age, female sex, poor ambulatory status and movement ability, a previous history of falls and fractures, dementia, Parkinsonism, postural hypotension, dizziness, poor vision, high number of medications, use of sedatives, and environmental hazards (Tinetti et al. 1988, Nevitt et al. 1989, Myers et al. 1991, Sattin 1992, Jäntti et al. 1993, Malmivaara et al. 1993, O'Loughlin et al. 1993, Ryynänen 1993, Cummings et al. 1995, Johnell et al. 1995, Luukinen et al. 1995). Although it is impossible to prevent all falls, it has been seen to be important to identify patients with a high risk of falling and then focus the prevention strategies on these individuals (Myers et al. 1989, Tinetti and Speechley 1989, Rubenstein et al. 1994, Kanis and McCloskey 1996, Graafmans et al. 1996). It has furthermore been suggested that especial importance attaches to identifying those fallers who run a high risk of injurious falls, since only few falls lead to a fracture (Hayes et al. 1996). On the other hand, the problem with this type of case-finding approach is the same as with medication, i.e., treating risk factors can substantially reduce an individual person's risk of fracture, but it is difficult to reduce the rate of fractures substantially at population level by reason of the low prevalence of each risk factor in a population and because the intervention usually reaches and changes the risk factors in only a limited proportion of the population (Cummings 1998).

Apart from osteoporosis and falls, effective prevention of upper body fractures could probably be achieved by reducing the fall-induced impacting force with softer floor coverings or with injury site protection (Streit and Cavanagh 1994, Parkkari 1997, Kannus et al. 1999c). The former strategy is still in its developmental phases, while preventing hip fractures with an external hip protector has turned out to be an effective fracture-reducing strategy (Kannus et al. 2000c). The possibilities of preventing upper body fractures with similar devices should be examined more closely in the future.

Overall, since the ultimate goal in the field of osteoporosis is fracture prevention, we believe that the findings in this series have important implications. We suggest that in addition to the traditional means of preventing upper body fractures, i.e., increasing peak bone mass and preventing age-related bone loss, the modern prevention strategy should include serious efforts towards a reduction in the number and severity of falls among older adults. Only when all major risk factors are included in the prevention program can true decreases in fracture incidence be expected.

CONCLUSIONS

In keeping with the original aims of the study (p. 24) the conclusions reached here are:

1. The number and incidence of hospitalized elderly patients sustaining an osteoporotic fracture of the proximal humerus, distal humerus or ribs, as well as similar patients with a fall-induced severe head injury, clearly rose in Finland in the period 1970-1995 and this increase could not be explained by demographic changes alone. The increase in head injuries, a representative of a non-osteoporotic injury category, is likely to reflect an increase in the number and severity of falls among older Finnish adults.

2. Genetic factors are not strongly related to the likelihood of osteoporotic fracture, particularly in elderly women.

3. Osteoporotic upper extremity fractures among older adults have their specific injury mechanisms. A great majority of these fractures occur as the result of a fall and subsequent direct impact at the fractured site.

SUMMARY

In the first four studies (papers I-IV) all Finnish older adults were used to bring out time trends in the absolute numbers and the incidences of hospitalizations for osteoporotic proximal humerus, distal humerus, or rib fracture, or fall-induced severe head injuries, between 1970 and 1995. Using the National Hospital Discharge Register (NHDR) and the unique personal identification number it was possible to focus the analysis on the first recorded admission and to eliminate multiple admissions due to transfers between hospitals or hospital departments and readmissions due to complications. The absolute number of osteoporotic proximal humerus fractures in Finland increased from 212 in 1970 to 844 in 1993, the number of women's osteoporotic distal humerus fractures from 42 in 1970 to 175 in 1995, the number of minimal-trauma rib fractures from 270 in 1970 to 576 in 1994, and the number of fall-induced severe head injuries from 554 in 1970 to 1393 in 1995. Correspondingly, the age-specific incidence of these fractures and injuries increased, especially in the older age groups. If the current trend continues, the total number of osteoporotic proximal humerus fractures among older Finnish adults aged 60 years or more is predicted to be about 1400 in the year 2010, 2000 in the year 2020, and 2600 in the year 2030. Correspondingly, the total cases of osteoporotic distal humerus fractures among Finnish women will be about 250, 340 and 440, in the years 2010, 2020 and 2030. The number of older people's minimal-trauma rib fractures will be approximately 1000 in the year 2010, and the number of fall-induced severe head injuries approximately 2050, 2800 and 3650 in the years 2010, 2020, and 2030, respectively.

In the study of heritability in the context of osteoporotic fractures in older Finnish twins (paper V), all 50-year-old or older twin cohort members who were admitted to Finnish hospitals between 1972 and 1996 for primary treatment of an osteoporotic fracture were selected from the NHDR to determine whether genetic factors play a role in explaining the variation in the risk of such fractures. In women, the pairwise concordance rate for fracture, that is, the relative number of twin pairs in whom fracture was sustained by both twins in a pair, was 9,5% in monozygotic pairs and 7,9% in dizygotic pairs. In men, the figures were 9,9% and 2,3%. Thus, susceptibility to osteoporotic fractures in older Finns was not strongly influenced by genetic factors, especially in older women.

The purpose of the case-control study of injury mechanisms involved in osteoporotic

upper extremity fractures in older adults (paper VI) was to determine how falls leading to a fracture of the upper extremity occur and to compare these mechanisms with those in control fallers, and in this way to gain an insight into the etiology and pathogenesis of upper extremity fractures with an eye to fracture prevention. A total of 287 case and 108 randomly selected control subjects were recruited from the two main emergency rooms in the city of Tampere between September 1995 and December 1997. All subjects were interviewed first by open and then by structured questions, and their fresh hematomas and bruises were recorded. The study showed that each of the most typical osteoporotic upper extremity fractures in older adults (proximal humerus, elbow and wrist fractures) had its own specific injury mechanisms. The great majority of these fractures were the result of a fall, the most typical fall direction was obliquely forward, and in the great majority of victims the main impact of the fall was directed straight to the fractured site. These observations indicated that effective prevention of osteoporotic upper extremity fractures could probably be achieved by minimizing the obvious risk factors for falling and by reducing the fall-induced impacting force with injury-site protection.

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