Chapter 3
The Residential Fire Injury Pyramid

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Abstract The injury pyramid is a commonly used model in order to illustrate the relationship between non-injurious events and fatal events, as well as the various injury-levels in-between. From a residential fire perspective, there is also the added aspect of whether fires are attended to or not. In practice, this means that the understanding of the residential fire problem is often understood merely from the perspective of fatal fires that are attended to by rescue services. However, as will be seen in this chapter, merely focusing on these incidents and the risk factors associated with these fires or victims produces a distinctly skew view of the residential fire problem. As such, it is important to attempt to assess and understand the entire residential fire injury pyramid.

Keywords Injury pyramid · Morbidity · Mortality · Non-fatal fires · Fatal fires · At-risk groups

1 Introduction

In terms of injury prevention, the concept of the injury pyramid has become well-established. While often used to illustrate the distribution of injuries, it has also come to function as a foundation to injury prevention interventions. Presented in 1931, in the book *Industrial Accident Prevention: A Scientific Approach* by Herbert Heinrich [1], the injury pyramid was the result of studying more than 75,000 industrial accidents. Heinrich's conclusions from these investigations were threefold. First, he declared that in terms of severity, the relationship between accidents resulting in serious injuries, accidents resulting in minor injuries and accidents resulting in no injuries was a 1:29:300 ratio (see Fig. 3.1). Second, he declared that in terms of causes, 88% of incidents were caused by the unsafe acts of people, 10% were

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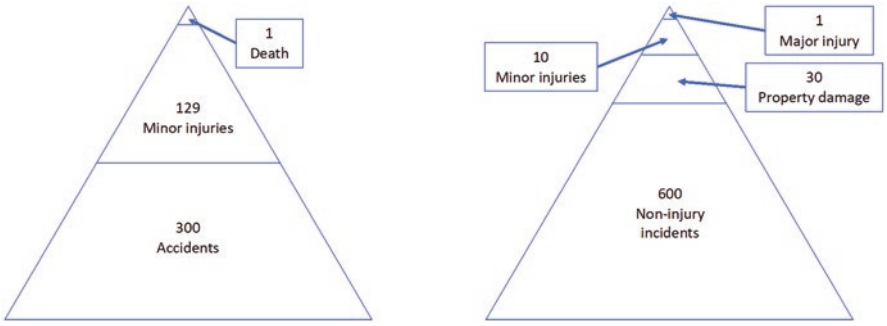

Fig. 3.1 Schematic injury pyramids according to Herbert Heinrich [1] and Frank Bird [3]

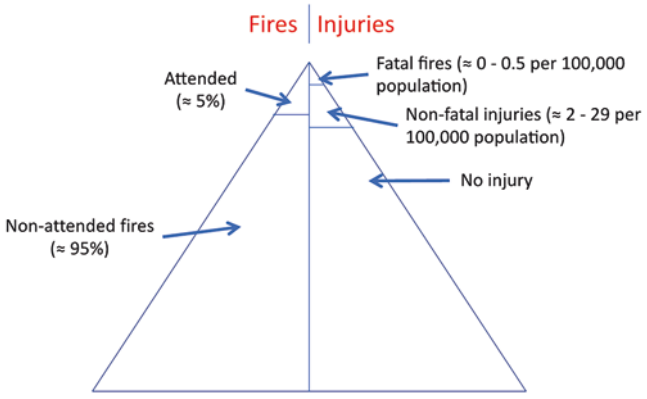

Fig. 3.2 A schematic injury pyramid of residential fires and the injury outcome

caused by unsafe conditions and 2% were not preventable. Third, Heinrich indicated that the causes of minor and major incidents are generally the same, stating that the repetition of non-injury incidents inevitably leads to major incidents [2].

Since the original claims, a number of authors (in particular within occupational and industrial safety) have continued to elaborate on Heinrich's conclusions. In particular, the 1966 book *Damage Control* by Frank Bird elaborated on the thoughts of Heinrich and presented a new ratio of 1 *major injury* to 10 *minor injuries* to 30 *property damage* to 600 *non-injury incidents* [3] (see Fig. 3.2). Also, in a later book *Practical Loss Control Leadership*, together with George Germain, the injury pyramid was further reiterated as was the concept that by reporting, investigating and preventing near hits or minor incidents, the pyramid can be flattened and the number of serious incidents can be reduced [4].

The presumption that minor incidents are simply potentially major incidents that have been luckily or skilfully avoided (based on the assumption that a large majority of incidents are caused by the unsafe acts of individuals) presides also today, not

least within fire safety. It has been argued that *"unreported fires are important to note in the estimation of total fire hazards as they could have developed into potentially dangerous fires if they had not been detected or controlled early"* [5]. Despite the empirical evidence suggesting that hindering minor incidents will not hinder major incidents, both researchers and practitioners continue to (incorrectly) claim that a systematic approach of hindering near-misses will not only have an effect on the base of the pyramid (i.e. minor incidents), but also the top of the pyramid [6]. Similarly, the opposite is true. Reducing, for example, the incidence of fatal residential fires by focusing on the underlying causes of these incidents will not necessarily have an effect on the incidence rates of residential fires in general.

However, although there are considerable problems associated with the concept of the injury pyramid, there are practical uses in terms of residential fires. First and foremost, presenting injury data in an injury pyramid can be an illustrative exercise when comparing different countries or different injury types. Second, following an injury pyramid over time can give valuable insights into the successes of preventative measures as well as injury severity levels where more work is required.[1] Third (and ironically considering the original purpose of the injury pyramid), when combining the numbers in the injury pyramid with background data, the injury pyramid can effectively illustrate the differences between the severity levels in terms of who is at most risk, where these incidents can occur, which types of fires are overrepresented as well as differing contextual factors. As such, it is also possible to assess what potential effect different preventative measures will have on each level.

Despite the considerable problems with the original purpose and thinking behind the injury pyramid, this chapter aims to present a brief overview of the injury pyramid for residential fires. Focus will predominantly be on the qualitative differences in the severity levels, in accordance with the reasoning above. Importantly, given the differences in global fire mortality, in particular regarding determining factors for fire-related injuries [8, 9], this chapter will focus on the injury pyramid from a high-income country perspective.

2 Residential Fires Not Attended to by Rescue Services

The base of an injury pyramid is often composed of near-misses or incidents without injury. As such, the base of the pyramid regarding residential fires consists of residential fires that were extinguished without the need of help from rescue services.

Numerically, it is difficult to know exactly how regular such residential fires are given that no organisation has been present and therefore no registration has occurred. However, based on the results from a telephone interviews in the United

[1] N.b. in order for this to be possible it is important to have similar data collection procedures as well as taking into account changes in, for example, coding practices [7]

States in 2004 [10], it is clear that this level in the injury pyramid is by far the largest. According to the results, an estimated 7.2 million residential fires occur each year that are not attended to by rescue services and approximately 130,000 (usually minor) injuries are caused by these fires [11]. Importantly, compared to data from 1984, when an estimated 23.7 million residential fires occurred annually, the number of residential fires seems to have decreased dramatically [12].

Given the difficulty in collecting data regarding these types of fires, a limited number of studies have investigated this dimension of residential fires. However, despite this, the results are surprisingly similar regarding the socio-demographic groups that have a higher risk. An increased risk has been observed in households with members under 18 years [10, 13–17], those with a high educational level [10, 13–17], smokers [10, 13–16], those living in rented accommodation [10, 14], households with many family members [10, 16] and in immigrant households [17].

These results are in some senses surprising. Although individuals living in rented accommodation, smokers and ethnic minorities are known to have a high risk of fire-related mortality [18], high education as well as households with many family members and children have a distinctly lower risk for residential fire mortality [18–20]. One potential explanation as to why households with several individuals, high educational level and children are overrepresented in the risk of residential fires yet underrepresented in fatal fires is the preventative measures that are taken by different groups [21]. It is likely that in households with several individuals, high educational level and children, there is an increased chance of being alerted to a fire (either due to the presence of smoke alarms or simply due to the large number of individuals in the household) and the household having the equipment and training to handle the fire themselves.

While this may suggest that fatal fires are simply small fires that could have been stopped if the correct equipment had been in place, this would assume that the effectiveness of the intervention was the same in all groups and that the fires were of the same type. In regard to the higher risk of fire in households with children, it is well-known that children in the 6–12 year age group (that are the largest child risk group [17]) are more likely to experiment with matches and candles due to a lack of understanding of the potential consequences, thereby causing fires, compared to older age groups [22]. However, in terms of fatal fires, candles are only known to be a risk factor for elderly, often disabled, individuals [23]. Also, when analysing the potential of implementing different safety interventions on fatal fires, it is clear that interventions such as fire-safe cigarettes and flame-retardant clothes, bedding or furniture would be highly effective in reducing the fatal fire risk for the group that now dies in residential fires [24]. However, this type of equipment is almost completely absent from the households of those who to a larger degree have smaller fires that are handled independently [17]. Likewise, the equipment that is prevalent in low-risk homes (such as smoke alarms and fire extinguishers) have relatively low potential effect on reducing the risk of fatal fires in high-risk homes [24].

3 Non-fatal Fires Attended to by Rescue Services

The next stage in the injury pyramid is the level consisting of residential fires that the individual, or alternatively the individual's social network, was unable to extinguish. I.e., fires where the help of rescue services was required and where the victims survived.

On a yearly basis, again using the United States as an example, rescue services attend to approximately 360,000 residential fires [11], i.e., approximately 5% of all residential fires. Although the number of rescue service attended fires, at least in some respects, increased during the 1990s [25], in similarity to the risk of fatal fires [26, 27], the number of fires attended to by rescue services has decreased considerably during the last decades in Sweden, the United Kingdom and the United States [27–29]. Although this is obviously a positive development as it would suggest more fire-safe societies, there are also problems with such a development. For example, less residential fires means that rather than focusing on fires, a very large proportion of the rescue services' calls are either "false alarms" or related to other societal safety issues, such as traffic-related incidents [28, 29]. As such, at least in the UK, the maintaining of full-time stations is increasingly questioned [28] which is problematic in itself considering the importance of time in hindering fatalities [30].

In terms of comparisons, very few results exist regarding the differences between non-attended and attended residential fires or in relation to the general public. However, in general, smoke alarms seem to be more prevalent in homes that manage the fire themselves compared to those requiring help [31]. As such, this would indicate that an important difference between non-attended and attended residential fires is the size of the fire given that a smoke alarm will notify inhabitants of a smaller fire. As noted above, socio-demographic differences in safety equipment are considerable [21]. Therefore, it is unsurprising that rescue services are more often called out to areas with higher rates of unemployment, economic deprivation, low education and high rates of ethnic minorities [32, 33].

In terms of comparisons between fires attended by rescue services and fatal fires, it is clear that some characteristics increase the probability of being rescued. First, the presence of others seems to be an important element in increasing survival. Previous studies have shown that living with others is a strong protective factor against fire-related mortality [34] and this is also shown in a comparison between non-fatal and fatal fires [35, 36]. Similarly, living in an apartment is also protective [27, 35, 37], most likely due to the increased possibility of a fire being noticed early on in the process, as shown by the fact that neighbours are the most common individual to alert rescue services [35]. Combined with the fact that non-fatal fires are often attended to more quickly than fatal fires [35, 37], it is likely that the time from fire ignition to rescue is considerably shorter for non-fatal fires [37]. As such, urban dwellings are likely to increase the possibility of being rescued, a factor relatively unsurprising given the known increase in risk of fatal fires in rural locations [18, 30, 38].

The second factor visible in the published material is the physical and mental capabilities of the victim. Put simply, fires that occur in the homes of individuals who are under the influence of alcohol or drugs, have physical or mental disabilities or are of high age are considerably more likely to result in fatalities compared to those with the opposite characteristics [35, 37]. Interestingly, also circumstantial aspects that reduce the individual's awareness and capabilities also severely affect the outcome. Most notably, if the victim is awake when a fire starts, the chance of survival is considerably greater, irrespective of whether there were functioning smoke alarms [36].

A third factor is the type of fire. Smoking-related fires are a considerable cause of fatal fires [23], despite the fact that smoking-related fires account for a relatively small number of attended residential fires [11]. However, in terms of electrical and cooking-related fires, these are considerably more common among non-fatal rescue service attended fires than in fatal fires [35, 36]. It would seem, therefore, that focusing on minimising the number of electrical and cooking-related fires would most likely have a limited effect on the total number of fatal fires though would affect the number of rescue service-attended fires.

A final element that is interesting to note in regard to this level in the incident pyramid is that elderly individuals, as also shown in the lower risk of having a residential fire without needing the help of rescue services [17], are less likely to be involved in a non-fatal fire requiring the help of rescue services [33]. Given the increased risk of elderly being involved in a fatal fire compared to younger populations [18, 39], this would clearly indicate that the mortality risk is less related to the risk of experiencing a fire and more related to the consequences once a fire has started.

4 Non-fatal Injurious Residential Fires

Residential fires that lead to injury, though are not fatal, can be seen to be the next step in the injury pyramid. Obviously, these injuries are a part of either of the first two categories. However, in the previous two levels, individuals who have not sustained an injury are a clear majority meaning that if injured individuals have specific individual or fire characteristics, the previous levels may not be representable. Given that the primary goal for fire safety is the protection of human lives, it is therefore important to distinguish this perspective of fire safety despite them being included in several levels.

There are some aspects that are important to note before presenting this level. First, studies on fire-related injuries are often focused on burns, regardless of whether these were caused by an unintentional or intentional fire and regardless of whether the fire was residential or non-residential. Although some studies present the proportion of burns in relation to the type of fire, this is only in the descriptive statistics, not in the later analyses. This means that it can be difficult to ascertain exact socio-demographic factors for residential fire-related injuries. As such, much

of the presented material in this section is related to burns in general. Also, the category of "non-fatal fire-related injuries" includes a broad array of injuries; from injuries merely requiring first-aid to long-term care in specialised burn units. While it would be beneficial to differentiate between these groups, this is difficult for a number of reasons. First, given that some type of data collection is required, a common cutoff for studies is whether an individual visited an emergency department (ED). However, the criteria for whether individuals receive care at an emergency department or other medical institutions can vary between countries, making international comparisons difficult. Second, there seems to have been a change in policies in many countries with more minor burns being admitted to specialised burn units than previously, not least as a consequence of a greater acceptance of the psychological impact burns can have on victims [40]. Although the relationship between different injury severity categories seems to be relatively similar with approximately 5–10% [9, 41–43] of burn victims presented at an ED needing specialised care, these aspects mean that differentiating severity is difficult, as is clearly seen by the fact that the rates of burns treated in hospitals vary between 2 and 29 per 100,000 inhabitants in Europe [44].

Regardless of these issues, a decrease has been observed in the rates of ED visits for burns between the 1990s and 2000s in the majority of high-income countries [9, 40]. Likewise, the injury severity (i.e. burn depth) and length of stay in hospitals seem to have decreased in many countries [40], at least in part due to improved medical treatment [45].

In terms of socio-demographic factors, studies from the United Kingdom, the United States and Australia have shown injury rates to be considerably higher in low-income neighbourhoods compared to more well-off areas [46–49]. As such, similar background factors are seen in attended residential fires. Families with low income seem to be particularly at risk in terms of burn injuries in general [50] and for children in low-income families the risk of attaining a burn injury is over eight times the risk for a child in a middle-to-high-income household [51]. However, in terms of education, although low-education is a risk factor for burns in some studies, this factor seems to have less of an impact on risk than income [50], i.e. an opposite result from non-attended residential fires.

Ethnic minorities have also been shown to be overrepresented regardless of whether only residential fires are studied or all types of burns are included [49, 50]. Although it is most likely that at least some of this increase in risk can be explained by socioeconomic confounders [9], results from Australia indicate that injury reductions have been less prominent among indigenous groups compared to the rest of the population [52]. Therefore, this group deserves increased attention, not least considering a lower prevalence of safety equipment [53, 54]. Similarly, although the overrepresentation of burn victims in single-parent households [50] is most likely due to socioeconomic confounders and difficulties with supervision of children, this group also has less fire safety equipment in the home [21, 55] meaning that preventative measures aimed at this group could also be beneficial.

In terms of sex, men are considerably overrepresented [40] in all age groups despite small children (0–4 years and in particular 6–24 months) having by far the

greatest risk of receiving burn injuries that require hospitalisation [9, 56], followed by the age group of 15–44 years [57, 58]. In terms of elderly individuals, although the risk of attaining a burn injury is lower compared to younger groups, they are generally less well-equipped to cope with a fire. Case-fatality rates are considerably higher [59] (which may account for the relatively low hospitalisation rates in this age group, i.e., fires may more often be fatal than non-fatal), and when individuals survive, they have a high risk of needing to move to assisted living [9]. As such, this group may be more at risk than the statistics would suggest.

5 Fatal Residential Fires

Fatal residential fires are obviously the top of the residential fire injury pyramid. In terms of mortality rates in a total population, these vary from 0 to 0.5 per 100,000 in high-income countries [60]. In terms of general fire mortality, one of the most prominent risk factors, at least in high-income countries, is age [23, 61]. From a European perspective, the average fire-related mortality rate among older adults between 2005 and 2014 was 2.86 per 100,000. Notably, however, there was considerable variation between countries (a low of 0.55 in Iceland to a high of 14.65 in Latvia) [34].

The fact that old age is such a considerable risk factor for mortality despite not being a risk factor for the majority of the other levels in the injury pyramid is an important aspect. Old age has considerable effects on the physical and cognitive abilities of an individual [62], meaning that evacuation or more complex fire extinguishing can be difficult or impossible. Therefore, an early detection becomes the only reasonable preventative measure for older adults with reduced capabilities and could explain why this group generally focus on smoke alarms rather than other safety equipment [21]. It also helps to explain the inadequacies of applying an injury pyramid perspective to residential fires. As is clear from the typologies of fatal residential fires [23], certain types of fires are considerably more common among fatal fires than fires in general, for example regarding smoking-related fires. Often, these are relatively small fires that for a younger, well-functioning individual are easy to manage. For a disabled (either due to illness or substances) individual, however, such fires can be near impossible to manage.

Although the risk factor of age differs between fatal fires and other levels, there are also a number of socio-demographic risk factors that are similar with previous levels. These include being male [23, 63], living alone [34, 63–65], belonging to an ethnic minority [20, 46, 66], having low educational attainment [19, 20], as well as other deprivation-related factors such as having a low disposable income, receiving social allowance, being unemployed, receiving health-related early retirement pension, etc. [19, 36, 39, 46, 64, 65, 67, 68]. Interestingly, many of these socio-demographic differences have been observed since the 1970s [69, 70], though seem to have become even more pronounced since then [36, 64].

6 Discussion

As is hopefully clear from this chapter, in terms of the quantitative relationship between the different levels in the residential fire pyramid, there are a number of uncertainties, not least given that certain levels include the same fires. Also, certain levels are related to the number of fires, while others are related to the number of individuals. However, despite this, the quantitative relationship is valid to present as it clearly illustrates the large base of the pyramid. Due to the fact that whether fires are attended to or not is not necessarily related to the fire's outcome, the pyramid needs to be divided and separated from the perspective of the fire and the outcome.

As is seen in the figure above, based on an approximate ratio of data from Europe and the United States, a number of interesting aspects are seen. First and foremost, it is clear that a very large number of residential fires are managed within the household without the help of rescue services. Practically, this means that in most cases rescue services, or other government organisations that are responsible for preventative interventions, have no knowledge regarding approximately 95% of all residential fires (n.b. this number varies somewhat between countries). Although this in itself is not necessarily a problem, given that rescue services should focus on those households that have difficulty in extinguishing or evacuating, it is important for rescue services to be aware that their preconceptions regarding residential fires are largely constructed from the most severe cases or those households that need help.

Second, a very large number of residential fires do not lead to injuries or fatalities and traditional risk measurements can be highly misleading. Most rescue service statistics are based on only the three highest levels and therefore the risk of injury or death per residential fire can be understood as considerable. By including the base, however, it is clear that this is not the case. In fact, from a community perspective, the risk of injury or death is very low per residential fire. However, this is not the case when specific socio-demographic groups are compared.

	At-risk groups			
	Fatal fires	*Non-fatal injurious residential fires*	*Non-fatal fires attended to by rescue services*	*Residential fires not attended to by rescue services*
Age	Elderly	Children	Adults	Adults and children
Sex	Men	Men	–	–
Income level	Low	Low	Low	–
Education level	Low	Low	Low	High
Ethnicity	Minority groups	Minority groups	Minority groups	Minority groups
Physical or mental function	Low[a]	–	–	High
Household characteristics	Single occupancy	Single-parent households	Multi-person households	Multi-person households
Type of accommodation	Houses/ rural areas	–	Apartment/urban areas	–

[a]Either caused by physical or mental illness, or due to effects of alcohol and/or drugs

As is evident from the literature review in this chapter, which in turn is compiled in the table above, the socio-demographic groups most at risk differ considerably between the different levels. From a national or population perspective, it is clear that there is a socio-demographic scale in regard to residential fires. Healthy individuals who have been educated and who live with others are considerably more likely to handle a fire themselves. If their socio-demographic level is slightly lower, they are also highly likely to remain uninjured despite needing help from rescue services.

The importance of socio-demographic factors is further supported by studies showing a significantly lower use of preventative measures or practices among ethnic minority families [21, 53, 54, 71, 72], single-households and low-income families [21, 55], families in rented accommodation [21, 73], individuals with a lower educational level [21, 74, 75] as well as those living in socially deprived areas [76, 77]. Fire protection, therefore, seems to follow a "sociodemographic protection maturity U-curve" in which younger individuals living in single households with low income tend to exhibit low levels of fire protection. The level of protection then increases with socio-demographic development, to peak during middle-age, to then decrease again with old age [21, 78].

Whether this is true from an individual perspective, i.e., that the level of protection varies throughout an individual's life, is unknown. However, previous studies have shown that risk-taking generally decreases as one gets older [79] and adding a child to a household greatly increases the probability of the household having an existing fire escape plan [80, 81], thereby indicating that individual development may occur. Regardless, socio-demographic factors seem to be possible to overcome [82] given the effectiveness of interventions such as smoke alarm installations, education or multifaceted programs [63, 82–84]. It could therefore be hypothesised that by ensuring that all households had the same level of protection, many of the problems would be eliminated.

However, this is oversimplifying the issue. Although many interventions are effective on a general level, the potential effectiveness varies considerably between different socio-demographic groups [24, 85]. For example, simple interventions such as smoke alarms are relatively ineffective for frail, disabled smokers [24]. Similarly, hinders in the ability to evacuate, i.e. a crucial step in the fire process to minimise the risk of both death and injury [86], due to illness, intoxication, living alone, living in rural areas, etc., are all factors that are overrepresented among fatal fire victims [18]. Put simply, while a functioning smoke alarm will most likely be highly effective for the most at-risk group for *Residential Fires Not Attended to by Rescue Services*, its effectiveness for the most at-risk group for *Fatal Fires* is low.

In conclusion and in accordance with previous research [87–89], differences in fire risk and the consequences of fires are clearly the results of complex interactions of individual, societal and structural factors. A very small and insignificant fire can in one contextual setting result in a non-attended fire, while in another setting it can be a fatal fire. As such, there are no one-size-fits-all strategies. Rather, holistic,

multifaceted programs are required that take the different levels of the residential fire injury pyramid into consideration.

By understanding the construction and internal relationship of the residential fire injury pyramid, the societal risk picture also becomes clearer. Specifically, the very large majority of residential fires never come to the attention of rescue services. Those that do are generally not representative of the total population. Instead, the households in which help from rescue services is required, or where injuries and deaths most often occur, have innate elements that decrease their ability to handle a fire independently. The more this ability is reduced, the greater the risk of a residential fire becoming a fatal residential fire. As such, although the risk of fatality per fire is very low for a large majority, for some individuals with particular characteristics, the risk of fatality per fire is high.

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