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Bachelor's Thesis

Falling Through the System: Quantitative Visualization of Patient Pathways Surrounding Inpatient Falls

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Ich erkläre weiterhin, dass ich die Arbeit in gleicher oder ähnlicher Form noch keiner anderen Prüfungsbehörde vorgelegt habe.

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DeepL and ChatGPT were used to improve the reading experience of this thesis.

Zusammenfassung

Diese Bachelorarbeit im Bereich Gesundheitsmanagement und Gesundheitsanalytik verwendet einen quantitativen Ansatz, um Stürze in verschiedenen klinischen Abteilungen stationärer Einrichtungen zu untersuchen. Ziel ist es, die Faktoren zu identifizieren, die zu Stürzen beitragen, und abteilungsspezifische Unterschiede aufzuzeigen, um die Gesundheitskosten zu senken und das Wohlbefinden der Patienten zu verbessern. Die quantitativen Analysen basieren auf elektronischen Gesundheitsakten eines deutschen Universitätsklinikums, die den Zeitraum von Mai 2016 bis April 2022 abdecken. Anhand der Dokumentation stationärer Stürze untersuchten wir die Unterschiede in der Inzidenz von Stürzen, die demografischen Muster der Stürzenden, die zeitliche Verteilung der Stürze und die Schwere der sturzbedingten Verletzungen zwischen Abteilungen mit 200 oder mehr Stürzen im Beobachtungszeitraum. Die Analyse ergab eine krankenhausweite Sturzinzidenz von 0,21 Stürzen pro 1.000 Patiententage, wobei die geriatrische Abteilung eine über 45-mal höhere Inzidenz aufweist (9,53). Unsere Analyse deutet darauf hin, dass Männer häufiger stürzen, wobei sich die Stürze fast gleichmäßig über den Tag verteilen. Es wurde kein signifikanter Zusammenhang zwischen der Gesamtverletzungsrate und der Rate der schweren Verletzungen infolge von Stürzen festgestellt (p=0,6246). Außerdem entwickelten wir auf Abteilungsebene einen "Fall Vulnerability Score" (Sturzgefährdungs-Score), der das Auftreten von Stürzen, die Schwere von Sturzverletzungen und Sturztrends berücksichtigt. Dieser Score ergab, dass die Abteilungen Gastroenterologie, Intensivmedizin und Neurologie am stärksten durch Stürze belastet sind. Darüber hinaus ergab unsere Analyse der Patientenpfade, dass Patienten, die das Krankenhaus zunächst durch die Notaufnahme betreten oder die häufig in dieselbe Abteilung zurückkehren, ein erhöhtes Risiko für Stürze mit schweren sturzbedingten Verletzungen aufweisen.

Abstract

This bachelor's thesis in healthcare management and health analytics employs a quantitative approach to examine inpatient falls across different clinical departments. The objective is to identify the factors contributing to inpatient falls and to highlight departmental variations, thereby reducing healthcare costs and improving patient well-being. The data was obtained from electronic health records at a German university hospital, spanning the period from May 2016 to April 2022. By examining the documentation of inpatient falls, we investigated the differences in the fall incidence, the demographic patterns of fallers, the temporal distribution of falls, and the severity of fall-related injuries across departments with 200 or more falls during the period under investigation. The analysis yielded a hospital-wide fall incidence of 0.21 falls per 1,000 patient days, with the Geriatrics Department exhibiting a rate over 45 times higher (9.53) than the hospital-wide average. The findings indicate that males fall more often, with the occurrence of falls distributed almost equally throughout the day. No significant correlation was identified between the overall injury rate and the rate of major injuries resulting from falls ($p=0.6246$). We developed the Fall Vulnerability Score for departments, incorporating fall occurrence, injury severity, and fall trends. This score identified the Gastroenterology, Intensive Care, and Neurology Departments as the departments most vulnerable to falls. Additionally, our patient pathway analysis demonstrated that patients admitted through the Emergency Department or those with frequent returns to the same department are at an elevated risk of falls with major fall-related injuries.

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1. Introduction

Falls represent the leading non-disease cause of death in Germany. Even when not fatal, inpatient[1] falls significantly increase the hospital length of stay and associated medical costs (Morello et al. 2015; Dunne, Gaboury, and Ashe 2014). The annual costs of falls are estimated to be between 0.85% and 1.5% of the total healthcare expenditures of a country (Heinrich et al. 2010). In Germany, with an annual healthcare expenditure of 498 billion EUR, this equates to a range of 112.8 to 199 million EUR per year. Of these costs, those associated with falls with severe injuries are particularly high (DESTATIS 2022). Falls are a significant concern for individuals aged 65 and above due to a multitude of age-related illnesses, including diminished skeletal muscle strength, balance, and coordination (Morris and O'Riordan 2017; Heinze, Halfens, and Dassen 2007; Halfon et al. 2001). Considering the German population aging, the costs associated with falling incidents will likely continue to increase in the foreseeable future (Montero-Odasso et al. 2021). This is particularly the case in a clinical setting, where the most vulnerable members of our society are present. In light of these considerations, inpatient falls represent a significant concern for hospitals (Heinze, Halfens, and Dassen 2007).

Cameron et al. (2010) found that up to 30% of inpatient falls are preventable. Consequently, this presents a substantial opportunity for hospitals to achieve cost savings and improve patient well-being. To prevent inpatient falls or mitigate their consequences, it is essential to gain a comprehensive understanding of the circumstances surrounding the fall, with a particular focus on falls with serious outcomes.

The subject of inpatient falls has been the focus of considerable attention in recent literature, with numerous papers examining risk factors, prevention strategies, and predictive models. Extensive meta-studies have made a substantial contribution to these areas of research. For instance, Tinetti and Kumar (2010) identified seventeen fall risk factors, including previous fall events, gender, and age. Moreover, Morris and O'Riordan (2017) conducted a meta-analysis to evaluate the efficacy of diverse prevention strategies, while Parsons et al. (2023) examined a range of predictive models, encompassing expert knowledge and machine learning approaches.

However, despite hospitals adopting recommendations to prevent patients from falling, inpatient falls still occur and therefore remain a significant challenge for the German health system (Mikos et al. 2021). The considerable variation in falls across different clinical departments, coupled with limited hospital resources, results in inadequate support for the most vulnerable departments and potentially excessive support for departments with fewer falls.

1. An inpatient is defined as an individual who has been admitted to a hospital to receive medical care for a minimum of one night (*Inpatient* 2024).

This imbalance further complicates the challenge of departmental fall discrepancies, a topic that has been insufficiently addressed in the existing literature. Only a few studies, such as Mikos et al. (2021) and Schwendimann et al. (2008), have examined inpatient falls across multiple clinical departments, highlighting different incidence rates and trends. However, there is a clear necessity for additional fall analysis across clinical departments to gain a more profound comprehension of these discrepancies.

1.1. Research Subject

Further analysis of falls at the departmental level, as recommended by Mikos et al. (2021), undoubtedly benefits the scientific community, as it would outline which departments and patient groups are most vulnerable to falls. However, there is currently a lack of research in this area. This type of study could assist in identifying departments with an elevated risk of falls, thereby contributing to the broader objective of reducing overall fall-related costs and enhancing patient well-being.

To enhance our understanding of inpatient falls at the departmental level and contribute to the fields of healthcare management and health analytics, we employ a dual-faceted analytical approach. We first use descriptive analysis to examine inpatient falls across various clinical departments. Subsequently, we conduct a pathway analysis to explore the trajectories of patients who fall, identifying structural differences between departments and pinpointing pathways associated with higher fall risk. These analyses are designed to address two interconnected research questions:

1. **What are the variations in the incidence and other characteristics of inpatient falls across different clinical departments?**
2. **How do patient pathways of those who experience falls vary across clinical departments?**

The first question is answered through descriptive analysis, while the second is explored using pathway analysis.

1.2. Course of Action

To address the research question, we will examine pseudonymized Electronic Health Records (EHRs) from a 3,300-bed universal hospital. This dataset spans six years, from May 2016 until April 2022. Before analysis, we will preprocess the data to ensure a clean dataset. The first research question will be addressed through descriptive data analysis. Additionally, we will develop a Fall Vulnerability Score (FVS) for each department. This FVS assesses departmental vulnerability to falls based on four factors: the proportion of falls, fall prevalence, fall injury severity, and fall trends. This score helps determine the departments most vulnerable to falls.

To explore the different patient pathways of those who fall, we will address the second research question by creating and interpreting a visual representation of patient pathways for those falling in the departments scoring highest on the FVS.

1.3. Contribution

This thesis constitutes a substantial contribution to the theoretical and practical aspects of the fields of study.

Theoretically, this work advances the scientific community's comprehension of inpatient falls across various clinical departments. We further compare our findings to the work of Mikos et al. (2021), Schwendimann et al. (2008), Kerzman et al. (2004) and Healey et al. (2008), offering a classification of our results. Additionally, we implement health analytics methodologies for visualizing patient pathways, demonstrating the practical utility of these techniques and contributing to the evolving field of patient pathway visualization in health analytics.

From both theoretical and practical standpoints, this thesis introduces the FVS for hospitals. The FVS aids in identifying departments and areas most susceptible to falls, thus providing valuable support to both researchers and hospital management. The ultimate aim of this score is to reduce the incidence of falls and the severity of fall-related injuries. This, in turn, is expected to decrease fall-related costs and enhance patient well-being.

Moreover, from a practical perspective, this thesis identifies departments and patient groups that are particularly vulnerable to falls based on an analysis of inpatient falls and patient pathway analysis. This knowledge equips on-site hospital staff with actionable information to target and mitigate fall risks effectively, thereby reducing fall incidences and related injury severity in these high-risk areas.

2. Theoretical Background

This chapter offers a comprehensive overview of the scientific community's knowledge of inpatient falls, establishing a foundation for subsequent comparison with the findings presented later in this thesis. Furthermore, we examine the existing literature on EHR visualization techniques, which will inform our subsequent work on visualizing patient pathways.

We begin by defining what constitutes a fall, identifying the populations most affected, and discussing the associated medical and economic consequences. Furthermore, we examine the management of falls in clinical settings, exploring the various risk levels and preventive measures designed to mitigate inpatient falls.

In addition, we conduct an in-depth analysis of inpatient falls, investigating multiple perspectives on falls such as fall incidence, age, gender, time of fall, and fall-related injury severity. This analysis is conducted at the hospital and departmental level to identify patterns and at-risk groups. Furthermore, this approach allows us to identify gaps in the existing literature that warrant further exploration.

On a more technical note, we review existing research on EHR visualization techniques. This review is essential for understanding how to present patient data effectively and will support our efforts to visualize patient pathways.

2.1. Falls

Falls represent a significant concern in both clinical and community settings. To understand their complexity, it is essential to precisely define what constitutes a fall, identify who is affected by falls, determine where these incidents occur, and explore why they warrant scientific attention.

The World Health Organization (WHO) defines a fall as an event in which a person unintentionally comes to rest on the ground, the floor, or lower level (WHO 2021). While there are other definitions, such as those distinguishing between assisted and unassisted falls or excluding intrinsic events like strokes (Cooper and Nolt 2007; Zhang et al. 2020), we will adopt the WHO definition for its broad applicability and general acceptance.

Not everyone is equally affected by falls. The most significant indicator of fall risk is age (WHO 2021). At both ends of the age spectrum, the incidence of falls is high, with a parabolic course in between. Nevertheless, while young children frequently fall, most of these falls have minimal consequences, as it is their natural developmental process (WHO 2008b). Consequently, for this thesis, children will be excluded from consideration. On the other end of the age spectrum, the risk of falling increases significantly with increasing age. While up to 35% of individuals aged 65 years or above fall at least once per year, this share rises further for those aged 70 or above (WHO 2008a).

A review of the literature reveals significant differences between the genders with regard to the environments in which they fall. While older females are more likely to fall in the house, older males tend to fall predominantly in the garden. Moreover, the majority of individuals who experience a fall do so on flat surfaces rather than on stairs or other elevated areas. However, the houses of fallers are not more dangerous than those of non-fallers, indicating that the environment plays a limited role in falls (Mulley 2001). In the context of this thesis, it is especially important to examine inpatient falls. Krauss et al. (2007) found that in hospitals, 82% of falls occur in the patient's room, while 47% of inpatient falls are associated with bathroom activities. Of all the inpatient falls reported, 85% are unassisted, indicating that they occur without the direct influence of others.

Falls present a significant public health concern for several reasons. While the majority of falls result in no or minor injuries, those that result in major injuries potentially have serious consequences. Approximately 34.4% of falls lead to bone fractures, and around 26.8% necessitate hospitalization (RKI 2016). More critically, individuals who remain on the floor for an hour after a fall face a 50% mortality rate within the following six months (Mulley 2001). From an economic standpoint, falls with severe injuries impose a substantial financial burden. A systematic review by Heinrich et al. (2010) estimates that the direct costs of each fall range from 1,059 USD to 10,913 USD, with fall-related hospitalization costs reaching up to 42,840 USD. The demographic shift in Germany, marked by an aging population and an increased risk of falls among older adults, is expected to lead to a rise in the frequency and therefore the number of falls with severe fall-related injuries. Consequently, the financial resources required to address these injuries will increase significantly, worsening the financial burden of falls on Germany's healthcare system. Thus, falls represent a significant challenge for the German healthcare system and require scientific attention.

2.2. Inpatient Fall Management

Effective inpatient fall management involves a comprehensive approach to prevention, response, and post-fall care. Understanding these processes is crucial for a meaningful analysis of EHRs. By understanding the context in which fall-related data is generated, we can better analyze and interpret this data.

Given the considerable financial implications of inpatient falls, the investigated university hospital from which we analyze the EHRs has implemented several standard operating procedures to prevent as many falls as possible and manage occurring falls in the best possible manner. Therefore, at the time of patient admission, the fall risk of each patient is assessed, and the patients are assigned to risk groups. This allows for implementing targeted measures and a consequent reduction in falls.

The risk assessment process in the university hospital follows a predefined path: When a patient is admitted to any department, his fall risk is assessed by a nurse within the first six hours of his stay. The responsible nurses use a test developed by Rikli and Jones to assess the risk of falls for a patient (Rikli and Jones 1997). The patient is then assigned to one of three risk groups based on the results of the fall risk assessment. If the assessment indicates no risk of falls, the patient is placed in the *no risk* group. Conversely, if the assessment indicates a higher risk of falls, the patient is placed in the *low risk* or *high risk* group. Following that, the implementation of fall prevention measurements begins (prevention measures, see Table A.1). No fall prevention measures are taken if a patient is in the *no risk* group. However, due to patients' conditions often fluctuating, the fall risk is reassessed after a maximum of five days. In addition, if a patient falls, is transferred to another department, or experiences a change in cognition, he will be reassessed. This procedure continues until the patient is transferred or discharged (see Figure 2.1).

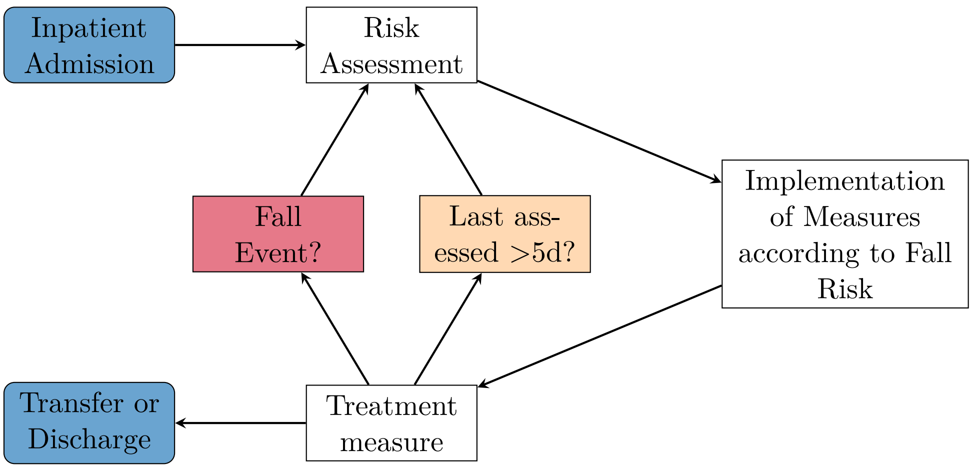

Figure 2.1.: Process of Fall Management

In the event of an inpatient fall, a different standard operating procedure is employed to guide the handling of the situation. This states that after treating fall injuries, every inpatient fall must be documented by a nurse using standardized fall documentation.

Moreover, as previously stated, following a fall incident, the fall risk is reassessed, and the patient is reassigned to a fall risk group (see Figure 2.1). The aforementioned prevention measures are adjusted according to the group in question. In the event of significant injuries resulting from the fall, nurse roundings or debriefings with the department team become obligatory.

2.3. Investigation of Inpatient Falls

In this section, we explore the characteristics and frequency of inpatient falls within clinical and departmental settings, expanding on our previous investigation into fall occurrences and their management in a clinical context. By analyzing the variations in falls across different clinical departments, we can identify the areas most impacted and gain valuable insights to reduce the number of falls and fall-related injury severity. Furthermore, the findings of this literature review will later provide us with a basis for comparing our results with the current scientific knowledge on inpatient falls.

In a comprehensive literature review, we identified three department-level studies (Mikos et al. 2021; Schwendimann et al. 2008; Kerzman et al. 2004), as well as a detailed hospital-level study by Healey et al. (2008) that include data from 472 institutions. Despite being published between 2004 and 2021, the studies in question collectively represent the most contemporary and extensive sources of knowledge on the subject. They were all published in peer-reviewed medical journals and adopted a quantitative retrospective approach, analyzing data sourced from EHRs or incident reports using descriptive statistics.

The studies vary significantly in their scope: For instance, while Kerzman et al. (2004) and Healey et al. (2008) examine falls over just one year, Schwendimann et al. (2008) and Mikos et al. (2021) extend their investigations over five years. Furthermore, the size of hospitals under investigation also varies considerably. Schwendimann et al. (2008) and Mikos et al. (2021) conduct their studies on hospitals with 300 and 350 beds, respectively, whereas Kerzman et al. (2004) focus on a hospital with 2,000 beds. Notably, Healey et al. (2008) cover falls across 472 UK National Health Service organizations. These variations lead to substantial differences in reported numbers. For example, while Kerzman et al. (2004) report 677 fallers, Healey et al. (2008) identify 206 350 fallers.

The following sections synthesize the findings from the aforementioned studies, categorized according to the common categories identified. Table A.2 provides a concise overview of the categories explored and the extent of their investigation in each study. Tables A.3,A.4, A.5 and A.6 provide an overview of the findings of each of the four studies, as presented in the original articles with certain numbers derived from the respective findings to allow for more effective comparison.

Fall Incidence

Except for the study by Mikos et al. (2021), all studies reviewed provide data on the occurrences of hospital falls relative to patient numbers. Healey et al. (2008) and Schwendimann et al. (2008) report a hospital-wide fall incidence of between 4.95 and 7.0 falls per 1,000 patient days[1], respectively. A higher hospital-wide number is reported by Kerzman et al. (2004), with a fall rate of 51.5 falls per 1,000 admissions, which equates to a fall incidence of 9.9 falls per 1,000 patient days[2].

1. In medical statistics, "patient days" represent the total number of days patients spend in a healthcare facility. To illustrate, if 300 patients each stay for 6 days, this results in 1,800 patient days.

2. Kerzman et al. (2004) does not provide a specific fall incidence. Therefore, we estimated fall incidences for the hospital and each department using the average national length of stay in Israel, where the study was conducted. With a national average hospital stay of 5.2 days in 2000 (OECD 2000), the hospital-wide fall rate of 51.5 per 1,000 admissions translates to a fall incidence of 9.9 per 1,000 patient days.

Only Kerzman et al. (2004) and Schwendimann et al. (2008) differentiate fall incidences between departments. In the Surgical Department, both studies report comparatively low incidences of 1.73 and 3.2, respectively. In contrast, incidences in the Geriatrics Department surpass the clinical mean in both studies (22.12 and 10.7, respectively). However, there is a notable discrepancy of 11.42 falls between the incidences reported in the Geriatrics Department. Moreover, both studies present fall incidences in the Internal Medicine Department. While the incidence reported by Kerzman et al. (2004) is relatively low (0.96), that reported by Schwendimann et al. (2008) is significantly higher (9.6) and above the hospital mean. Notably, Kerzman et al. (2004) mentions that the hospital under investigation established a new Geriatrics Department, which took over the care of elderly patients previously managed in the Internal Medicine Department. This organizational change likely accounts for the increased fall incidences in the Geriatrics Department and the corresponding decrease in the Internal Medicine Department.

In summary, the findings indicate a considerable discrepancy in the incidence of inpatient falls across different departments and studies. While the hospital-wide mean fall incidence is reported to be between 4.95 and 9.9, there is notable variation between different departments and between departments of the same specialty. This suggests that the incidence is not solely influenced by the type of department but also by the policies at the corresponding hospital.

Gender Distribution

The gender distribution of fallers is provided by all four studies, with notable discrepancies observed across studies and departments. Kerzman et al. (2004) and Healey et al. (2008) find that the distribution of falls between females and males is almost equal (f: 49.78%, m: 50.22% and f: 49.2%, m: 50.8%, respectively). In contrast, Schwendimann et al. (2008) and Mikos et al. (2021) report a higher incidence of falls among females (f: 57.2%, m: 42.8% and f: 57.62%, m: 42.38%, respectively).

To reach a definitive conclusion, it is essential to compare the distribution of falls to the overall distribution of patients. Only Schwendimann et al. (2008) provides such data, indicating that, on average, females are 3.6% more susceptible to falls than males. This discrepancy is most evident in the Surgical Department (5.9%), whereas males in the Internal Medicine Department are more vulnerable to falls (3.2%).

The extant literature demonstrates that females are more susceptible to falls, although the specific gender affected can vary by department (Wei and Hester 2014; Stevens and Sogolow 2005; Peel, Kassulke, and McClure 2002). Gale, Cooper, and Aihie Sayer (2016) posit that the elevated prevalence among females may be attributable to diminished bone density resulting from menopause. However, conflicting evidence exists. Healey et al. (2008) notes that despite an equal distribution of falls, 45.4% of bed days were occupied by males and 54.6% by females, suggesting that males are more prone to falls.

Overall, a significant body of research indicates that females are more likely to experience falls, although this remains a topic of contention.

Age Distribution

All four studies provide data on the age of patients who experience falls. Two studies (Healey et al. 2008; Kerzman et al. 2004) present age distributions, while the others report mean ages. The mean fallers' age varies significantly between studies. For instance, Kerzman et al. (2004) reports the lowest hospital-wide mean fallers' age (65.95 years), while Schwendimann et al. (2008) reports the highest mean fallers' age (79.9 years). To facilitate meaningful comparison, we calculated the mean fallers' age across all studies (73.79 years).

Only Mikos et al. (2021) and Schwendimann et al. (2008) provide age data at the department level. Both studies report elevated mean fallers' ages in Internal Medicine (77.70 years and 78.3 years, respectively), indicating that these fallers are, on average, 3.91 to 4.51 years older than the hospital-wide mean fallers' age across all studies. In other departments under study, there is considerable variation in the reported mean ages. For example, the mean fallers' age in Rheumatology (65.81 years), Orthopedics (71.29 years), and Rehabilitation (72.81 years) is lower than the mean across all studies (Mikos et al. 2021). In contrast, the Geriatrics Department exhibits the overall highest mean fallers' age, at 84.1 years (Schwendimann et al. 2008).

Moreover, Schwendimann et al. (2008) compare the mean age of inpatients to the mean fallers' age, demonstrating that fallers are, on average, 1.1 years older in the Geriatrics Department and 17.1 years older in the Surgical Department, with an overall mean age difference of 12.5 years towards the fallers. This reflects two key points: Firstly, the average age of individuals who experience falls is generally higher than the mean age of the overall patient population. Secondly, the Geriatrics Department has a high proportion of elderly patients, with a mean inpatient age of 83 years.

Furthermore, Healey et al. (2008) present an age distribution emphasizing the prevalence of falls among older patients. Specifically, 82.6% of falls occur in individuals aged 66 and above, and 32.4% occur in those aged above 85. Notably, patients aged above 85 represent only 14.7% of the inpatient population.

In conclusion, the studies demonstrate that elderly individuals are particularly susceptible to falls, with the risk increasing as they age. However, the average age of fallers varies significantly across departments. While the type of department and its specific patient demographics are likely the primary factors for fallers' age variations across departments, local demographics may also play a role (Mikos et al. 2021).

Time Distribution

In their studies, Mikos et al. (2021), Schwendimann et al. (2008), and Kerzman et al. (2004) provide insights into the distribution of falls across different shifts (day: 07:00-15:00, evening: 15:00-23:00, night: 23:00-07:00)[3]. Mikos et al. (2021) and Schwendimann et al. (2008) provide prevalence data, both highlighting the night shift as the most vulnerable to falls (38.82% and 37.3%, respectively). In contrast, Kerzman et al. (2004) report that the day shift has the highest prevalence of falls at 39.29%, while the night shift has a lower prevalence at 30.13%. The results are inconclusive regarding the shift with the lowest prevalence of falls. Kerzman et al. (2004) and Schwendimann et al. (2008) both find the evening shift to have the lowest prevalence, with values of 28.36% and 29.1%, respectively. However, Mikos et al. (2021) report the day shift as having the lowest prevalence, with a rate of 29.19%.

The Internal Medicine Department is the only department examined in multiple studies regarding the timing of falls (Mikos et al. 2021; Schwendimann et al. 2008). Both studies indicate that the night shift has the highest prevalence of falls, with rates of 43.09% and 40.6%, respectively. Mikos et al. (2021) suggest that the day shift has the lowest prevalence, while Schwendimann et al. (2008) report the evening shift as having the fewest falls in the department. The discrepancy between the two studies for the Internal Medicine Department is slight, with an average difference of 3.73 percentage points in the prevalence of falls between the same shifts.

Overall, the Neurology Department, as reported by Mikos et al. (2021), exhibits the most balanced distribution of falls (35.56% day; 33.70% evening; 30.74% night). In contrast, the Surgical Department, investigated by Schwendimann et al. (2008), shows the most uneven distribution (33.4% day; 24.6% evening; 42.1% night). Neither study explains these discrepancies.

Although the night shift is generally associated with a higher prevalence of falls, Kerzman et al. (2004) present arguments for a high incidence of falls during all shifts. They suggest factors such as patients' reluctance to disturb others or navigate unfamiliar environments at night versus increased daytime activity (e.g., clinical procedures and therapy sessions) could influence fall occurrences. In line with these findings, Kerzman et al. (2004) note that there is no scientific consensus on the timing of inpatient falls.

Severity of Fall Injury

Schwendimann et al. (2008) and Healey et al. (2008) document the severity of injuries resulting from falls in a clinical setting. Both studies employ a classification system for such fall-related injuries, although the specific categories utilized differ. Schwendimann et al. (2008) employ

3. Mikos et al. (2021) provide time distribution of fallers in four groups of six hours each, starting at 06:00, 12:00, 18:00, and 24:00. For better comparison with the other studies, we adjusted the groups to the mentioned three shifts under the assumption of an equal distribution of falls within the respective groups.

a classification system that differentiates fall injuries as none, minor, or major. In contrast, Healey et al. (2008) utilize a more expansive scale, which adds a moderate and death category. While Schwendimann et al. (2008) define minor injuries as pains, bruises, hematomas, and lacerations, major injuries as fractures, internal head injuries, and dislocations. Healey et al. (2008) define minor injuries as those requiring only first aid or minor treatment, moderate injuries requiring hospital admission or surgery, major injuries as permanent harm such as brain damage or disability, and death as a fatality resulting directly from a fall. Nevertheless, it is feasible to map the categories in a manner that aligns none and minor directly, while moderate, major, and death, as defined by Healey et al. (2008), correspond to major, as defined by Schwendimann et al. (2008). These aligned categories will be adopted for the comparison in this chapter.

The overall injury rates of falls reported by the two studies are strikingly similar, with Schwendimann et al. (2008) noting a rate of 35.2% and Healey et al. (2008) reporting 35.3%. Furthermore, the rates for minor injuries are comparable (30.1% versus 31.1%), as are those for major injuries (5.1% and 4.2%, respectively). These similarities reinforce the reliability of the findings across the two studies.

A detailed examination of injury rates at the departmental level is only provided by Schwendimann et al. (2008), which covers data from the departments of Internal Medicine, Geriatrics, and Surgical. Overall injury rates in these departments are relatively consistent, with figures ranging from 34.5% in Geriatrics to 37.4% in the Surgical Department. However, the severity of injuries varies significantly, with the Geriatrics Department experiencing a rate of severe falls that is more than twice that of the Internal Medicine Department (7.7% versus 3.8%). Schwendimann et al. (2008) attribute the higher rate of major injuries in the Geriatrics Department to the increased vulnerability of its patient population.

Overall, most patients who experience falls do not sustain injuries, with approximately two-thirds remaining uninjured. However, as both studies consistently demonstrate, only about five percent of falls result in major injuries.

Identified Gaps

Despite the considerable contributions of existing studies on inpatient falls, several crucial gaps remain. A significant shortcoming is the absence of comprehensive data. Although numerous aspects of inpatient falls have been examined, no single study has provided an exhaustive dataset encompassing all critical variables, such as fall injury severity, time distribution, and departmental differences, simultaneously. This fragmented methodology constrains the capability to gain a comprehensive understanding of the factors that contribute to inpatient falls.

A further notable gap is the limited number of departments that have been investigated. The extant studies concentrate on a small range of departments within hospitals, thereby limiting the applicability of their research to different hospital settings and departments.

2.4. Electronic Health Record (EHR) Visualization

To further identify areas with increased fall vulnerability, it is essential to understand the pathways faller patients take through the hospital during treatment. An understanding of these pathways might provide us with distinct movement patterns with an over-proportionally high number of falls, indicating such a vulnerability. To investigate these patient pathways, we can first visualize the movement of patients on a department level using EHRs and then analyze those visualizations for distinct movement patterns that result in a patient falling.

We conducted a further literature review to understand the scientific community's approaches to EHR visualization. A total of 14 papers were identified, four of which were deemed particularly useful for this thesis. The papers in question were all published in peer-reviewed journals, conference papers, or books with a computer science focus. The papers in question share a common objective: providing solutions for the visualization of EHRs or event sequences. Furthermore, in contrast to the literature on Investigation of Inpatient Falls, the investigated literature focuses on the creation of tools for investigation instead of findings from the use of such tools. This emphasis on tool development likely stems from the significant variation in visualizations, which depend heavily on the specific research questions and institutional policies of each hospital.

The papers differ significantly from the approaches to achieve EHR visualization. Domova and Sander-Tavallaey (2019) developed an online platform for dynamic analysis of patient flow data, while Kaushal et al. (2017) and Boudis et al. (2021) constructed more straightforward tools that generate multiple visualizations of the input data. Furthermore, Monroe et al. (2013) created a visualization tool that enables users to modify and filter sequential data to gain more insightful results.

The following sections outline key aspects leading up to visualizing EHRs, which we derived from the four aforementioned papers.

Data

The preliminary stage of analyzing EHRs entails a comprehensive understanding of the nature of the dataset. Typically, the dataset comprises multiple EHRs, each of which documents a patient's case with various events. Such events include medical activities, like the administration of medication, and non-clinical care activities, such as patient movement or the provision of meals. Each event usually is time-stamped, allowing for chronological sorting. By examining the EHRs, it is possible to determine which events should be investigated. For instance, an EHR may track the departments a patient visited, which can be visualized as a patient journey (see Figure 2.2).

Figure 2.2.: Exemplary Patient Pathway

Data Perspective

Once the event type to be investigated has been selected, the subsequent step is determining the perspective from which the data will be analyzed. In this regard, two perspectives are typically utilized. On the one hand, the **intra-record perspective** prioritizes the comprehension of the sequence of events within an individual record (e.g., the underlying reasons for a distinct patient's transfer to the Intensive Care Unit (ICU)). Conversely, the **inter-record perspective** seeks to identify population-level trends and patterns across a comprehensive set of records (Boudis et al. 2021; Monroe et al. 2013). This may, for instance, include the differentiation between the pathways of patients visiting the ICU.

Visualization

Once the perspective has been established, the most appropriate type of visualization must be selected. The reviewed papers propose several visualizations, each suited to a specific research need. For example, when the objective is to comprehend the hierarchical relationships between distinct occurrences (e.g., the clinical procedures that follow a diagnosis), **Sunburst charts** are recommended (Kaushal et al. 2017; Domova and Sander-Tavallaey 2019). However, when the objective is to visualize the aggregated flow of patients, a **Sankey diagram** is the most effective tool (Kaushal et al. 2017; Boudis et al. 2021).

Alignment Point

Selecting a visualization method necessitates defining an alignment point, which serves as the focal point of interest. By defining this point, all EHRs are aligned accordingly, bringing the area of interest into focus and enhancing clarity (Boudis et al. 2021; Monroe et al. 2013). For instance, when investigating patient movements at the department level before and after ICU stays, the ICU serves as the alignment point, given that some patients may have been admitted directly to the ICU. In contrast, others may have passed through multiple departments before reaching the ICU.

Filters

Medical data recorded in real-time is highly variable, and investigators typically lack control over the data generation. Therefore, it is imperative to filter this data effectively to ensure the precision and relevance of subsequent visualization. In light of these considerations, Monroe et al. (2013) propose a series of filtering paradigms specifically tailored to address the nuances of medical data and exclude irrelevant information:

- **By Record:** The inclusion or exclusion of entire records may be based on the presence or absence of specific events. For example, only EHRs from patients with a visit to the Geriatrics Department might be included.
- **By Category:** In each EHR, events related to specific categories, such as particular departments or treatments, can be excluded if deemed irrelevant. For instance, this could exclude all non-movement events if we are only interested in the departmental movements of a patient.
- **By Scope:** The scope filter defines the area of interest surrounding the alignment point. This can be time-based (e.g., 24 hours before and after the alignment point) or event-based (e.g., a specified number of events before and after the alignment point). All events outside of the scope are then discarded for visualization.
- **By Attributes:** Attributes within records can filter events or entire records. For example, only fall events that resulted in injuries or records with patients older than 65 might be included in the visualization.

Transformation

Ultimately, transforming the EHRs can facilitate further enhancement and simplification of the visualization. Monroe et al. (2013) propose several transformation techniques, including:

- **Interval Event Merging:** This involves combining several events of the same EHR into one. For example, merging multiple asthma medication refills into a single event.
- **Category Merging:** Multiple events can be grouped under a single category, such as merging moves to different ICUs into a general "move to ICU" category.
- **Insertion Marker Events:** To simplify visualization, marker events can be inserted to highlight points of interest. Those marker events can also be used as alignment points.

After undergoing those six consideration aspects, the data can be visualized.

3. Data and Methods

This chapter provides a detailed account of the data and methods employed to analyze inpatient falls. We commence with an overview of the data sources. Each table is described in detail, including the key statistics and the preprocessing steps to ensure high data quality. We then investigate the analytical methods employed to examine inpatient fall occurrences across departments. This encompasses the development of the FVS, indicating how vulnerable each department is to falls. Additionally, we address the visualization of patient pathways, particularly through Sankey diagrams, to illustrate the flow of patients that fell in one of the three departments with the highest FVS.

This combined approach establishes a clear understanding of both the data handling and analytical techniques used, setting the stage for the results presented in the subsequent Results chapter.

3.1. Data

To analyze inpatient falls, we utilized two data sources. The primary source was an EHR dataset from a German university hospital, which included case-to-patient data, records of patient movements, and detailed fall documentation. Complementing this, we used data from the hospital's cost centers as a supplementary source, which offered valuable insights into the hospital's structural characteristics. While the fall documentation provided comprehensive patient demographics for those who fell, access to the demographics of all patients was not available, thereby limiting the potential for interpretation of our findings.

Case-to-Patient Data

Upon admission to the hospital, a new hospital case (referred to as "case") is initiated for each patient, and a unique case ID is assigned. Each patient is assigned a single patient ID that is retained for all subsequent visits, establishing a 1:n relationship between patients and cases. The **Case-to-Patient Data** table, allowed us to establish the connection between each case and the patient associated with that case. This **Case-to-Patient Data** table encompassed all case IDs and the associated patient IDs. In total, the table comprised 3,232,640 cases and 932,103 patients from all departments of the hospital, with a mean of 3.58 cases per patient.

Patient Movements

The **Patient Movements** table captures information on all patient movements across the hospital, spanning all campuses of the university hospital. Each entry in the table is connected to a case with a case ID, linking the movements to specific cases. The data includes various attributes such as destination (on ward level), type of movement (e.g., walking, in bed), and timestamps. In total, the dataset comprised 10,689,561 movements, averaging 3.21 movements per case.

Fall Documentation

The **Fall Documentation** table contains all of the information from the standardized fall documentation that nurses are required to complete after each fall (see Section 2.2). As with the previous tables, this one also includes a case ID, linking it to a distinct case. Additionally, the **Fall Documentation** provides information regarding the demographics of the patients who fell (age and gender). Furthermore, the table includes data related to the circumstances of each fall, such as the reason for a fall, the ward in which a fall occurred, the time and day of a fall, and the severity of fall-related injuries. Following JCAHO (2009), the severity of the fall-related injury is classified into four categories: none, minor, moderate, and major. Minor injuries are defined as those requiring only first aid or minor treatment. Moderate injuries necessitate further medical attention, such as the application of skin glue. Major injuries are those requiring surgical intervention, neurological consultation, or internal medical evaluation. A total of 14,556 falls were documented.

Cost Centers

Finally, we used a comprehensive table of all **Cost Centers** within the hospital for analysis. This table lists all units (including clinical wards) and organizes them under the corresponding (clinical) department. We used that table to map wards to the corresponding clinical departments. As the table contains all **Cost Centers**, the majority of the units listed are not clinical wards but rather educational or organizational units. In total, we identified 1,510 different units. However, only 213 units were identified as clinical wards with direct patient contact.

3.2. Data Preparation

In order to conduct a meaningful analysis of inpatient falls, we first had to ensure the accuracy and reliability of the data. Furthermore, we needed to elevate the abstraction level of patient location and movement from the ward to the department level, as the initial data provided this information only at the ward level. This section details the steps taken to ensure a consistent dataset at the required abstraction level.

To ensure data accuracy and reliability, we filtered both the **Patient Movement** and **Fall Documentation**, retaining only records within the study period. We excluded data outside this time frame, which reduced movements by 1,255,228 to 9,234,233 and falls by 296 to 14,260.

We conducted two rounds of validity checks and adjustments on the **Case-to-Patient Data** table. First, we verified that no hospital case was linked to more than one patient. In cases where multiple patients were connected to a single case, we randomly disconnected the case from one of the patients; this occurred only once and thus had no significant impact on the analysis. Next, we excluded patients with no recorded movement (indicated by the absence of the case ID in the movement table). This step removed patients who were not present in the hospital during the study period and corrected erroneous entries due to staff errors or IT issues. Consequently, the dataset was reduced by 407,776 cases and 87,706 patients, leaving 2,924,864 cases and 844,297 patients in the dataset.

To map the wards from the **Patient Movement** and **Fall Documentation** tables to their respective departments, we utilized the **Cost Centers** table. We first created an English translation of the departments listed in the **Cost Centers** table. Using this translation, we mapped the wards to the departments, successfully linking 213 medical wards to 60 medical departments.

Following these steps, the EHR dataset was prepared for investigation.

3.3. Inpatient Falls across Departments

To examine inpatient falls across clinical departments, we conducted a series of sub-analyses. Initially, we investigated inpatient falls in a hospital context. Subsequently, we analyzed the occurrence of falls across different departments. This entailed examining the fall incidence, gender distribution, age-related differences, the distribution of falls across shifts, and the differentiation of fall-related injuries. Finally, we developed the FVS.

Investigation on Hospital and Department Level

To generate the fall statistics on a hospital-wide level, we first merged **Case-to-Patient Data** table with **Fall Documentation** table, providing an overview of the number of falls per patient, both for those who fell and for all patients in the hospital.

Next, we investigated falls across all departments that reported fall incidents (hereafter referred to as "primary faller departments"). Departments with fewer than 200 falls in the period under study were aggregated into an "Other" category. We took this approach for several reasons. Firstly, it allowed us to focus on departments with higher occurrences of falls, ensuring our efforts target the most critical areas. Secondly, reducing the number of departments to analyze helped maintain a manageable scope, allowing for a more detailed and focused analysis of the most affected departments. Lastly, combining smaller departments into one category helped avoid statistical anomalies in the following analyses, providing a clearer picture of trends in departments with substantial data.

For each department, we calculated the fall rate (falls per 1,000 patient admissions) and estimated the fall incidence (falls per 1,000 patient days) using the overall mean length of stay in German hospitals from an external source (OECD 2022), as our dataset did not include patient length of stay. Additionally, we determined the fall percentages by gender and the average age of patients who fell. We also calculated the share of falls for four age groups (≤65, 66-75, 76-85, >85), following the categorization of Healey et al. (2008). Moreover, we examined the percentage of falls by shift, dividing a 24-hour day into three shifts: day (07:00-15:00), evening (15:00-23:00), and night (23:00-07:00). Lastly, we analyzed the severity of injuries resulting from falls at the department level. The results were merged into a table, analyzed, and visualized (see resulting Tables A.7, A.8 and A.9. For visualizations, see Chapter 4).

Development of the Fall Vulnerability Score (FVS)

As part of the objective of this thesis is to ascertain which departments are most vulnerable to falls, we devised a methodology that assesses the level of vulnerability of a department to falls from four distinct perspectives (metrics). We then combined these metrics into a single aggregated indicator, the **Fall Vulnerability Score (FVS)**.

First, we examined the **Fall Proportion** per each department. This metric identifies the primary target areas for reducing the number of falls from the hospital's perspective. We calculated this by dividing the number of falls in each department by the total number of falls across all departments.

Next, we analyzed the **Fall Prevalence** within each department, thereby identifying which departments experience the highest frequency of falls. We determined this metric by dividing the number of cases with falls in each department by the total number of cases in that department.

Third, we assessed the overall **Fall Injury Severity** in each department to evaluate the impact of falls on both the hospital and the patients. We assigned a value to each level of injury to reflect its financial burden and severity: no injuries were assigned a value of 1, minor injuries a value of 4, moderate injuries a value of 8, and major injuries a value of 20. We multiplied these values by the number of falls at each injury level within each department and added them up. To normalize for the total number of falls, we divided the resulting values by the total number of falls in each department, producing a standardized measure of fall injury severity for each department.

Fourth, we analyzed the **Fall Trend** in each department to assess recent changes in fall prevention efforts in each department. We used the monthly number of falls over six years (72 months) to perform quadratic regression, modeling the temporal distribution of falls. We then computed the derivative of this regression function to capture the monthly fall trend. To summarize this trend for each department, we first calculated the 72 monthly trend values. Each value was then weighted according to its position in the series to emphasize more recent trends:

$$\text{Weighted Trend Value}_i = \frac{\text{index } i}{\text{Number of Trend Values}} \cdot \text{Trend Value}_i$$

Where the initial trend value has a weight of:

$$\text{Weighted Trend Value}_1 = \frac{1}{72} \cdot \text{Trend Value}_1$$

And the final point is:

$$\text{Weighted Trend Value}_{72} = \frac{72}{72} \cdot \text{Trend Value}_{72}$$

Next, we summed the weighted trend values to produce a single fall trend metric for each department.

Finally, we ensured a fair comparison across metrics by applying min-max normalization to scale each metric from 0 to 1. We averaged the four normalized metrics by dividing their sum by four and then multiplied the result by 100 to obtain the final FVS for each department, which ranges from 0 to 100 points.

To avoid skewing results from small sample sizes, we included only departments with 200 or more falls in the FVS analysis. This threshold prevented outlier departments from disproportionately influencing the results, such as a department with only one severe fall having an inflated severity metric.

3.4. Patient Pathway

Following the development of the FVS, our objective was to create a visual representation of the patient pathways for individuals who experienced falls. We chose only to investigate those patient pathways for falls in one of the three departments with the highest FVS scores. Furthermore, we concentrated solely on cases involving major fall-related injuries, given their considerable impact on patient well-being and healthcare expenditures. We elected to focus on these three departments and major injury severity to maintain a manageable scope, as the generation and manual analysis of a single diagram for each department was both complex and time-consuming. By visualizing these pathways, we aimed to identify the most frequently taken paths that lead to severe falls, as they may serve as indicators for potential future falls. Our methodology was guided by the steps outlined in the Theoretical Background (see Section 2.4). This chapter describes the decisions and actions taken to achieve these visualizations effectively.

Visualization, Perspective, and Initial Transformations

We selected a Sankey diagram for the visualization of patient pathways for each of the top three departments. This approach aggregates all cases with major fall-related injuries in the appropriate department and displays their pathways through the hospital's departments. This approach visualizes with an inter-record perspective.

We first extracted all departments visited by each patient in each case and the order of visits from the **Patient Movement** table. This resulted in initial raw patient pathways for each case. Figure 3.1 illustrates such an exemplary raw pathway.

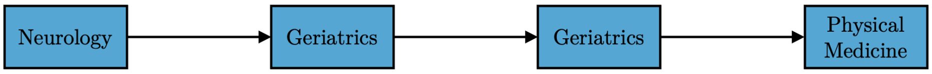

Figure 3.1.: Raw Patient Pathway

To refine the raw patient pathways, we merged redundant movements where transitions between consecutive visits occurred within the same department, following the concept of **Interval Event Merging**. These transitions represent internal movements between different wards of the same department, which fall outside the scope of our investigation.

Moreover, we incorporated start and end points of each patient pathway through the use of **Insertion Marker Events**, designated as *START* and *END*. This resulted in the adjusted patient pathway for each case, as illustrated in an example in Figure 3.2.

Figure 3.2.: Patient Pathway with Start and End Marker

Alignment Point

To create detailed and manageable visualizations, accounting for variations in patient pathway lengths and departmental involvement, it was crucial to focus on the most important data while preserving the essence of the visualization. However, we also needed to ensure that no critical information was overlooked. To achieve this, we defined all inpatient fall events as **Alignment Points**. These alignment points served as references for establishing the investigation scope and determining the areas of interest for the analysis.

Although fall events were not part of the movement path itself, they constituted a fundamental reference point for our analysis. By using the date and department from the **Fall Documentation**, we identified and integrated these events into the corresponding patient pathways.

To simplify the representation in the Sankey diagram and minimize visual complexity, we streamlined the dataset to include only one fall event per department visit. Specifically, for each case, we retained only the fall event with the highest injury severity for each department visit, following the concept of **Interval Event Merging**. This means that if a patient experienced multiple falls during the same stay in a department, only the fall with the most severe injury level was included. However, if a patient fell in one department, subsequently moved to a different department, and then returned to the initial department and fell again, both fall events were included as separate entries in the dataset.

Once the dataset was filtered and adjusted based on these criteria, the selected fall events were inserted as marker events (e.g., #FALL_Geriatrics#) into the existing patient pathways. Figure 3.3 illustrates an exemplary patient pathway with an inserted fall event in the Geriatrics Department.

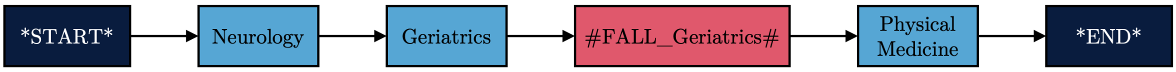

Figure 3.3.: Patient Pathway with Fall Event

Defining the Investigation Scope

To manage the variability in department visits across cases, we focused our visualization on a specific range of departments. Specifically, we limited our analysis to departments that fall within three movements before the alignment point[1]. Departments outside this range were grouped into summary events.

For each case, we generated summary events following any fall incident, containing the departments out of scope. Additionally, we created a summary event for the period out of scope preceding the first fall. These summary events consolidate departments beyond the three-department range into summarized entries. These summary events were included in the pathway visualization only if they contained departments. Figures 3.4 and 3.5 demonstrate this approach: the first example shows summary events for departments both before and after the fall event. In contrast, the second example illustrates a single summary event for departments following the second fall, marked as "(2)".

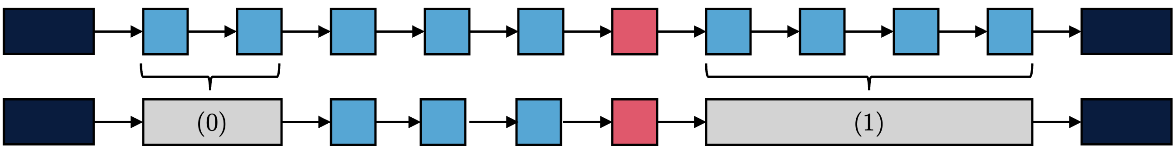

Figure 3.4.: Patient Pathway with two Summary Events

1. For a broader visualization without scope filters, see A.1. This wider view highlights the necessity for a focused scope.

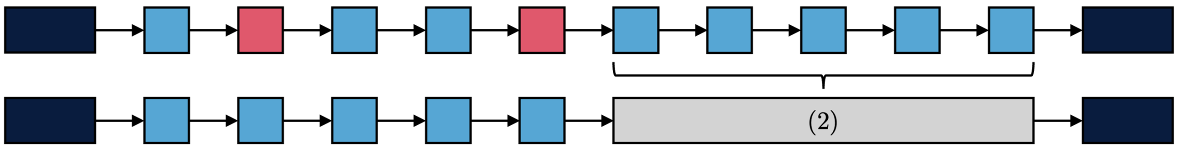

Figure 3.5.: Patient Pathway with one Summary Event

Final Filters

To prepare the data for our visualizations, we addressed each of the top three FVS departments individually. For each department, we first filtered out cases where patients did not experience a fall in that specific department (**By Record Filter**). Next, we excluded all cases where the fall did not result in major injuries (**By Attribute Filter**). This step-by-step process ensured that the final datasets for each department accurately reflected the pathways of patients who had fallen with major fall-related injuries within that particular department.

Lastly, it is important to note that while our final dataset is focused on major injuries, not every fall within it resulted in such injuries. Specifically, if a patient experienced multiple falls, at least one of those falls had to be classified as resulting in major fall-related injuries in the department under investigation, though not necessarily all of them. In 17.64% of cases, patients had multiple falls, some of which may involve less severe injuries. However, this proportion is relatively small and does not significantly impact the overall reliability of our dataset.

Following the aforementioned methodology, we proceeded to compile, visualize, and analyze the filtered data for each of the three departments separately.

4. Results

This chapter initially presents the findings of our inpatient fall analysis across the investigated departments. It then proceeds to examine the results of the patient pathway investigation, thereby establishing the data foundation for answering the research question in its entirety in the Discussion Chapter.

4.1. Inpatient Falls across Departments

This section presents the results of our analysis of inpatient falls across various hospital departments. During the six-year study period from May 2016 to April 2022, the hospital treated a total of 2,924,864 cases. Out of these, 11,242 cases reported falls, resulting in a total of 14,260 individual falls. Of 60 clinical departments, 29 reported fall incidents, with 13 departments documenting 200 or more falls. The remaining 16 departments with fall incidents were grouped under the category "Other". For clarity, we will refer to the 13 departments with 200 or more falls, plus the "Other" category, as the 14 primary faller departments. The detailed results of falls in these departments are summarized in Tables A.7, A.8 and A.9.

Our findings indicate significant discrepancies across departments. We exhibit an overall fall incidence of 0.21 per 1,000 patient days, with the Geriatrics Department reporting an incidence rate over 45 times higher than the hospital average (9.53), yet it has the lowest injury rate (18.64%, in contrast to the overall 25.35%). Moreover, the data indicates a higher frequency of falls among male patients and an increased incidence among older patients, particularly in the Geriatrics Department. Additionally, temporal analysis suggests that falls are distributed equally among shifts, with a slight inclination during the night shift. Furthermore, while minor and moderate fall-related injuries align with overall injury rates, there is no significant correlation between major fall-related injuries and injury rates. Finally, the FVS identifies the Neurology, Intensive Care, and Gastroenterology Departments as the departments most vulnerable to falls.

Fall Distribution

There is a notable variation in the distribution of falls across departments. For all departments, the Interquartile Range (IQR) of falls per department spans from 0 to 148.75, with a median of 0 and a mean of 237.66, indicating a substantial skew in the data. Moreover, for the faller departments, the IQR ranges from 1 to 660, with a median of 160 and a mean of 491.72. This pattern demonstrates a similar skew in the distribution of falls, yet with higher values. These distributions are illustrated in Figure 4.1.

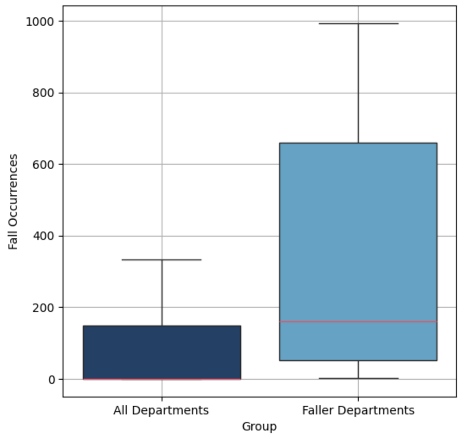

Figure 4.1.: Fall Occurrence Distribution, All Departments vs. Faller Departments

Additionally, we observed a strong positive correlation between the number of cases and the number of falls across all departments (Pearson r: 0.7972, p: 0.0000) and in faller departments (Pearson r: 0.7309, p: 0.0000).

Fall Incidence

Across the primary faller departments, a fall rate of 1.57 and a fall incidence of 0.21 were observed. Five of the 14 departments reported incidences below the hospital-wide average, and 11 departments demonstrated incidences below 0.3. It is noteworthy that the Geriatrics Department exhibited a markedly elevated incidence of 9.53, which is more than 45 times the hospital-wide mean. Conversely, the lowest incidence was observed in the "Other" category at 0.05, followed by the Dermatology Department with an incidence of 0.09.

Gender Distribution

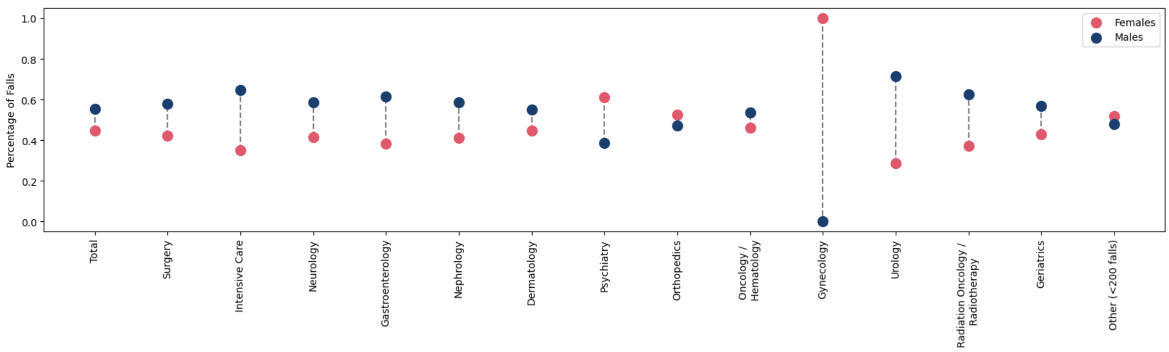

Figure 4.2.: Percentage of Falls by Gender Across Primary Faller Departments

Our data illustrates the distribution of falls among males and females across the primary faller departments (see Figure 4.2). Overall, there is a higher number of falls among males (55.41%) compared to females (44.59%). This pattern is prevalent across the departments, with 10 out of the 14 departments showing a higher percentage of falls among males. However, the gender distribution of falls varies significantly in specific departments. For instance, in five of the departments, the difference in gender distribution is below 10 percentage points, while in six, the difference exceeds 15 percentage points.

Notably, four departments demonstrate the most pronounced disparities. The Gynecology Department reports only female fallers, while the Psychiatry Department has a substantial majority of female fallers at 61.23%. Conversely, the Urology Department shows that 71.50% of falls involve males, and the Intensive Care Department reports males falling almost twice as often as females, with rates of 64.91% and 35.09%, respectively.

In addition, the "Other" category, the Orthopedic Department, and the Oncology/Hematology Department demonstrate slight gender-based discrepancies in fall rates, with percentage point differences of 4.06, 5.48, and 7.58, respectively. Falls are more prevalent among females in the initial two departments, whereas the Oncology/Hematology Department exhibits a higher incidence of falls among males.

Age Distribution

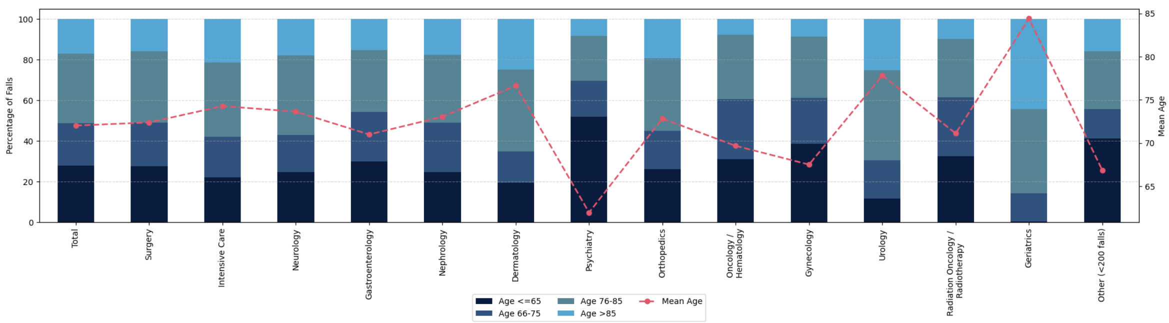

Figure 4.3.: Age Distribution and Mean Age of Fallers by Primary Faller Department

The analysis of age distribution among primary faller departments comprises two interrelated perspectives: the mean age of fallers and the distribution of fallers across different age groups (≤65, 66-75, 76-85, >85), both within each primary faller department. These perspectives are causally related, as a higher departmental mean age implies a larger proportion of individuals belonging to older age groups in the corresponding department (see Figure 4.3).

The mean age of fallers across the entire hospital is 72.03 (±15.70) years. This overall mean is reflected across departments, with six out of 14 departments having mean ages within two years of the hospital-wide mean and 10 out of 14 within five years. The youngest mean age is observed in the Psychiatry Department, with a mean age of 61.96 (±19.39) years, more than 10 years younger than the overall mean and nearly five years younger than the following youngest department. On the other hand, the Geriatrics Department exhibits a mean faller age (84.42 (±8.12)) that is more than 12 years above the overall mean and over six years above the following highest department.

The distribution of falls across age groups is consistent with the observed trends in mean age. The age group 76-85 is responsible for the highest proportion of falls (34.09%), representing more than a third of all falls. Subsequently, the age group comprising individuals aged 65 and below accounts for 27.95% of falls. The age groups 66-75 and >85 are similar in proportion, with 20.93% and 17.03% of falls reported in the respective groups. Furthermore, individuals 65 and older are responsible for 74.13% of all falls.

At the departmental level, the Nephrology Department exhibits the most uniform age distribution among fallers (±5.71%), followed by Gastroenterology (±6.14%). In contrast, the Geriatrics Department exhibits the most uneven distribution (±18.55%), with the age group >85 responsible for 44.39% of falls. Additionally, the Psychiatry Department accounts for the second most uneven distribution (±16.25%), with the age group ≤65 accounting for a notable 51.82% of falls.

Time Distribution

Our analysis classified the falls according to the time of day into three distinct shifts: the day shift (7:00-15:00), the evening shift (15:00-23:00), and the night shift (23:00-7:00). Across all hospital shifts, the percentage of falls was nearly equal, with a slight inclination towards the night shift (day: 32.71%, evening: 33.00%, night: 34.28%).

At the departmental level, nine departments identify the night shift as the most susceptible to falls, followed by the day shift (three departments) and the evening shift (two departments). Furthermore, eight departments indicate that the percentage of falls during the night shift is above 35%. In addition, all but one department exhibit fall distributions for each shift between 20% and 40%, further indicating that, while the night shift is marginally more prone to falls, the overall distribution is relatively balanced.

The Psychiatry Department is the sole department whose shifts fall outside the 20%-40% range. Their day shift accounts for 40.03% of all falls, while their evening and night shift account for 36.89% and 23.09% of falls, respectively. The Psychiatry Department also has the most uneven temporal distribution (Var: 0.0054), while the Surgical Department reports the most even distribution (Var: 0.0000).

Severity of Fall Injury

Our analysis revealed an overall injury rate of 25.35% (see Figure 4.4). The injury rate shows slight variation, with half of the departments exhibiting injury rates within a two percentage point range of the overall rate. It is noteworthy that four departments— Urology, Dermatology, Psychiatry, and "Other"—report injury rates that are significantly higher than the overall rate (Urology: 35.05%, Dermatology: 33.73%, Psychiatry: 33.00%, and "Other":

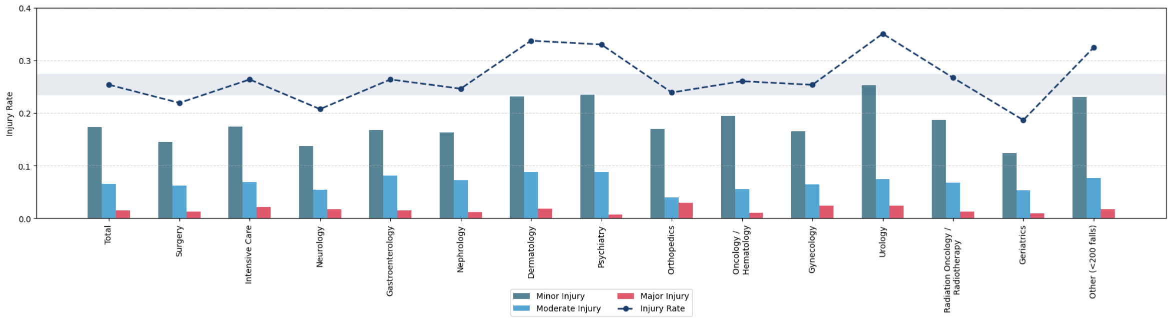

Figure 4.4.: Severity of Fall Injury by Primary Faller Department, with Two Percentage Point Range of Injury Rate Visualized as Horizontal Bar

32.44%). In contrast, the Geriatrics Department has the lowest injury rate, with only 18.64% of falls resulting in injuries.

A total of 17.33% of falls within the hospital setting result in minor injuries. A highly significant positive correlation is observed between the minor injury rate and the injury rate (Pearson r: 0.9821, p: 0.0000), indicating that departments with higher injury rates tend to have higher minor injury rates.

Moderate injuries occur in 6.49% of falls, and there is a high significant positive correlation between the moderate injury rate and the injury rate (Pearson r: 0.7515, p: 0.0019). This suggests that departments with more fall injuries also tend to have more falls with moderate injuries.

Major injuries are least prevalent, occurring in 1.53% of falls. No significant correlation was identified between the injury rate and the major injury rate (Pearson r: 0.1435, p: 0.6246), indicating that the occurrence of falls with major injuries is not strongly correlated with the rate of injuries. It is noteworthy that three of the four departments with the highest overall injury rates also report above-average major injury rates. The departments of Urology (2.34%), Dermatology (1.81%), and the "Other" category (1.73%) exhibited the highest rates of major injuries. Conversely, the Psychiatry Department as the fourth department, and the Geriatrics Departments reported the lowest and second lowest major injury rates across all departments at 0.75% and 0.91%, respectively.

Furthermore, it is insufficient to conclude that a low overall injury rate correlates with a low major injury rate. For instance, the Orthopedics and Gynecology Departments exhibit injury rates that are within two percentage points of the overall average. However, they report the highest and second-highest major injury rates (Orthopedics: 2.99%, Gynecology: 2.36%).

Ultimately, our analysis indicates that while certain departments with higher overall injury rates also experience increased minor and moderate injuries, this does not necessarily correlate with a higher rate of major injuries.

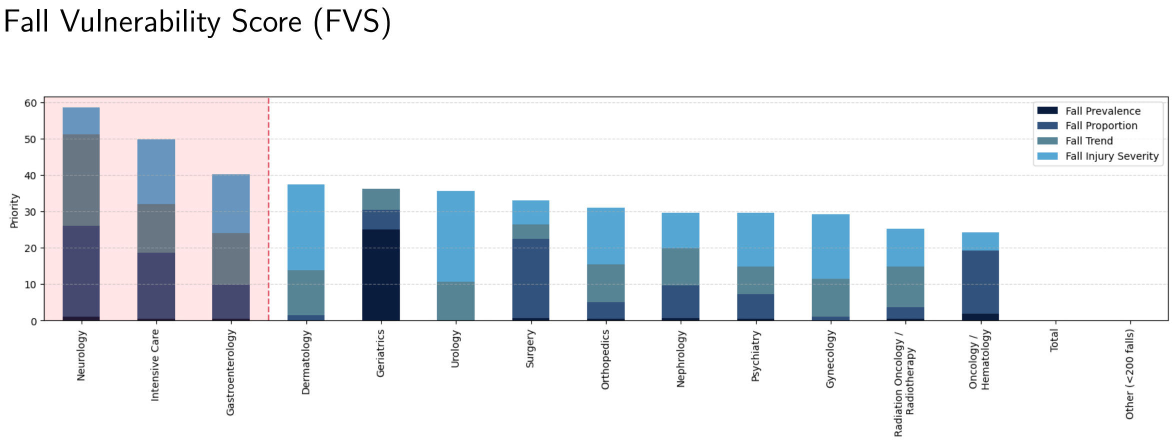

Figure 4.5.: FVS by Department with Four Underlying Metrics

Out of the 100 possible points a department could score on the FVS, all included departments scored between 20 and 60 points. We calculated these values only for departments with 200 or more patients to identify which departments would benefit the most from implementing additional fall prevention measures (see Figure 4.5).

At the upper end, the top three departments were Neurology, Intensive Care, and Gastroenterology, with scores of 58.55, 49.73, and 40.15 points, respectively. This was followed by a gradual decline, with Dermatology, Geriatrics, Urology, Surgical, and Orthopedics Departments scoring between 37.42 and 31.08 points. The scores for Nephrology, Psychiatry, and Gynecology Departments were closely grouped, with only a 0.28-point difference among them, scoring 29.57, 29.56, and 29.29 points, respectively. At the lower end of the scale, Radiation Oncology/Radiotherapy and Oncology/Hematology Departments scored 25.13 and 24.21 points, respectively.

Noteworthy is the distribution of points in each metric across departments. The Geriatrics Department scored the highest in the **Fall Prevalence** metric, with 25 points and an average score of 2.44 points in this metric. Furthermore, the Neurology Department, which leads overall, scored the full 25 points in both the **Fall Proportion** and **Fall Trend** metrics. In comparison, the average points across all departments in these metrics were 9.46 and 10.38 points, respectively. Lastly, the Urology Department achieved the full 25 points in the **Fall Injury Severity** metric, with an inter-departmental average of 13.04 points.

4.2. Patient Pathway

In this section, we present the findings from analyzing three Sankey diagrams that illustrate patient pathways within the departments with the highest FVS scores: Neurology, Intensive Care, and Gastroenterology. Our goal was to identify specific pathways associated with an increased risk of falls with major fall-related injuries.

For clarity, we refer to departments outside the scope of this analysis as "Summary Department". Those departments are visualized by the (<number>) events in the Sankey diagrams.

Neurology

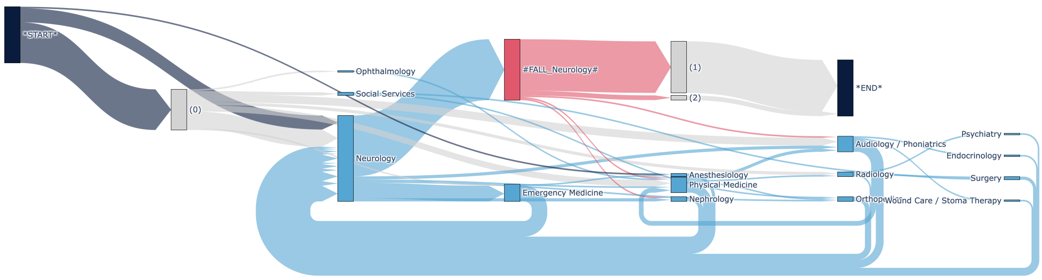

Figure 4.6.: Pathways of Falling Patients with Major Fall-Related Injuries in the Neurology Department

In the Neurology Department, we found records of 36 patients with major fall-related injuries from a total of 39 falls (see Figure 4.6). Most patients had a single fall, but three had two falls each. The Neurology Sankey diagram shows the most varied pathways compared to the other two departments with patient pathway investigation (see Figure 4.6, in contrast to Figures 4.7 and 4.8).

Out of these 36 patients, nine were first admitted to Neurology. One patient first went to the Anesthesiology Department, while the remaining 26 visited the Summary Department (0) before arriving at Neurology. Of the 26 patients who initially consulted with the Summary Department (0), 11 cycled through Neurology, went to other departments, and then returned. The remaining 15 patients took different paths among various other departments before falling in the Neurology Department.

Overall, the Neurology Department recorded 55 visits: 11 from the Summary Department (0), 10 from the Emergency Department, and nine direct admissions. Additionally, six patients came from the Physical Medicine Department and five from the Audiology/Phoniatrics Department. The remaining 14 came from various departments with three or fewer patients each. Notably, the three patients who fell twice were tracked through the Audiology/Phoniatrics, Physical Medicine, and Nephrology Departments.

Intensive Care

In the Intensive Care Department, we found that 37 patients had sustained major injuries due to a fall, 36 had suffered a single fall, and one had experienced two falls.

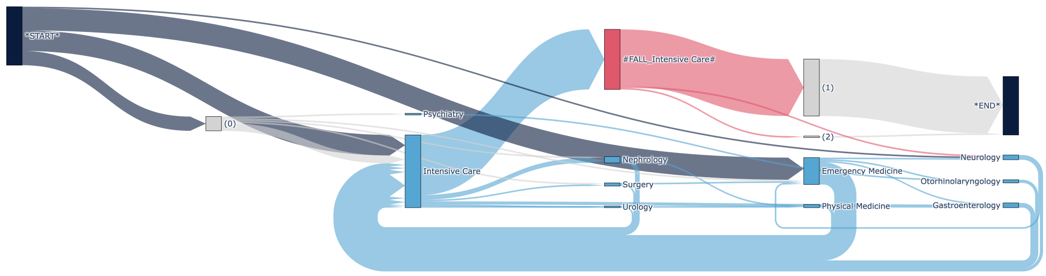

Figure 4.7.: Pathways of Falling Patients with Major Fall-Related Injuries in the Intensive Care Department

The Intensive Care Sankey diagram (see Figure 4.7) shows that 14 patients initially came through the Emergency Department, while 13 were directly admitted to the Intensive Care Department. One patient first visited the Neurology Department, and nine visited the Summary Department (0) before reaching the Intensive Care Department.

Of the 17 patients who were transferred from the Emergency Department, 14 were subsequently admitted to the Intensive Care Department. Those initially admitted to the Intensive Care Department and those transferred from the Summary Department (0) to the Intensive Care Department first visited other departments before falling in the Intensive Care Department.

Overall, the Intensive Care Department recorded 46 visits, with 38 resulting in falls. The patient who had multiple falls was transferred to the Neurology Department and then returned to the Intensive Care Department, where he fell again.

Gastroenterology

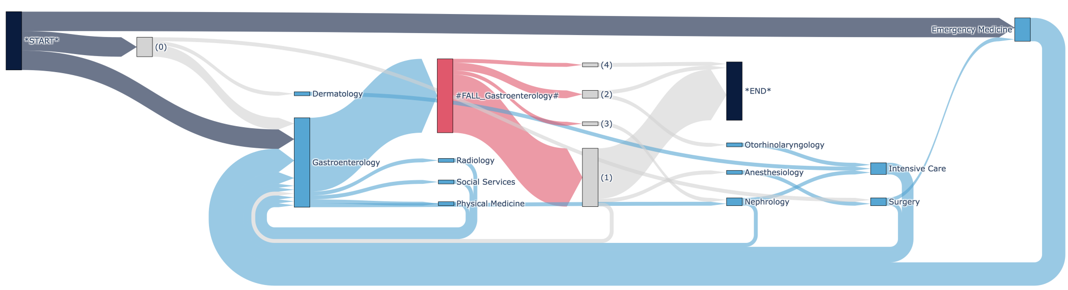

Figure 4.8.: Pathways of Falling Patients with Major Fall-Related Injuries in the Gastroenterology Department

The Gastroenterology Department documented 15 cases of patients who experienced falls with major fall-related injuries, resulting in a total of 19 reported falls. Of these cases, 13 were single falls, one patient experienced two falls, and another patient had four falls.

Figure 4.8 visually represents the pathways these patients traversed. Five patients proceeded directly to the Emergency Department, while another five were immediately referred to the Gastroenterology Department. The remaining five patients initially visited the Summary Department (0) before being transferred to the Gastroenterology Department. Patients who initially presented at the Emergency Department were promptly transferred to the Gastroenterology Department. In contrast, patients who initially presented at the Summary Department (0) were subsequently seen in the Gastroenterology Department, then referred to other departments, and subsequently returned to the Gastroenterology Department, where they fell with major fall-related injuries.

In total, there were 23 visits to the Gastroenterology Department, including some repeat visits. Nineteen visits resulted in falls within the Gastroenterology Department. Additionally, three patients were transferred from the Intensive Care Department, making it the third most common source of admissions to the Gastroenterology Department. Patients with multiple falls were seen in the Otorhinolaryngology, Anesthesiology, Surgical, and Nephrology Departments.

Over all Findings

A comparison of the three Sankey diagrams reveals a considerable degree of diversity in patient pathways, with notable variations in path length and departmental involvement. However, two commonalities are evident. Firstly, all three diagrams demonstrate that a substantial proportion of fallers with severe fall-related injuries originate from the Emergency Department, although the proportions vary. Furthermore, a high number of patients with severe fall-related injuries had previously been admitted to the same department where they subsequently experienced their falls. This pattern is notably evident in the Gastroenterology and Intensive Care Departments, indicating that returning patients are more prone to falls in previously visited departments.

5. Discussion

The objective of this thesis is to address two interconnected research questions: first, to identify the differences in characteristics of inpatient falls across various clinical departments, and second, to examine how patient pathways vary between those who experience falls. To answer this question, we conducted a comprehensive quantitative data analysis of inpatient falls across departments. Our investigation first focused on several key areas at both the hospital and department level: the incidence of falls, the distribution of gender and age among patients who fell, the temporal distribution of fall occurrences, and the severity of fall-related injury. In addition, we developed the FVS, a metric designed to assess how vulnerable each department is to falls. We later explored patient pathways of individuals who sustained major fall-related injuries, concentrating on falls in the three departments with the highest FVS.

In the following discussion, we will first examine our study's results, addressing each research question separately and in detail. We will then place these findings within the theoretical framework outlined earlier in this thesis (see Chapter 2). Finally, we will discuss the limitations of our study.

5.1. Inpatient Falls across Departments

Our findings revealed a notable disparity in fall occurrences across different hospital departments. Although falls are widespread across the hospital, they are not uniformly distributed. Specifically, 29 of 60 departments reported falls, with only 13 departments documenting 200 or more falls over six years—equivalent to an average of 2.78 falls per month. This underscores that while falls are not ubiquitous across the entire hospital, they remain a significant issue for the hospital and the healthcare system as a whole.

While analyzing fall occurrences at the hospital level provided an estimate of fall incidence and related characteristics, examining these incidents at the departmental level offered more detailed insights into variations within the hospital. For instance, the incidence of falls in the Geriatrics Department was more than 45 times higher than the overall hospital rate of 0.21 falls per patient. This elevated rate is likely due to age-related conditions such as diminished muscle strength, balance, and coordination (Morris et al. 2022; Heinze, Halfens, and Dassen 2007; Halfon et al. 2001).

Additionally, the data revealed gender-based disparities in fall rates. Overall, males were more susceptible to falls than females (m: 55.41%, f: 44.59%). However, this general trend varied by department. For instance, the Intensive Care and Urology Departments demonstrated a significantly elevated incidence of male falls. In contrast, the Gynecology and

Psychiatry Departments exhibited exclusively female falls or a higher incidence of female falls than male falls. Due to the lack of patient gender distribution data, we could not differentiate between a genuine predisposition to falls and a higher fall incidence resulting from a larger number of patients, making an interpretation impossible.

The analysis revealed that the mean age of fallers across the hospital is 72.03 (±15.70) years. Of the 14 primary faller departments analyzed[1], 10 reported average faller ages within five years of the hospital-wide average. The Geriatrics Department fell outside the aforementioned range, reporting the highest average age of fallers and the largest group of individuals over the age of 85. This aligns with the patient population typically treated by the department. In contrast, the Psychiatry Department reported a notably younger average age of fallers, potentially attributable to physical impairments associated with mental illnesses that affect a broad age range, resulting in an increased number of falls at an earlier age. Furthermore, in comparison to the hospital-wide average age, the Urology Department exhibited an elevated average age of fallers, though the specific underlying causes remain unclear. On the other hand, the "Other" category, which encompasses 16 distinct departments, exhibited a notably lower average age of fallers. However, the underlying reasons for this relatively low average age also remain unclear.

With regard to the temporal distribution of falls, the analysis indicates a relatively uniform occurrence throughout the day, with a slight increase during the night shift. Conversely, the Psychiatry Department exhibited a markedly elevated incidence of falls during daytime hours. This phenomenon may be attributed to the increased activity and vulnerability among patients with psychological impairments during the day.

In terms of fall injury severity, the overall injury rate across departments is 25.35%, with the Geriatrics Department reporting the lowest rate of 18.64%. The distribution of injuries includes 17.33% minor injuries, 6.49% moderate injuries, and 1.53% major injuries. While minor and moderate injury rates are positively correlated with the overall injury rate, no significant correlation was observed between the overall injury rate and the rate of major injuries. This suggests that major fall-related injuries are less predictable and may be highly influenced by department-specific management practices, as indicated by the low injury rate in the Geriatrics Department.

Moreover, our analysis identified the three departments with the highest FVS: Neurology, Intensive Care, and Gastroenterology. The Neurology Department is significantly affected by the overall proportion of falls and an increasing trend of falls. At the same time, the Intensive Care Department demonstrated a comparable, less severe pattern, albeit with a higher proportion of severe injuries. It is noteworthy that, despite its high incidence rate, the Geriatrics Department did not score as high on the FVS due to significantly lower severity of fall injury, positive trends, and fewer severe incidents. These departmental variations were

1. This includes 13 departments with 200 or more fallers and a category "Other", which groups all departments with fewer than 200 falls.

most likely influenced by factors such as the nature of each specialty, department-specific policies, recent policy implementations, and the size of each department. Consequently, the findings are likely to differ across hospitals.

In conclusion, this analysis addresses the first research question by illustrating the heterogeneous characteristics of falls across various clinical departments. It demonstrates that while falls are a prevalent issue throughout the hospital, departments such as Neurology, Intensive Care, and Gastroenterology exhibit distinctive patterns that contribute to their elevated FVS rates. These patterns render these departments particularly susceptible to falls.

5.2. Patient Pathway

The investigation into the patient pathways of fallers with severe fall-related injuries across the three departments with the highest FVS revealed substantial variability in the routes taken by these patients. This variability reflects the inherently diverse nature of patient journeys within hospital settings. However, two key trends emerged from the analysis that warrant further attention.

Firstly, a significant proportion of patients who later experienced falls were admitted through the Emergency Department. This finding was somewhat anticipated, given the Emergency Department's role as a primary entry point for hospital admissions. Nonetheless, it suggests that patients arriving via this route may have a higher risk of falls with severe fall-related injuries.

Secondly, in two out of the three departments investigated, a significant number of patients who experienced falls with major fall-related injuries had previously been admitted to the same departments. This suggests that the risk of experiencing falls with severe injuries might be elevated in departments where patients are recurrently treated. The exact reasons for this trend remain unclear, but it underscores a potential area for further investigation.

Despite these two trends, the overall findings from the analysis were less extensive than anticipated. The patient pathway analysis did not reveal additional significant patterns or trends beyond those mentioned, suggesting that the analysis was less informative than initially expected.

In conclusion, these findings emphasize the diverse pathways followed by patients who experience falls and illustrate how distinct patient pathways may impact fall risk, thereby addressing the second research question.

5.3. Theoretical Implications

This thesis offers substantial contributions to healthcare management and health analytics by leveraging EHRs to enhance the understanding of inpatient falls at the departmental level. A key innovation is the introduction of the FVS, a novel metric designed to identify hospital departments with higher susceptibility to falls, providing a valuable tool for researchers and practitioners alike. Moreover, the application of health analytics methods in modeling patient pathways demonstrates the practical utility of these techniques, contributing to the expanding field of patient pathway visualization in health analytics.

To contextualize the impact of our findings from the inpatient fall analysis, it is essential to compare them with existing research. Our analysis revealed several noteworthy contrasts with previous studies. For instance, while earlier research such as Healey et al. (2008), Schwendimann et al. (2008), and Kerzman et al. (2004) reported fall incidences ranging from 4.95 to 9.9 per 1,000 patient days, our study found a markedly lower incidence of 0.21 per 1,000 patient days. The Geriatrics Department in our analysis, with an incidence of 9.53, is an exception, aligning more closely with the higher ranges reported by Healey et al. (2008), Schwendimann et al. (2008), and Kerzman et al. (2004).

Regarding gender distribution, our study observed a higher incidence of falls among males (55.41%) compared to females (44.59%). This contrasts with previous studies that either suggest females are more prone to falls or show an equal distribution (Mikos et al. 2021; Schwendimann et al. 2008; Kerzman et al. 2004). Nonetheless, our findings align with those of Healey et al. (2008), who partly identified a higher fall incidence among males.

In terms of age, the average faller in our study is 72.03 ($\pm$15.70) years, with a departmental concentration within a five-year range around this mean. This is in the range of the average age of 73.79 across multiple studies (see Theoretical Background Section 2.3). Concerning the age distribution, our results differ from those of Healey et al. (2008), who report that 82.6% of falls occurred in individuals aged above 65 and 32.4% of falls in those aged 86 and above. Our analysis presents a more balanced distribution of fallers around the average age, indicating a less pronounced concentration in older age brackets.

Our findings on the temporal distribution of falls are consistent with Mikos et al. (2021) and Schwendimann et al. (2008), who observe a higher incidence of falls during night shifts. However, our analysis reveals a more even distribution of falls across all shifts, contrasting with the stronger night shift tendency observed in the aforementioned studies. Additionally, while Schwendimann et al. (2008) identify a highly uneven distribution of falls throughout the day in the Surgery Department, our analysis found this department to have the most even distribution among the 14 departments analyzed.

When examining injury rates, our overall hospital rate of 25.35% is notably lower than the 35.2% and 35.3% rates reported by Schwendimann et al. (2008) and Healey et al. (2008), respectively. Despite some departments in our study showing injury rates exceeding 30%, none surpass the levels reported in the aforementioned studies. Variations in definitions and categorization of injury levels complicate direct comparisons (see Subsection 2.3). Nonetheless, when we aggregate our moderate (6.49%) and major (1.53%) injury rates to match the major injury threshold used in cited studies, we find our combined rate (8.02%) to be notably higher than the rates reported by Schwendimann et al. (2008) (5.1%) and Healey et al. (2008) (4.2%). Interestingly, although Schwendimann et al. (2008) report the Geriatrics Department as having the highest incidence of falls resulting in major injuries, our analysis indicates that this department ranks second lowest in major injury rates.

5.4. Practical Implications

From a practical perspective, the objectives of our work are twofold: first, to reduce the overall costs associated with falls, and second, to improve patient well-being. To address these goals effectively, we propose an approach that focuses on both reducing the number of falls and the severity of fall-related injuries.

We developed the novel FVS, which can help on-site hospital staff identify fall-vulnerable departments. With the FVS, we identified three departments—Gastroenterology, Intensive Care, and Neurology—as areas particularly vulnerable to falls. Additionally, using a patient pathway analysis, we pinpointed patients admitted through the Emergency Department or those with frequent visits to the same department as more likely to face a fall with major fall-related injuries.

To address these risks, we recommend the utilization of the hospital's existing fall risk classification system, as detailed in Section 2.2. The system categorizes patients based on their fall risk and applies tailored preventive measures accordingly. Therefore, for patients in particularly vulnerable departments and those belonging to one of the aforementioned patient groups, we propose reclassifying their fall risk to the next higher category. This adjustment will prompt the implementation of more fall prevention measures designed to address the elevated risk.

By adopting this approach, we aim to reduce both the incidence and severity of fall-related injuries, thereby lowering associated costs and improving patient safety. However, given the potential for additional costs due to the increased use of staff and equipment such as special beds, we advise conducting a pilot trial to evaluate the effectiveness and financial impact of these measures before broader implementation. This trial will help ensure that the proposed interventions balance cost-efficiency with enhanced patient safety.

5.5. Limitations

This thesis is subject to several limitations that impact the reliability and generalizability of its findings. A significant concern is the potential for underreporting due to the standardized reporting system for inpatient falls. This system may introduce bias by not capturing all incidents accurately. Furthermore, the involvement of a large number of nurses in documenting falls can lead to inconsistencies in the data, compounded by staff turnover during the study period. The frequent changes in personnel can affect documentation practices and contribute to data inconsistencies.

Another limitation is the lack of comprehensive patient data for the entire patient population, as the study focuses only on the demographics of patients who experienced falls. This restricts the ability to contextualize findings, such as comparing the gender or age distribution of fallers to the overall patient population of the department. The absence of comprehensive patient data also constrains the precision of our fall incidences, as we had to calculate the average length of stay using a single external source, without accounting for department-specific variations.

Additionally, the temporal scope of the analysis is limited to data from 2016 to 2022, which may not accurately reflect current fall trends and impacts the validity of findings related to the FVS. Moreover, the FVS fall trend does not account for contradictory trends observed in different wards of the same department.

Finally, the patient pathway analysis exclusively considers the pathways of patients who fell without including those who did not. This selective approach restricts the study's internal validity.

6. Conclusion

This thesis presents a comprehensive investigation into inpatient falls at the departmental level. Our objectives were to examine the incidence rates, demographic patterns, temporal trends, and severity of fall-related injuries across various clinical departments. To this end, we developed the FVS, a novel tool designed to identify departments most susceptible to falls. The FVS successfully pinpointed the hospital's departments with the highest fall risk. Additionally, we conducted an in-depth analysis of patient pathways for those who experienced falls within these high-risk departments.

Our findings reveal significant disparities in fall incidences across departments. For instance, the Geriatrics Department exhibited a fall incidence of more than 45 times higher than the hospital average. However, these falls mostly resulted in no or minor injuries. Additionally, we observed that males experienced falls more frequently and that falls were almost evenly distributed throughout the day, with a slightly higher incidence during the night shift. While a strong positive correlation was found between the overall injury rate and rates of minor and moderate injuries, no significant correlation was observed between the injury rate and the incidence of major injuries, suggesting that major fall-related injuries are less predictable and may be heavily influenced by department-specific management practices. The application of the FVS identified the Gastroenterology, Intensive Care, and Neurology Departments as the most vulnerable to falls, indicating they would benefit most from targeted fall prevention measures.

Furthermore, our patient pathway analysis indicated that patients admitted through the Emergency Department and those with a history of frequent visits to the same department are at an elevated risk of falling and sustaining major injuries.

This study contributes to the field of healthcare management in two key ways. Theoretically, it advances existing literature on healthcare management and fall prevention by providing novel insights into departmental variations in inpatient falls. It also introduces the FVS, a tool that can aid both researchers and operational staff. Practically, the FVS offers a framework for hospitals to identify high-risk areas for falls and to implement targeted prevention measures. The thesis outlines a methodology for implementing fall prevention strategies in the most vulnerable departments, with the ultimate goal of reducing overall fall-related costs and enhancing patient well-being.

While this thesis improves our understanding of inpatient falls at the departmental level and proposes a methodology to reduce falls and associated injury severity, several areas require further investigation. The existing literature on departmental differences in inpatient falls is limited and somewhat outdated. Therefore, more recent research is needed to enhance our understanding of these interdepartmental variations. Although we have identified high-risk areas and proposed potential preventive measures, we have not explored these measures in depth. Further research should aim to establish a connection between our findings and specific fall prevention strategies. Finally, as previously recommended, an evaluation of the cost-effectiveness of adjusting fall risk scores for patients in high-risk areas should be conducted, as discussed in our Practical Implications section.

As the healthcare landscape continues to evolve, preventing inpatient falls remains a critical concern. A thorough understanding of the factors contributing to falls, especially those resulting in severe injuries, is essential for maintaining affordable and high-quality healthcare for an aging population. Continued research in this area will support the development of effective and sustainable fall prevention strategies in the long term.

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A. Appendix

A.1. Inpatient Fall Management

<table>
<tr><th>Risk Group</th><th>Measures</th></tr>
<tr><td rowspan="3">+</td><td>Basic Measures
Information for patient/caregiver
Minimize environmental fall hazards (e.g., lock mobile furniture in place, adjust bed height)
Closed, non-slip footwear
Enable use of own aids</td></tr>
<tr><td>If: Physical Mobility Impaired (in addition to all above)
Assist/accompany during transfer/getting up/using the toilet, etc.
Provide a functional walking aid (if necessary)
Physiotherapy (if necessary)</td></tr>
<tr><td>If: Acute/Chronic Confusion (in addition to all above)
Regular preventive inspections</td></tr>
<tr><td>++</td><td>Increased Attention (in addition to all above)
1 to 2 hourly tour and between 5:30 - 7:00 a.m. offer for toilet accompaniment
Check preferred lying position and ensure easy access to essentials</td></tr>
</table>

Table A.1.: Fall Prevention Measures

A.2. Investigation of Inpatient Falls

Category \ Study	Mikos et al. *2021*	Healey et al. *2008*	Schwendimann et al. *2008*	Kerzman et al. *2004*
Fall Incidence	n	y	y	y
Gender Distribution	y	y	y	y
Age Distribution	(y)[b]	(y)[c]	(y)[b]	(y)[b]
Time Distribution	y	n	y	(y)[a]
Severity of Fall Injury	n	y	y	n
a: Only Total Numbers, No Department Level; b Only Mean Age; c Only Age Distribution				

Table A.2.: Summary of Categories Investigated in Each Study and Their Respective Depths

Note: In the following tables provided in this section, values shown in *italics* were calculated based on data from the corresponding studies.

Department	Total	Cardiology	Internal Medicine	Neurology	Orthopedics	Rheumatology	Rehabilitation
Number of Hospitalization	*99,366*	11,980	39,811	7,517	9,673	24,849	5,536
Falls	*734*	47	469	45	14	53	106
Gender *(Fallers)*							
Females	*57.62%*	38.30%	54.58%	37.78%	57.14%	81.13%	76.42%
Males	*42.38%*	61.70%	45.42%	62.22%	42.90%	18.90%	23.58%
Age *(Fallers)*							
Mean	*76.03*	77.94	77.70	77.76	71.29	65.81	72.81
Falls per Shift							
Morning (06:00-12:00)	-	25.53%	19.98%	26.67%	42.86%	26.42%	19.81%
Day (12:00-18:00)	-	31.92%	19.40%	26.67%	0.00%	32.08%	27.36%
Evening (18:00-24:00)	-	23.40%	26.23%	24.44%	28.57%	16.98%	29.25%
Night (24:00-06:00)	-	19.15%	35.39%	22.22%	28.57%	24.53%	23.59%
Adjusted Shifts[a]							
Day (07:00-15:00)	*29.19%*	*37.24%*	*26.35%*	*35.56%*	*35.72%*	*38.06%*	*30.19%*
Evening (15:00-23:00)	*32.63%*	*35.46%*	*31.56%*	*33.70%*	*23.81%*	*30.19%*	*38.06%*
Night (23:00-07:00)	38.82%	27.31%	43.09%	30.74%	40.48%	31.76%	31.77%

Table A.3.: Findings of Mikos et al. (2021)

a. Calculated Assuming Linear Distribution within shifts

Department	Total[a]	Acute Hospitals	Community Hospital	Mental Health Unit
Falls	206,350	152,069	28,198	26,083
Fall Incidence[b]	*4.95*	4.8	8.4	2.1
Gender *(Fallers)*				
Females	49.2%	48.6%	53.0%	48.5%
Males	50.8%	51.4%	47.0%	51.5%
Age *(Fallers)*				
Mean[c]	73.38	-	-	-
$\leq$ 65	17.4%	-	-	-
$>$ 65	82.6%	-	-	-
65-74	15.1%	-	-	-
75-84	35.1%	-	-	-
$>$ 85	32.4%	-	-	-
Fall Injury				
No Injury	64.7%	66.5%	63.0%	55.5%
Injury Rate	35.3%	33.5%	37.0%	44.5%
Minor	31.1%	29.5%	32.4%	39.1%
Moderate	3.6%	3.3%	4.2%	5.1%
Major	0.6%	0.7%	0.4%	0.3%

Table A.4.: Findings of Healey et al. (2008)

a. No Total given. Calculated, based on Given Department Values
b. Fall Incidence: Falls per 1000 Patient Days
c. Calculated, Assuming Linear Distribution within Given Groups (Min. 18, Max. 90)

Department	Total	Internal Medicine	Geriatrics	Surgical
Number of Hospitalization	34,972	17,386	2,765	14,821
Falls	2,512	1,550	663	299
Fall Incidence[a]	7.0	9.6	10.7	3.2
Gender				
Females *(All)*	53.6%	54.5%	72.7%	49.1%
Males *(All)*	46.4%	45.5%	27.3%	50.9%
Females *(Fallers)*	57.2%	51.3%	71.5%	55.0%
Males *(Fallers)*	42.8%	48.7%	28.5%	45.0%
Age				
Mean *(All)*	67.3	70.4	83.0	60.6
Mean *(Fallers)*	79.8	78.3	84.1	77.7
Falls per Shift				
Day (07:00-15:00)	33.6%	31.4%	38.6%	33.4%
Evening (15:00-23:00)	29.1%	27.9%	34.1%	24.6%
Night (23:00-07:00)	37.3%	40.6%	27.3%	42.1%
Fall Injury				
No Injury	64.8%	65.0%	65.5%	62.6%
Injury Rate	35.2%	35.0%	34.5%	37.4%
Minor	30.1%	31.2%	26.8%	31.4%
Major	5.1%	3.8%	7.7%	6.0%

Table A.5.: Findings of Schwendimann et al. (2008)

a. Fall Incidence: Falls per 1000 Patient Days

Department	Total	Internal Medicine	Surgical	Rehabilitation	Psychiatry	Gynaecology	Geriatrics	Paediatric	Other
Falls	677	82	77	91	101	12	242	31	41
Fall Rate[a]	*51.5*	5	9	85	91	-	115	4	-
Fall Incidence[bc]	*9.9*	*0.96*	*1.73*	*16.35*	*17.50*	-	*22.12*	*0.77*	-
Gender[d] *(Fallers)*									
Females	*49.78%*	*41.46%*	*51.95%*	*36.26%*	*72.28%*	*100.00%*	*48.76%*	*48.39%*	*29.27%*
Males	*50.22%*	*58.54%*	*48.05%*	*63.74%*	*27.72%*	*0.00%*	*51.24%*	*51.61%*	*70.73%*
Age *(Fallers)*									
Mean[ef]	*65.95*	-	-	-	-	-	-	-	-
< 50	*19.88%*	-	-	-	-	-	-	-	-
50-64	*13.65%*	-	-	-	-	-	-	-	-
$\geq$65	*66.16%*	-	-	-	-	-	-	-	-
Falls per Shift									
Day (07:00-15:00)	39.29%	-	-	-	-	-	-	-	-
Evening (15:00-23:00)	28.36%	-	-	-	-	-	-	-	
Night (23:00-07:00)	30.13%	-	-	-	-	-	-	-	-

Table A.6.: Findings of Kerzman et al. (2004)

a. Fall Rate: Falls per 1000 Admissions
b. Fall Incidence: Falls per 1000 Patient Days
c. No Length of Stay given, see 2.3
d. Calculated, based on Given Absolute Numbers
e. Calculated, Assuming Linear Distribution within Given Groups (Min. 18, Max. 90)
f. Age Groups Calculated, based on Given Absolute Numbers

A.3. Patient Pathway without Scope

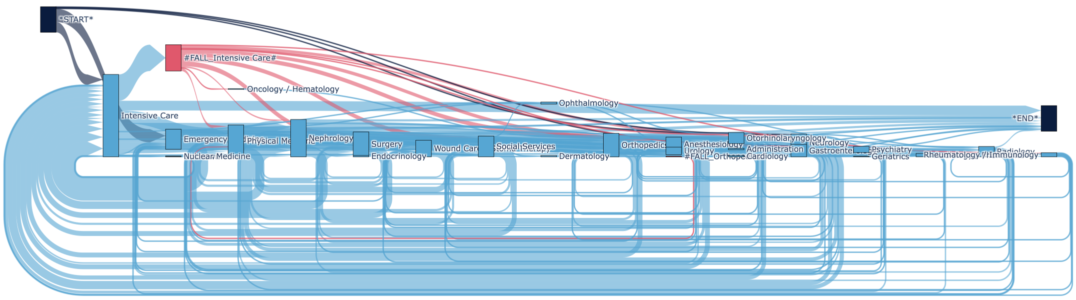

Figure A.1.: Pathways of Falling Patients with Major Fall-Related Injury in the Intensive Care Department without Scope Filter

A.4. Inpatient Falls Data Across Primary Faller Departments

Department	Total	Surgical	Intensive Care	Neurology	Gastro-enterology	Cardiology / Nephrology
Department Visits	9,085,069	1,003,622	940,927	679,513	589,914	489,333
Falls	14,260	2,031	1,730	2,311	994	971
Fall Rate[a]	1.57	2.02	1.84	3.40	1.68	1.98
Fall Incidence[b]	0.21	0.27	0.25	0.45	0.22	0.26
Gender *(Fallers)*						
Females	44.59%	42.20%	35.09%	41.41%	38.43%	41.19%
Males	55.41%	57.80%	64.91%	58.59%	61.57%	58.81%
Age *(Fallers)*						
Mean (±SD[c])	72.03 (±15.70)	72.39 (±14.59)	74.28 (±14.60)	73.64 (±15.02)	71.00 (±15.37)	73.05 (±14.40)
≤65	27.95%	27.62%	22.14%	24.79%	29.98%	24.72%
66-75	20.93%	21.37%	19.83%	18.22%	24.14%	24.20%
76-85	34.09%	35.25%	36.76%	39.07%	30.58%	33.57%
> 85	17.03%	15.76%	21.27%	17.91%	15.29%	17.51%
Falls per Shift						
Day (07:00-15:00)	32.71%	33.09%	30.58%	35.09%	26.76%	31.72%
Evening (15:00-23:00)	33.00%	32.69%	31.79%	37.04%	33.80%	31.31%
Night (23:00-07:00)	34.28%	34.22%	37.63%	27.87%	39.44%	36.97%
Fall Injury						
No Injury	74.65%	78.09%	73.64%	79.27%	73.64%	75.39%
Injury Rate	25.35%	21.91%	26.36%	20.73%	26.36%	24.61%
Minor	17.33%	14.52%	17.40%	13.67%	16.70%	16.27%
Moderate	6.49%	6.15%	6.82%	5.37%	8.15%	7.21%
Major	1.53%	1.23%	2.14%	1.69%	1.51%	1.13%
FVS	35.33	32.91	49.73	58.55	40.15	29.57

Table A.7.: Table 1 of 3: Inpatient Falls by Department Findings

a. Fall Rate: Falls per 1000 Admissions
b. Fall Incidence: Falls per 1000 Patient Days
c. SD—standard deviation

Department	Dermatology	Psychiatry	Orthopedics	Oncology / Hematology	Gynecology	Urology
Department Visits	482,665	430,154	428,910	352,734	310,563	261,871
Falls	332	797	603	1 675	296	214
Fall Rate[a]	0.69	1.85	1.41	4.75	0.95	0.82
Fall Incidence[b]	0.09	0.25	0.19	0.63	0.13	0.11
Gender *(Fallers)*						
Females	44.88%	61.23%	52.74%	46.21%	100.00%	28.50%
Males	55.12%	38.77%	47.26%	53.79%	0.00%	71.50%
Age *(Fallers)*						
Mean (±SD[c])	76.64 (±14.10)	61.96 (±19.39)	72.84 (±16.06)	69.68 (±13.54)	67.51 (±16.48)	77.83 (±12.21)
≤65	19.58%	51.82%	26.20%	31.04%	38.51%	11.68%
66-75	15.36%	17.69%	18.74%	29.61%	22.64%	18.69%
76-85	40.06%	22.08%	35.66%	31.46%	30.07%	44.39%
> 85	25.00%	8.41%	19.40%	7.88%	8.78%	25.23%
Falls per Shift						
Day (07:00-15:00)	35.84%	40.03%	31.18%	30.03%	31.42%	29.91%
Evening (15:00-23:00)	30.72%	36.89%	30.85%	30.87%	29.05%	32.24%
Night (23:00-07:00)	33.43%	23.09%	37.98%	39.10%	39.53%	37.85%
Fall Injury						
No Injury	66.27%	67.00%	76.12%	73.97%	74.66%	64.95%
Injury Rate	33.73%	33.00%	23.88%	26.03%	25.34%	35.05%
Minor	23.19%	23.46%	16.92%	19.46%	16.55%	25.23%
Moderate	8.73%	8.78%	3.98%	5.55%	6.42%	7.48%
Major	1.81%	0.75%	2.99%	1.01%	2.36%	2.34%
FVS	37.42	29.56	31.08	24.21	29.29	35.54

Table A.8.: Table 2 of 3: Inpatient Falls by Department Findings

a. Fall Rate: Falls per 1000 Admissions
b. Fall Incidence: Falls per 1000 Patient Days
c. SD—standard deviation

Department	Radiation Oncology / Radiotherapy	Geriatrics	Other (<200 falls)
Department Visits	229,945	9,230	2,875,688
Falls	487	660	1,159
Fall Rate[a]	2.12	71.51	0.40
Fall Incidence[b]	0.28	9.53	0.05
Gender *(Fallers)*			
Females	37.37%	43.03%	52.03%
Males	62.63%	56.97%	47.97%
Age *(Fallers)*			
Mean (±SD[c])	71.12 (±10.98)	84.42 (±8.12)	66.85 (±19.85)
≤ 65	32.44%	0.30%	41.07%
66-75	29.16%	13.94%	14.58%
76-85	28.54%	41.36%	28.39%
> 85	9.86%	44.39%	15.96%
Falls per Shift			
Day (07:00-15:00)	31.21%	36.06%	34.77%
Evening (15:00-23:00)	28.95%	30.15%	34.69%
Night (23:00-07:00)	39.84%	33.79%	30.54%
Fall Injury			
No Injury	73.31%	81.36%	67.56%
Injury Rate	26.69%	18.64%	32.44%
Minor	18.69%	12.42%	23.04%
Moderate	6.78%	5.30%	7.68%
Major	1.23%	0.91%	1.73%
FVS	25.13	36.12	-

Table A.9.: Table 3 of 3: Inpatient Falls by Department Findings

a. Fall Rate: Falls per 1000 Admissions
b. Fall Incidence: Falls per 1000 Patient Days
c. SD—standard deviation