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ABSTRACT

Background: Traffic accident-related traumas are the leading cause of mortality among adolescents and young adults aged 15 to 29 years. Furthermore, they represent a considerable financial burden on public finances, with estimated costs of approximately 3% of the annual GDP, impacting sectors such as healthcare, infrastructure, and productivity. Accidents commonly result in polytrauma, and various criteria have been established to assess injury severity in frontal vehicle collisions. Therefore, this study aims to conduct a literature review to investigate the main patterns of injuries observed in frontal vehicle collisions over the past five years.

Methodology: This is a literature review conducted between November and December 2024, utilizing the MEDLINE database. The search employed the keyword "frontal car crashes" and was restricted to studies published within the last five years. The initial search yielded 102 articles, and after screening, using inclusion criteria such as reporting injuries from frontal vehicle collisions with human models or real-life cases, other literature reviews were excluded. A total of 8 articles were selected.

Keywords: multiple trauma, Accidents, emergency medicine.

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I. INTRODUCTION

Traffic accident-related traumas are the leading cause of mortality among adolescents and young adults aged 15 to 29 years. Moreover, they represent a significant financial burden on public finances, with estimated costs of approximately 3% of the annual GDP, impacting sectors such as healthcare, infrastructure, and productivity [1]. In developed countries, such as the United States, traffic accidents began to be recognized as a serious problem throughout the 20th century due to the rapid increase in the number of automobiles. In developing countries, such as Brazil, the social significance of this issue emerged in the 1970s, partly due to the growing reliance on motor vehicles for urban mobility and goods transportation, exacerbated by the lack of alternatives such as railway transportation [2].

A car accident encompasses multiple factors, such as human error, vehicle conditions, and the physical and social environment surrounding the incident [3]. The human factor is the most significant, responsible for up to 90% of traffic accidents. In this regard, one of the aspects studied is the driver's behavior while driving, particularly overconfidence and engaging in activities during driving that may distract them and significantly impair their ability to operate a vehicle [4], such as reaching for objects, adjusting the radio, eating, drinking, and using electronic devices like cell phones, GPS, and tablets, among others. Engaging in these activities causes the driver to divert their attention, impairing their ability to react promptly and avoid a collision [5].

Still within this context, accidents commonly result in polytrauma, and several criteria have been established to assess injury severity in

frontal collisions. Among the parameters used to evaluate vehicle occupant responses to impact are acceleration, force, and torque, which are applied in biomechanical studies [6]. Different criteria have been proposed for various body regions to assess the severity of injuries in car accidents, such as the head injury criterion, which is based on the acceleration of the head during the collision [7].

In this context, given the growing importance of the topic, this article aims to conduct a literature review to identify and analyze the main patterns of injuries in frontal vehicle collisions. Through the analysis of recent studies and data from various research efforts, the goal is to understand the characteristics and severity of the most common injuries in these situations, as well as to evaluate factors contributing to the intensity of impact and the human body's response.

II. METHODOLOGY

This is a literature review conducted between November and December 2024, utilizing the MEDLINE database. The search used the keyword *"frontal car crashes"* and was restricted to studies published within the last five years. The initial search yielded 102 articles. After screening, which used the following inclusion criteria: studies that reported only the outcomes of frontal collisions betweenvehicles, whether involving similar models or real-case scenarios, literature review studies were excluded. A total of 8 articles were selected.

The stages of this research were organized as follows: first, the appropriate descriptors were determined; then, in a sequential manner, the search strategy was developed, the databases were selected, the most relevant titles were chosen, and a complete reading of the texts was performed. Finally, these steps culminated in the preparation of the text.

Due to the use of secondary data from public domain sources, it was not necessary to submit the project to a Research Ethics Committee.

III. RESULTS

Table 1 presents the research results, organizing the studies according to the year of publication and their objectives. This structure was chosen for its ability to provide a comparative overview of the selected studies.

Table 1: Studies Obtained from A Literature Review on the Medline Platform, Categorized by Author, Year, Methodology and Results

Autor	Year	Methodology	Results
Khojastepour *et al*	2024	The study evaluated 91 patients with frontal sinus fractures treated at Rajaee Hospital in Shiraz between 2014 and 2019, all victims of trauma	The prevalence of frontal sinus fractures was higher among car accident victims. Combined fractures of the anterior and posterior tables were more commonly observed than isolated involvement of either the anterior or posterior table. Most frontal sinus fractures were treated conservatively without surgical intervention.
Ranmal *et al*	2024	German weighted data from 1999–2021 analyzed risk curves to predict rib and sternum fractures in automobile frontal collisions	The analysis revealed an increased risk of rib and sternum fractures in the population over 65 years old compared to individuals aged 18–65 years. Females were at a higher risk of these injuries compared to males. Sternum fractures frequently occur in isolation.

Kuwuhara *et al*	2024	The National Automotive Sampling System/Crashworthiness Data System was used to analyze maternal history, collision characteristics, outcomes, and the scores from the Abbreviated Injury Scale (AIS).The scale scores injuries in various body segments according to severity. The score ranges from 1 to 6 points, with higher scores indicating greater severity.	The results showed comparable injury severity between pregnant and non-pregnant women concerning the outcomes of abdominal injuries. Adverse outcomes for the fetus were associated with the severity of the abdominal injury. Comparison of driver seat use versus front passenger seat use by pregnant women showed no significant difference in the rate of AIS 2+ injuries or in maternal and fetal outcomes.
Ellahi *et al*	2023	Initially, a model consisting of a human body and a car was used, with muscular function activated in the lower extremity of the human model. In a second step, a deceleration pulse with a peak of 186 m/s^2 was applied to the car to simulate a frontal collision. Based on this, joint analyses were conducted to observe the responses of the lower limbs to collision forces.	This study demonstrated that the risk of femoral injury was reduced with the useof knee pads and foot cushions; however, there was a simultaneous increase in the risk of tibial injuries. The results indicated that the maximum load on the left and right legs during impact was 1.29 and 1.22 kN, respectively. Meanwhile, the maximum moment was 28.82 and 52.17 Nm, respectively. The maximum stress in the lower extremity was 87.35 MPa, and the maximum tibia index was 0.230.
Joodaki *et al*	2020	A retrospective cohort study was conducted, analyzing 13,470 cases of adult occupants with varying BMI values involved in frontal collisions. The selected data were obtained from the US National Automotive Sampling System Crashworthiness Data System.	It was observed that occupants with obesity had a higher risk of injuries to the upper extremities (4.79% vs. 2.92%), lower extremities (8.37% vs. 3.23%), and spinal column (1.53% vs. 1.09%) compared to other occupants. Talus fractures were the most common injury among the obese population. The variation in injuries based on BMI is related to the interaction between the individual, the seatbelt, and the interior of the vehicle.
Tang *et al*	2019	The study conducted parametric simulations using validated vehicle driver compartment models, a restraint system model, and a medium-sized male crash test dummy model. The risk factors considered in the study included occupant seating posture, collision pulse, vehicle inclination angle, seat design, anchorage pretensioner, dynamic locking tongue, and shoulder belt load limiter.	The results demonstrated that the risk of occupant submersion in vehicles was reduced in newer vehicle models, with an increase in lumbar injuries, indicating a direct conflict between submersion and lumbar spine fractures. The seat structure was the most significant factor in determining lumbar spine force. The severity of the collision pulse, the time at which the peak deceleration was reached, and the vehicle's tilt angle were also crucial. An increased vehicle tilt angle led to higher force on the lumbar spine but reduced force on other body regions. The initial collision pulse was more strongly associated with lumbar spine damage than later pulses.
Jermakian *et al*	2019	The methodology used was a review of case series involving rear seat occupants wearing seatbelts who were severely	In the results, 36 patients were selected who met the AIS 3 criteria, along with 81 fatalities identified in the FARS

		injured or killed in frontal collisions. Accidents were identified using the National Automotive Sampling System Crashworthiness Data System (NASS-CDS) from 2004 to 2015 and included all eligible occupants with at least one injury rated as Abbreviated Injury Scale (AIS) 3 or higher. Fatal accidents were identified in the Fatality Analysis Reporting System (FARS) for 2014-2015, and local law enforcement jurisdictions were then contacted for complete accident records.	database. Initial observations revealed that more than half of the injured and deceased rear seat occupants exhibited greater injury severity compared to front seat occupants involved in the same collision. This study observed a discrepancy in the effectiveness of rear seat belt protection compared to that of front seatbelts. Thoracic injuries and traumatic brain injuries were the main causes of high morbidity and mortality among these victims.

IV. DISCUSSION

Injuries resulting from the mechanism of frontal collisions in automobile accidents are associated with high rates of morbidity and mortality in the adult population. The main injuries from these collisions occur due to the interaction of the victim with the automobile. Facial, aortic, and extremity injuries are the most commonly reported in frontal vehicle collisions. Trauma related to the steering wheel is directly linked to thoracic structures, such as rib fractures, sternum fractures, myocardial contusion, aortic injuries, and pulmonary injuries. The lower extremities are directly impacted by forces opposing the victim's ejection, resulting from the interaction of the pelvis and lower limbs with the vehicle's dashboard [8].

The epidemiological analysis conducted by Ranmal *et al* [9] collected weighted German data from 1999 to 2021, evaluating risk curves to predict rib and sternum fractures in frontal automobile collisions. The review revealed that elderly individuals and women have a significantly higher risk of thoracic injuries in accidents with this collision mechanism. Rib and sternum fractures were more commonly associated with the population over 65 years old compared to individuals aged 18-64 years. The data showed that women have a higher risk of sustaining more severe rib injuries and isolated sternum injuries compared to men.

Khojastepour *et al* [10] assessed the prevalence of frontal sinus injuries in 91 trauma patients treated at Rajaee Hospital in Shiraz between 2014 and 2019. The analysis revealed a higher prevalence of these injuries among victims of automobile accidents caused by frontal collision mechanisms. Frontal sinus injuries occurred frequently (74.7%) in conjunction with other facial injuries. Furthermore, combined fractures of the anterior and posterior table were more commonly observed than isolated involvement of either table.

Both Ranmal and Khojastepour [9,10] demonstrated that there is a pattern of injuries associated with facial and thoracic injuries that correlate with the mechanism involved in automobile accidents. A frontal collision promotes the projection of the individual against the vehicle's structure, significantly impacting facial and thoracic regions. The injuries are varied and exhibit a wide spectrum of severity, ranging from fatal to those with a good prognosis without the need for immediate medical intervention [8].

Ellahi *et al* [11] evaluated patterns of injuries in frontal vehicle crash tests against fixed barriers, aiming to analyze trauma patterns in biofidelic human body models. The study quantified the pressure required for structural injury occurrence. The megapascal (MPa) is a unit of pressure measurement in the International System of Units (SI) that represents force applied per unit area, equivalent to 1 million pascals (Pa). A pascal is defined as 1 newton per square meter (N/m^2). Rib fractures (5-7) were observed at stresses of 120 MPa in the left lateral vertebrosternal region. In the lower extremity, ligament ruptures were identified at 70.80 MPa, while fractures in the tibia and femur occurred at 236 MPa. Cranial stresses were limited to 11 MPa, suggesting the possibility of concussions rather than fractures. Therefore, traumatic injuries

highlight a significant relationship between the individual and the vehicle, with the main complications arising from impacts causing considerable deceleration of the vehicle-victim system [12].

Tang *et al.* [13] demonstrated through simulations that the incidence of submersion in victims of frontal collisions is reduced in newer vehicles. However, they observed a higher risk of lumbar spine fractures associated with these collisions. The findings indicated that factors reducing the risk of submersion simultaneously increased the forces affecting the victim's lumbar spine. From a biomechanical perspective, the primary mechanism of lumbar spine fracture is high-energy axial compression, with or without flexion transferred to the region [14, 15, 16, 17, 18, 19]. The vehicle's angle of inclination was identified as the most influential parameter in determining the lumbar spine injury pattern, with increased angulation raising the risk of fractures. On average, an erect posture applies less force to the lumbar spine compared to a reclined posture, resulting in a reduced risk of lumbar fractures in frontal vehicle collisions [13]

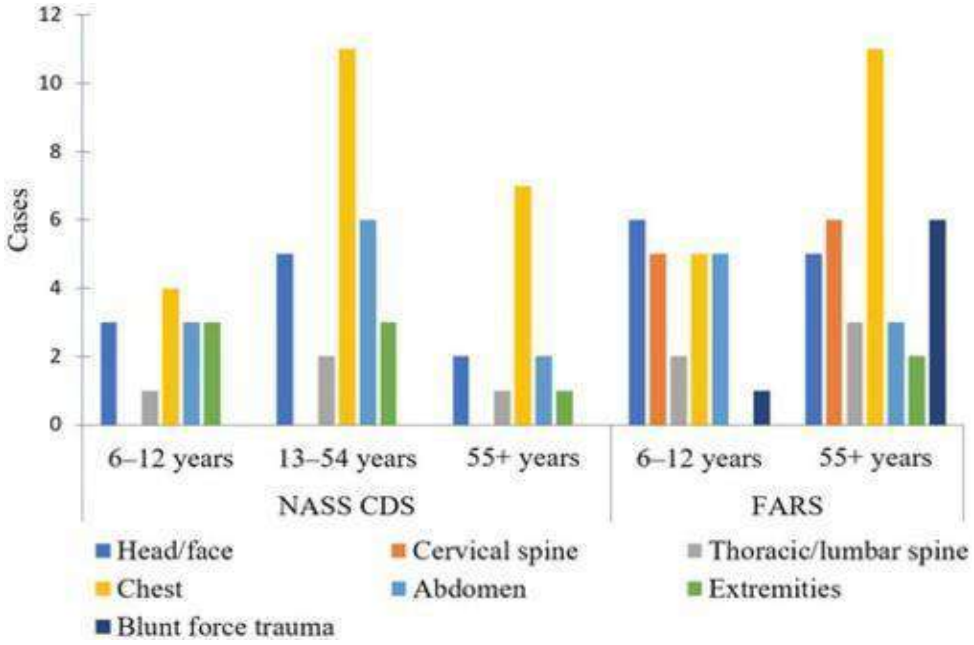
Joodaki *et al.* [20], in a retrospective cohort study, analyzed 13,470 frontal collision cases from the US National Automotive Sampling System-Crashworthiness Data System. The aim was to evaluate the influence of body mass index (BMI) on injury risks across different body regions. Results revealed an increased incidence of injuries in obese individuals compared to non-obese individuals: 4.79% versus 2.92% in the upper extremities; 8.37% versus 3.23% in the lower extremities; and 1.53% versus 1.09% in the spinal column. Among lower extremity injuries, talus fractures were the most common. These differences in injury patterns are linked to the interaction between overweight individuals, seatbelt use, and the vehicle's interior, which affect the forces during collision impacts.

Kuwahara et al. [21] observed that non-pregnant women sustained more moderate to severe injuries, with higher scores on the AIS scale, particularly in head injuries, compared to pregnant women. No evidence was found indicating an increased risk of abdominal injuries in pregnant women, regardless of abdominal protrusion or gestational week. Other non-pregnancy-related factors appeared to be more closely associated with abdominal injuries, showing similar numbers between pregnant and non-pregnant women. Regarding fetal risk, fetal harm was more closely linked to the severity of the maternal abdominal injury, with more severe cases being more detrimental to the fetus.

Additionally, changing the pregnant woman's seat position did not demonstrate any significant impact on the risk to the maternal-fetal dyad during frontal automobile collisions.

Jermakian *et al.* [22], analyzing data from the National Automotive Sampling System Crashworthiness Data System (NASS-CDS, 2004-2015) and the Fatality Analysis Reporting System (FARS, 2014-2015), demonstrated greater severity of injuries among rear-seat occupants involved in automobile crashes compared to front-seat occupants. In frontal collisions, after adjusting for variables such as occupant age, impact direction, and other factors, no increased risk of death was identified for rear-seat occupants compared to those in the front seat. However, frontal impacts were responsible for a higher proportion (34%) of fatalities among rear-seat occupants who were restrained.

The affected body regions varied according to the lethality of the event and the victims' age (Figure 1). Among survivors, thoracic injuries were the most prevalent, followed by facial and head injuries, regardless of age. In fatal cases, differences in injury patterns were observed based on age groups. For victims over 55 years old, thoracic injuries were the most common. In contrast, among children aged 6 to 12 years, head and facial injuries were more frequent [22].



Source: Jermakian et al

Figure 1: Injured body regions of vehicle occupants stratified by age and data source. FARS counts were limited to cases with documented injuries (n = 17 for ages 6–12 years and n = 20 for ages 55+ years)

Jermakian *et al.* also investigated collision and restraint factors related to injuries and deaths among rear seat occupants during frontal impacts in newer vehicle models. The primary factors responsible for injuries included seatbelt loading and impact with the vehicle's interior. In fatal cases, the most relevant factors were seatbelt loading and the severity of the collision, considered unsurvivable. Chest compression caused by the seat belt resulted in different injury patterns depending on the victim's biophysical profile and age. Children experienced a higher incidence of blunt pulmonary injuries, while adults showed a greater frequency of rib fractures, cardiac injuries, and vascular injuries (Table 2).

Table 2: Factors Associated with Injuries and Fatalities in Rear-Seat Occupants During Frontal Impacts in Newer Vehicle Models

	N	Possible Contributing Factors To Injury (Number Of Cases)
6-12 years old		
Head/face	12	Catastrophic intrusion/unsurvivable collision (6; 4 due to severe collision, 2 due to slight overlap) Non-catastrophic intrusion (1) Associated cervical injury (3) Insufficient information (2)
Chest	7	Should belt loading (4) Catastrophic intrusion/unsurvivable collision (2) Insufficient information (1)
Abdomen	5	Seat belt only, submersion (1) Loading of the neck and shoulder seat belt on dry organs (3) Insufficient information (1)
55+ years old		
Head/face	6	Seat belt only (1) Catastrophic intrusion/unsurvivable collision (1) Intrusion requiring occupant extraction (1) Associated cervical injury (1) Insufficient information (1)
Chest	11	Shoulder belt loading (7) Obesity (2) Abdominal belt only (1) Insufficient information (3)
Abdomen	3	Shoulder belt load on the liver/spleen (3) Non-catastrophic intrusion (1)

Source: Adapted from Jermakian et al, 2019

The prevalence of traumatic injuries in frontal collisions is heterogeneous and influenced by various factors, particularly the interaction between the individual and the automobile.

Among the variables related to the victims, body mass index (BMI), seating position in the vehicle, and the collision's intensity are the most significant factors described in the literature [Concerning the automobile, the restraining force of the seatbelt and the impact with the vehicle's interior represent the primary interactions during the collision event [22].

V. CONCLUSIONS

The analysis of the 8 selected articles provided relevant information regarding the patterns of trauma in victims of automobile accidents with frontal collision mechanisms, offering insight into the factors influencing the severity of injuries in these accidents.

The analyzed data demonstrate that the patterns of trauma in frontal collisions exhibit wide variability and are influenced by multiple factors related both to the individual characteristics of the victim and the characteristics of the vehicle. Variables such as BMI, position in the vehicle, and the collision's intensity have a direct relationship with the likelihood of injury occurrence and the severity of the trauma. Furthermore, vehicle-related factors, such as the restraining force of the seatbelt and impact with the interior of the vehicle, play a determining role

in the dynamics and severity of injuries, as evidenced by the studies analyzed in the literature review and compared with current medical literature [13, 20, 22]. These findings underscore the importance of addressing the biomechanics of injuries from a multidimensional perspective to better understand the complexity of trauma in collisions.

The findings also indicate differentiated patterns of injuries in children and adults, highlighting the importance of the biophysical profile during impact. These differences reflect not only physical characteristics but also the specific mechanisms of impact dynamics and individual biomechanical responses. Therefore, analyzing these patterns should be considered in prevention strategies and the development of safety devices tailored to different age groups.

Furthermore, the data suggest that the prevention of injuries in frontal collisions should involve both vehicle adaptation and awareness of individual risk factors. Strategies such as improving restraint systems, adjusting seat belt mechanisms, and advancing automobile design can significantly reduce the impact of collision-associated factors. Thus, through multidisciplinary approaches involving engineering, medicine, and public traffic policies, it is possible to implement measures that enhance occupant safety and decrease the incidence and severity of injuries resulting from automobile accidents.

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