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Computer Aided Design of Protective Gear and the Mathematical Statistics for Mechanical Mechanism from Falls

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Abstract: Increasing aging population lies great pressure on our country, and the health monitoring of the elderly arises as a very urgent problem to be solved. The elderly's body function is degraded in many aspects, and tumble, a problem elderly people most often encounter, brings unpredictable and serious injury or even leads to life risk behavior to them. In order to reduce the injury caused by falls, it is necessary to design protective devices that conform to the characteristics of the elderly. In this paper, by searching the current status and possible trend of aging population in China, we investigate the accident rate and harm caused by elderly tumble. Consider the head injury of the elderly as an example, a numerical simulation was conducted to analyze the mechanical mechanism of the head injury of the elderly falling. Combining the mechanical mechanism of the head injury, we compared several protective materials and selected the one that optimized our goal of head protection. Therefore, we designed one head-wearing buffering protective device, which is of great significance to the head injury prevention of the elderly falling.

Keywords: Population Aging; Elderly Tumble; Head Injury; Mechanical Mechanism; Design of Protective Device.

1. Introduction

In recent years, China is experiencing an increasingly serious aging of population, with which, the health and quality of life of the elderly have become the focus of increasing concern around the world. As people enter the stage of senior, their overall barycenter shifts forwards with a risk of tumble. In recent years, the incidence of fall injury is on the rise in the elderly population, and tumble has become a major factor threatening the physical and mental health of the elderly: accidental fall can lead to injury and disability, or even life threatening. Elderly tumble increases not only the economic pressure of the family, but also the social burden, so the need for protective measures to prevent falls of the elderly has become very urgent. We analyze the mechanical mechanism of the head injury in the elderly falling down, distribution characteristics of the head impact injury in the elderly falling down, and the extent of the injury site injury, and then obtains the protection needs of the elderly falling head impact protector. At the same time, combing the analysis of the elderly fall behavior, we determine the elderly fall head anti-impact protection principle. Taking flexible protection check fabric as the breakthrough point, by considering the performance and composite form of design, we first design a head buffer protection model through comparison and optimization of the head protection material. Finally, a conceptual design model of protective gear based on the characteristics and comfort of the elderly is proposed.

2. Current Situation and Future Possible Trend of Population Aging

According to the old rights protection in our country, the elderly refers to the citizens over 60 years old. The ratio of the elderly population occupied in a country is an indicator of the extent to a country's population aging. According to Population Ageing and Its Socio-economic Consequence proposed by the United Nation in 1956 which determines the classification standard, if a country or region's senior aged 65 and above accounted for more than 7% of the total population, the country or region has entered the aging society. According to the standard, China has entered the aging society since 1999. The latest data shows that the proportion of senior citizens in China was 18.7 percent in 2020 and is expected to reach 24.6 percent by 2030, 28 percent by 2040 and over 30 percent by 2050. Population ageing would become a severe challenge to China.

According to the information provided by the annual Statistical Bulletin of the National Bureau of Statistics (2006-2019), the main data Bulletin of the sixth National Population Census in 2010 (No. 1), and the results of the seventh National Population Census in 2021, we gather the data on the proportion of the population aged 60 and above from 2006 to 2021 and draw the following trend chart related to China's population ageing problem.

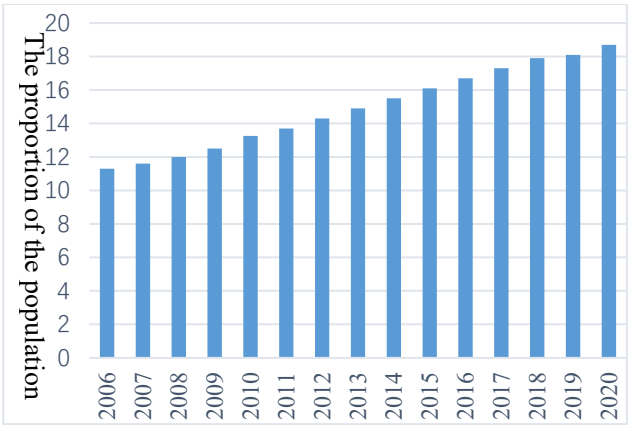

Figure 1. Development trend of Population aging in China (2006-2020)

Table 1. Statistics (2006 -2020)

year	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Senior (%)	11.30	11.60	12.00	12.50	13.26	13.70	14.30	14.90	15.50	16.10	16.70	17.30	17.90	18.10	18.70

According to the chart, the proportion of the elderly increased from 11.3% in 2006 to 18.70% in 2020, showing a continuous upward trend. However, according to the results of the seventh National census in 2021, the population aged 0-14 is 25,3383,938, accounting for 17.95%; the population aged 15-59 is 894,376,020, accounting for 63.35%; the population aged 60 and above is 26,4018,766, accounting for 18.70%, among which the population aged 65 and above is 19,0635,280, accounting for 13.50%. The general demographic data of China shows that the proportion of the population aged over 60 has surpassed that of the population aged 0-14. The elderly has become the second largest population in China, which indicates the urgency to pay more attention to the health and safety of the elderly.

3. Current Situation and Harm of Tumble

Tumble is a sudden, involuntary and unintentional change in position to fall to the ground or a lower plane than the initial position. The incidence of tumble among the elderly in urban and rural areas in China is 15%-20%, with the elderly falling once accounting for 7%, and the elderly falling twice, three times and more than four times accounting for 3.8%, 1.6% and 1.4% respectively. Injuries caused by falls include abrasions, fractures, sprains, concussions, and even life-threatening injuries. Tumble has gradually become the leading cause of injury death in the elderly. Among the elderly aged 60 and above, most of them are hospitalized with injuries which include mainly hip fractures, concussions, and upper limb injuries. Taking the 782 elderly people in a certain community in Chengdu from January to December 2017 calculated by Xie Na et al. in 2018 as an example, there were 104 cases of falls, including 68 cases of injuries, and 68 cases of injury types were analyzed here (see Table 2).

Table 2. Statistics of fall injury types in a community in Chengdu.

Injury types	Number of injured	Percentage
Bruises/abrasions	32 cases	47.06%
fracture	21 cases	30.88%
Sharps/bites/open wounds	7 cases	10.29%
Sprains/strains	4 cases	5.88%
Concussion/brain contusion	4 cases	5.88%

According to the above chart, it can be seen that bruises/abrasions are the most common injuries caused by falls in the elderly. However, although head injuries in the elderly are not the most common type of injury, they are quite harmful to the elderly. Take a concussion for example, the concussion caused by a fall will not only cause temporarily coma to the elderly but also bring about the sequelae of the concussion, such as headache, dizziness, memory impairment and psychological distress. The sequelae of concussion can last more than 3 years after injury. From this point of view, the concussion brings both physical and psychological harm. At the same time, the hazard lasts for a longer time, rather than a short-term trauma such as a bruise. Nevertheless, a concussion is only a mild brain injury, and a more serious brain contusion can cause intracranial hypertension, disturbance of consciousness, and even direct death.

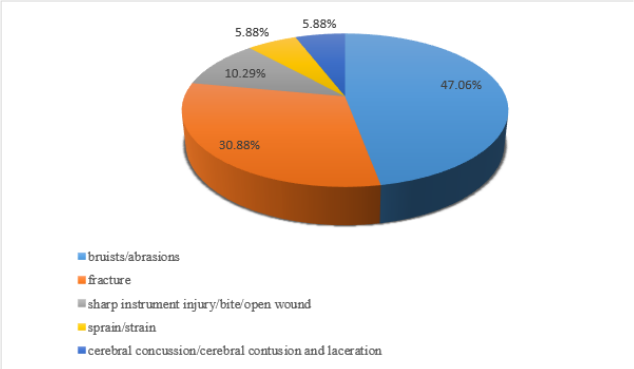

Figure 2. Distribution of fall injury types in a community in Chengdu

Falls are listed as one of the most common accidental injuries among the elderly. It is also an important factor leading to the disability of the elderly. Due to being in bed for a long time after a fall, complications such as pressure sores, pulmonary embolism and infection can be induced. At the same time, it will affect the mental health of the elderly. Falls not only endanger the physical and mental health of the elderly and reduce their quality of life, but also bring a heavy burden to the family and society. As the population ages, the base of the elderly will gradually rise. If no preventive measures are taken, the number of elderly people who fall will also increase, followed by various injuries, many of which are serious injuries such as brain injuries. Therefore, head injuries caused by falls in the elderly should arouse the attention of all sectors of society. In order to prevent the elderly from falling and ensure the high quality of life of the elderly, it is necessary to design a wearable protective gear that can protect the head of the elderly.

4. Mechanical Mechanism of Head Injury Caused by Fall of the Elderly

Impulse is an integral process reflecting the force on the object against time, which has been used to quantify the force on the body part and the process of energy conversion. The damage caused by falling and impact on the body is resulted from the mechanical action of each stress position and its contact surface. Harm brought by the strike of the tumble results from the mechanical mechanism occurred between different stress-bearing parts and the ground. We analysis the mechanical mechanism of head injury in the elderly falling through numerical simulation of the variation of acceleration, stress and strain in the process of head impact.

Calculation condition setting: the head is geometrically simplified as an elliptical ring, which represents the skull; the density of the bone was set as 1.04g/cm3, the elastic modulus was set as 500kg/mm2, and the initial speed was 4m/s.

Boundary conditions: hard contact boundary is set at the bottom of the whole model. A particle spring system was used to analyze the dynamic damage process of head impact.

Firstly, the strain (Figure 3) and stress (Figure 4) of the elderly falling and hitting their heads without wearing protective gear were analyzed. At the moment when the head makes contact with the ground, the point where the head makes contact with the ground bears the greatest strain. At the time, there is strain only on the local contact point. Then, over time, the strain and stress are transmitted to the whole skull in about 1ms.

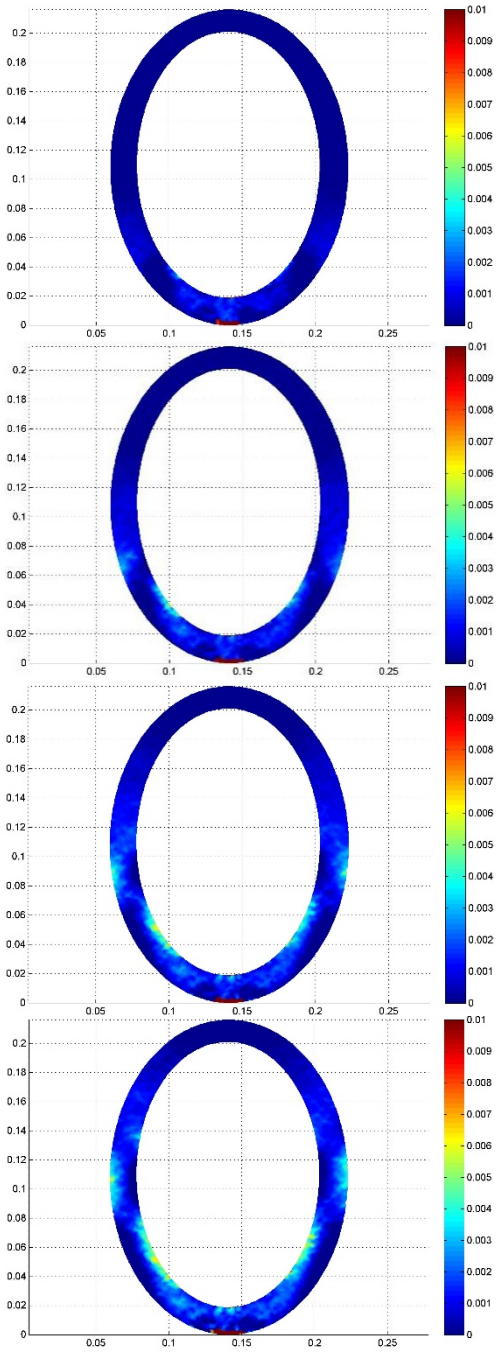

Figure 3. Strain change process of head impacting skull

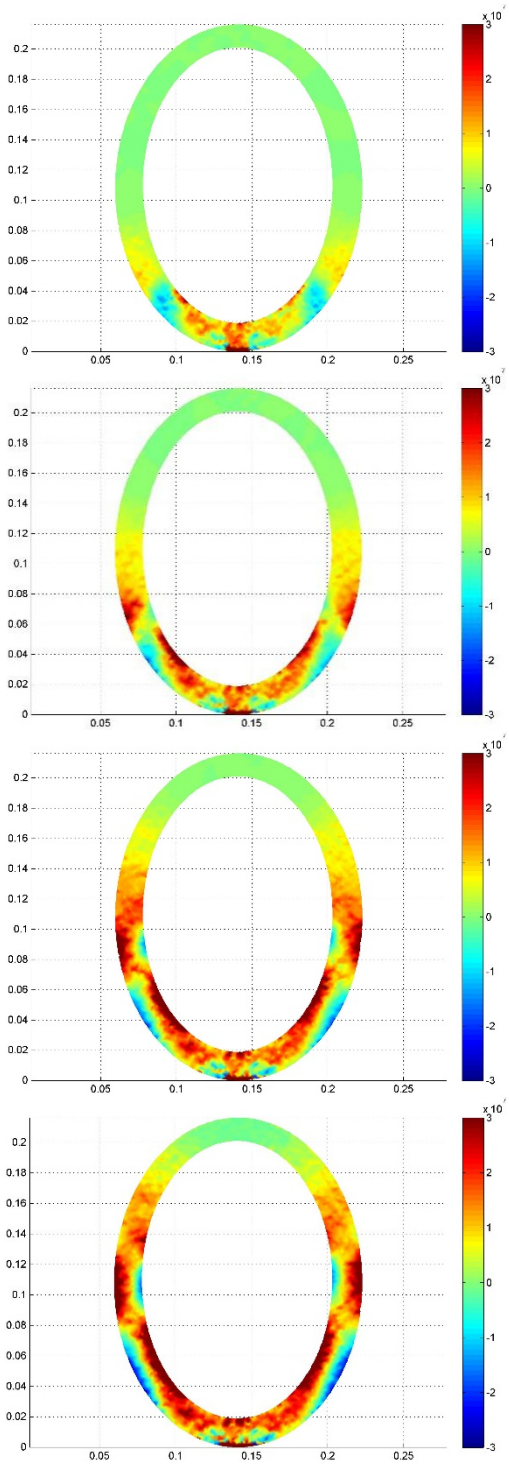

Figure 4. Stress change process of head impacting skull

The biggest damage was in the area where the head made contact with the ground, and the other damage could be divided into direct impact damage and secondary damage to the head near the contact point caused by vibration. Direct injury mainly occurred in the lateral, secondary injury both lateral and medial, and the medial injury may cause damage to the internal cranial tissue.

5. Material Design of Anti-fall Head Protector for the Elderly

Combined with the mechanical mechanism of head injury caused by falls in the elderly, a protective cap was designed to numerically analyze the strain and stress change process of head hitting the skull when wearing the protective cap. The

results showed that wearing protective gear can play a good role in protecting the head of the elderly.

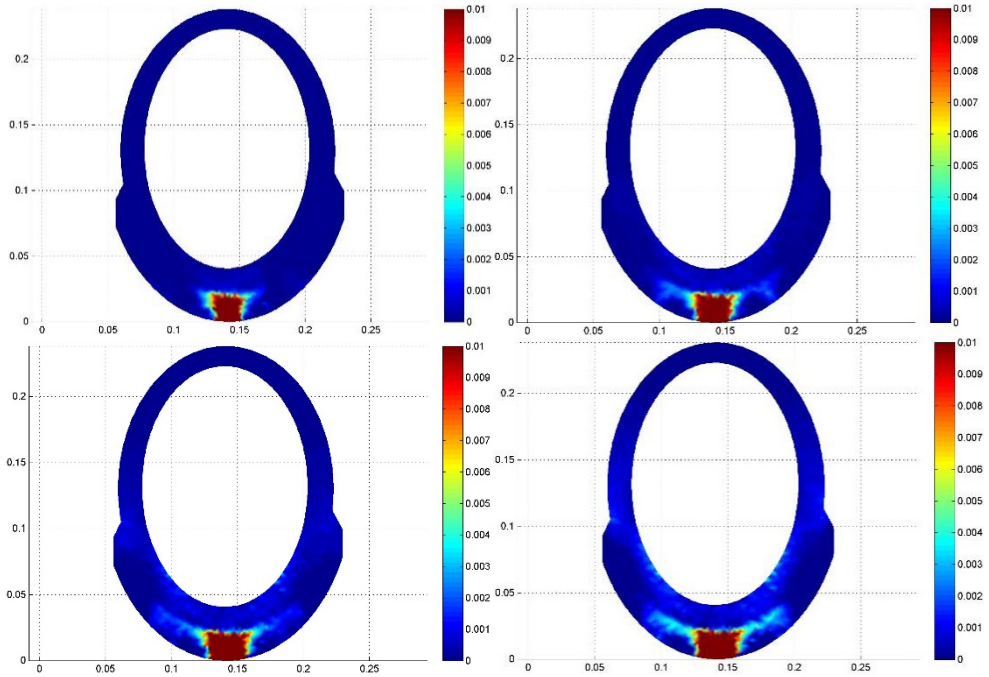

Figure 5. Strain change process of head impact on the skull with protective gear

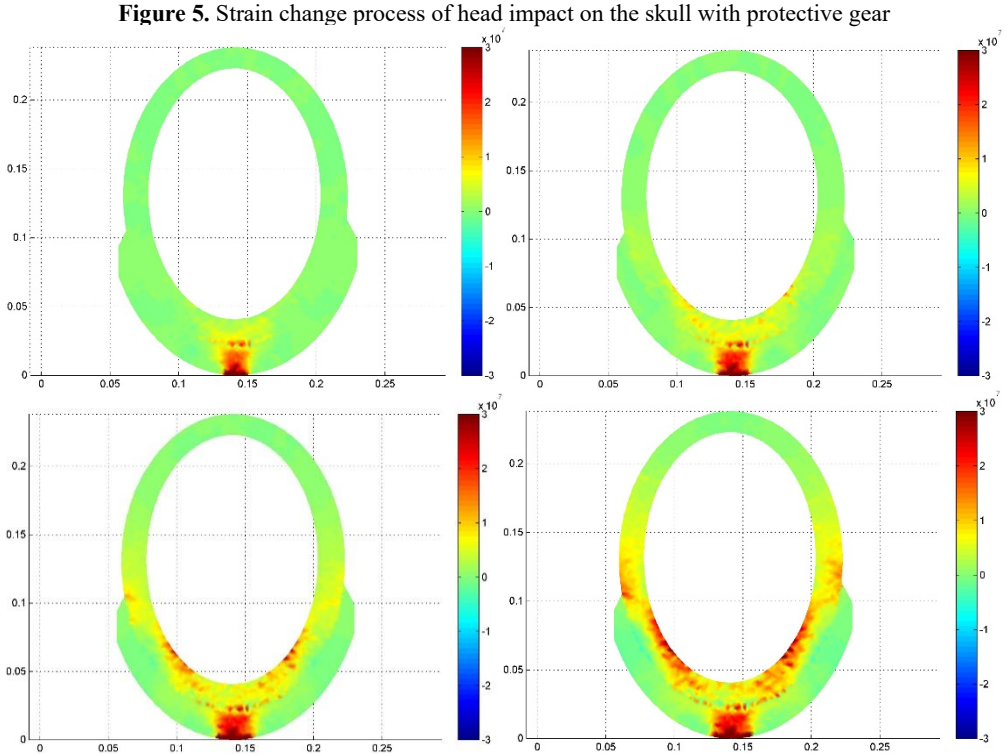

Figure 6. Stress change process of head impact on the skull of wearing protector

The process of head injury caused by the fall of the elderly wearing protective gear was analyzed. When the protective gear touched the ground, the deformation of the whole system mainly occurred inside the protective gear (FIG. 4). In comparison, the partial deformation of the head in contact with the protective gear was very small. The analysis results of stress showed that the maximum stress was concentrated in the inside of the protective gear, and internal forces were also caused by vibration of the head at and near the contact point (FIG. 5). Compared with FIG. 3, the size and scope of internal forces were far smaller than those without protective gear. Protective devices can effectively protect the elderly from head injuries caused by falls.

Summarizing from research of protective materials, we find that there are two main potential materials that encounter our need of effective protection: gutta-percha material and three-dimensional fabric composite material. Both materials have significant advantages as well as significant disadvantages. When the gutta-percha material was added with thermal expansion physical microspheres and sulfur, the human body's pain sensation decreased to nearly 400% in the face of impact from less than 9 square meters, demonstrating excellent protection ability against high-speed impact. However, for materials similar to rubber, there is a great defect in this kind of material which is its poor air permeability. Obviously, as a protective device, comfort level is also a very important factor to be considered.

For three-dimensional fabric composite material, three-dimensional elastic woven fabric is a kind of three-

dimensional structure of textile products, through the change of the organization between layers, resulting in the high elastic recovery performance of the whole fabric, so that the fabric has good compressive elasticity. It can also provide the overall weaving of fixed and protective role of ankle, knee, elbow, wrist, according to the shape of joints and limbs. The unique three-dimensional structure of three-dimensional knitted spacer fabrics has the advantage of preventing moisture and heat from touching the skin, creating a good microclimate around the body. Using its structural characteristics, a new three-dimensional sports protector can be designed and woven, which is close to the skin layer, i.e., the surface layer is water-repellent, the middle layer is used for moisture and air circulation, and the outermost layer is water-absorbent, which can efficiently absorb heat and dissipate heat. Therefore, three-dimensional fabric is chosen as the material of protective cap type fall protection.

6. Conclusion

(1) The statistical results show that the aging of China's population as a whole is on the rise, the elderly health monitoring is an important aspect to ensure the quality of life of the elderly.

(2) Stumble is one of the most common accidental injuries in the elderly, and also an important factor leading to disability in the elderly. The head injury caused by falling in the elderly should be concerned by the society.

(3) The choice of comfortable three-dimensional fabric material and the aesthetic design of protective cap type head protector can effectively avoid the head injury of the elderly tumble.

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