A Parameter Study on the Knee Injuries in Car-pedestrian impacts

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Abstract: In the accidents of car-pedestrian impact, the injury of the knee of the pedestrian is a common kind of injuries. In this paper, a car-pedestrian impact simulation model has been developed. By changing the structure parameters of the front of the car, and analyzing its effect to the injury of the knee, the superior intervals of the structure parameters that cause minor injuries to the knee of the pedestrian have been researched. Then based on the superior intervals, optimize combinational analyses have been carried out. The car-front structures that cause minor injuries to the knee of pedestrian have been proposed.

Keywords: Car-pedestrian impact, Knee injury, Computer simulation

1. Introduction

In all the traffic accidents，pedestrian is most vulnerable and have no protection. In 2003，Fatalities related to pedestrian accidents account for 10% [1]of total traffic accidents in American; In some European countries and Japan, pedestrian account for 30% [1] of fatalities. In China, the number of pedestrian injured in the traffic accidents is 55104、75137、76779、68040 in 2000、2001、2002 and 2003, which accounts for 13.16%、13.75%、13.66%、13.8% respectively [2]. In non-fatal car-pedestrian accidents, lower extremities account for around 40% of the most commonly injured body parts [3]. These injuries will lead to long term or permanent disability, which will bring much inconvenience to the victims’ lives. So, making a study of how to reduce the damage to the pedestrian’s legs and knee joints during car-pedestrian impact will have great significance in reducing the loss and pain of the victims.

2. Method

By changing the main structure parameters of the front of the car, such as the height of bumper，the distance between bumper and bonnet leading edge (BLE), the vertical width of bumper(distance between the upper and lower plane), the height between BLE and the ground, this paper analyzes the injuries of knee joints of pedestrian influenced by the front structure of the car in detail. During the research, single parameter is discussed first, which means changing one parameter at a time, finding the superior intervals of the structure parameters that cause minor injuries to the knee of the pedestrian. Then based on the superior intervals, combinational analyses have been carried out, the car-front structures that cause minor injuries to the knee of pedestrian have been proposed, which can instruct the design and development of the car.

3. Simulation of Car-Pedestrian Impacts

3.1 Establishment of car model

Figure 1 shows the car model. The model refers to the size of a mass-produced European car. The major parameters list as below: the height between the center of the bumper and ground is 395mm, the distance between bumper leading edge and BLE is 20mm, the vertical width of bumper is 180mm, the height between BLE and ground is 608mm. It is composed of eight ellipsoids and three planes that represent windscreen, hood, lead of the hood, bumper, two tires, and floor respectively. The ellipsoids that may contact with pedestrian have been defined the contact characteristics, and the data come from actual experiments [4].

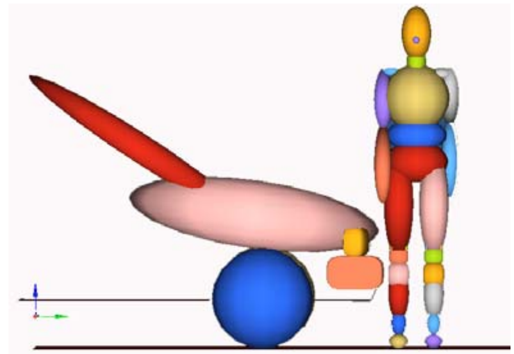
Figure1 car-pedestrian multi-body model

3.2 Establishment of pedestrian model

This paper applies multi-body pedestrian model developed by Yang et. Al[5] .the model is a 50-percentile male model, 1.75m high and weighs 78kg. In the multi-body model of knee joint, femoral head is simulated by two ellipsoids, tibial head is simulated by four planes, ligaments and collagenous tissue between femur and tibia are simulated by six spring-dampers that represent the anterior cruciate ligament (ACL), the posterior cruciate ligament (PCL), the medial collateral ligament (MCL), the lateral collateral ligament (LCL), the middle collagenous tissue and the lateral collagenous tissue. The sizes and function characteristics of these ellipsoids, planes and spring-damper elements adopt the data related to actual body that are measured from biomechanical experiments. So it may qualitatively analyze the under stress condition of the knee joints.

3.3 Establishment of car-pedestrian model

Generally, the collision position is at the front of the car, and the pedestrian is crossing the road. So the pedestrian is in travel posture in the simulation model, two legs appropriately apart, left leg forwards and right leg backwards, the car collides the pedestrian from the right side of the pedestrian. According to a research report of National Highway Traffic Safety Administration, 76.2% of the car's speed in car-pedestrian collision is below 45km/h [6]. Therefore, the speed in the simulation is 40km/h. Figure 1 shows the car-pedestrian simulation model.

4. Analyses of the Simulation Results

The injury parameters calculated from the pedestrian knee joints model include displacement of knee joint, stress and elongation of ligaments. Some experiments related to biomechanics show that condyle or ligament of knee joint may get AIS3 injury (serious injury) or above when the displacement of knee joint exceeds 6mm, or when the elongation of ligament exceeds 0.2 [5].

4.1 Influence of the Height of Bumper

Based on the primary car model, this paper analyzes the injury extent of knee joints in terms of changing the height of bumper. Table 1 shows some results of the simulations.

In order to analyze pedestrian injuries influenced by the height of bumper relatively accurately, and to find the height intervals that cause minor injuries to the knee, this paper analyzes with figure that horizontal ordinate stands for the changing of the height of bumper; vertical coordinate stands for injury parameters. Figure 2 and 3 show the changing trends of parameters along with the changing of the bumper of height.

Table1 Pedestrian injuries influenced by the height of bumper

Height	Displacement	Elongation of ligaments of left knee				Elongation of ligaments of right knee			
(mm)	(mm)	ACL	PCL	MCL	LCL	ACL	PCL	MCL	LCL
100	41	0.459	0.088	-0.16	0.575	0.533	0.638	1.096	-0.29
50	26	0.117	0.094	-0.11	0.362	0.176	0.495	0.747	-0.24
0	10	0.13	0.102	-0.14	0.398	0.129	0.142	0.357	-0.18
-50	9	0.105	0.057	-0.14	0.327	0.115	0.129	0.315	-0.13
-100	8	0.077	-0.02	-0.11	0.192	0.123	0.107	0.318	-0.13

When the bumper gets higher, condyle displacement of knee joint increases and elongation of ligaments also increase. By the decreasing of the height of bumper, especially when the height of bumper is at least 50mm lower than the primary model, the injury parameters of knee joints decrease obviously. So it is suitable when the height between the center of bumper and ground is lower than 345mm.

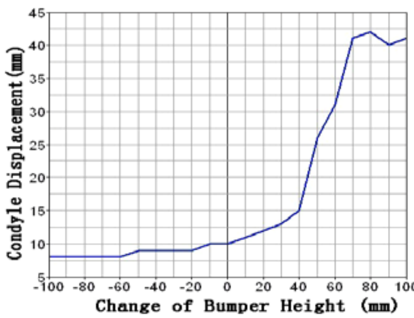

Fig. 2 Condyle displacement influenced by the height of bumper

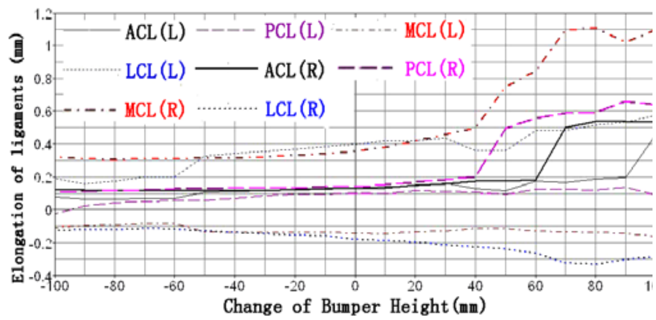

Fig.3 Elongation of ligaments influenced by the height of bumper

4.2 Influence of the distance between bumper leading edge and BLE

Figure4 and 5 show the simulation results by the changing of the distance between bumper leading edge and BLE: when the distance increases, positive displacement (the direction of displacement that head of femur relatives to head of tibia is at the car moving direction) and elongation of ligaments decrease obviously, while negative displacement increases a little. When the distance is at least 40mm forwards than the primary model, the injuries are minor, namely it is better when the distance between bumper leading edge and BLE is larger than 60mm.

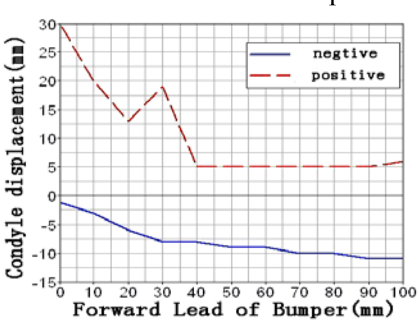

Fig. 4 Condyle displacement influenced by forward lead of bumper

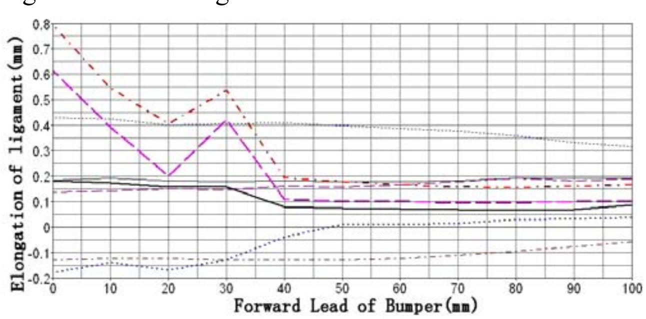

Fig.5 Elongation of ligaments influenced by forward lead of bumper

4.3 Influence of the width of bumper

Figure6 and 7 show the injuries of knee joints influenced by the width of bumper. When the bumper gets wider, condyle displacement of knee joint decreases obviously. When the width increases more than 60mm, condyle displacement is minor; elongations of ligaments of knee joints, such as right PCL, MCL, decrease obviously, while elongation of other ligaments change just a little. So the width of bumper is better larger than 240mm.

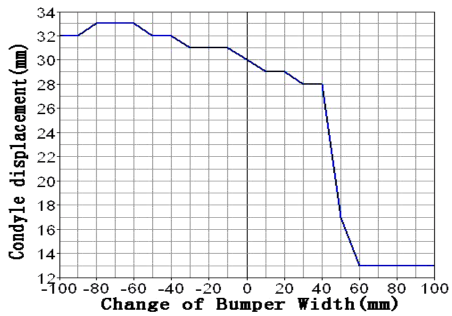

Fig. 6 Condyle displacement influenced by the change of the width of bumper

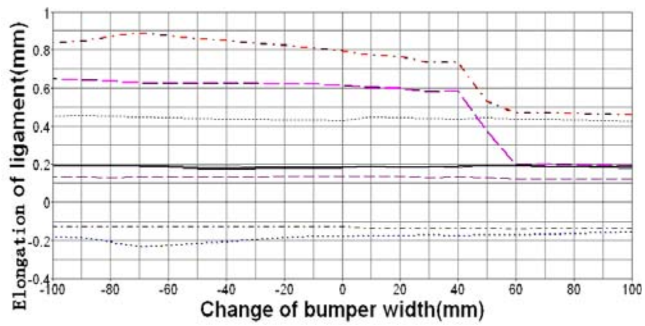

Fig.7 Elongation of ligaments influenced by the change of the width of bumper

4.4 Influence of the height of BLE

Figure 8, 9 show the influence of the height of BLE. By the decreasing of the height, condyle displacement and elongation of ligaments decrease obviously, when the decrease of height is more than 90mm, condyle displacement is less than 5mm. Therefore, as long as it satisfies assembly requirements, it is better to decrease the height of BLE as much as possible, and lower than 530mm is the best.

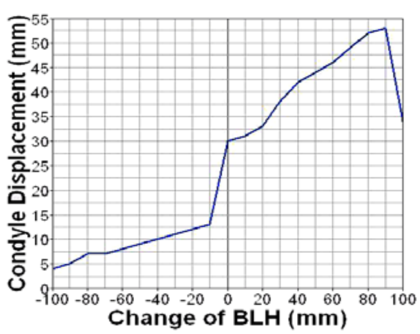

Fig. 8 Condyle displacement influenced by the height of BLE (BLH)

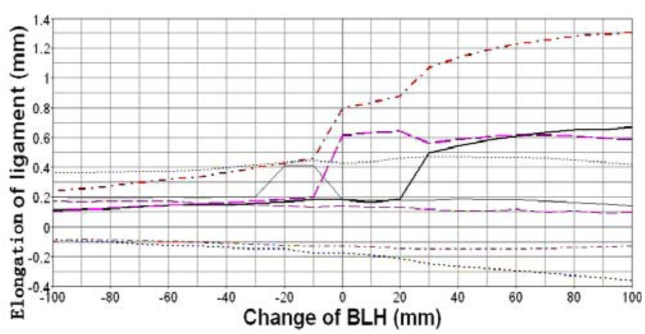

Fig.9 Elongation of ligaments influenced by the change of BLH

4.5 Combinational Analyses

Based on the analyses above, this part analyzes the parameters of the shape of bumper in combination with position. As Table 2 shows: H1 and H2 stand for the height of bumper that lowers 50mm and 80mm separately; W1 and W2 stand for the width of bumper that increases 60mm and 100mm separately; F1 and F2 stand for the bumper 40mm and 80mm forward separately. As the simulation results show in Table 3, positive displacement of knee joints decrease to less than 6mm, but negative displacement increases slightly; elongation of ligaments decrease obviously compared with primary model, furthermore, elongation of ligament of LCL of left knee, MCL of right knee decreases to less than 0.2. Thus it can be seen that the car-front structures in combination analyses can decrease injuries to the knee joints obviously. The height of bumper and the distance between bumper and BLE have great influence on injures of knee joints. Properly decreasing the height of bumper and increasing the distance between bumper and BLE are good for the safety of knee joints of pedestrian.

Table 3 Knee injuries parameters influenced by car front structures

Number	Displacement (mm)		Elongation of ligaments of left knee				Elongation of ligaments of right knee			
	Negative	Positive	ACL	PCL	MCL	LCL	ACL	PCL	MCL	LCL
A	-8	4	0.12	0.11	-0.12	0.308	0.056	0.079	0.14	0.033
B	-8	4	0.114	0.1	-0.12	0.29	0.054	0.077	0.137	0.029
C	-10	4	0.128	0.128	-0.04	0.19	0.076	0.065	0.121	0.069
D	-10	3	0.125	0.125	-0.04	0.186	0.069	0.063	0.12	0.07
E	-8	5	0.097	0.086	-0.07	0.181	0.058	0.073	0.139	0.027
F	-8	5	0.099	0.088	-0.07	0.183	0.053	0.074	0.138	0.034
G	-10	5	0.11	0.11	-0.05	0.159	0.045	0.058	0.123	0.07
H	-9	5	0.11	0.11	-0.05	0.16	0.062	0.06	0.124	0.07
Primary	-2.1	10	0.13	0.102	-0.14	0.398	0.129	0.142	0.357	-0.18

Based on the combinational analyses of the shape and position of bumper, this analysis selects the parameters of E group and simulates according to the changing of BLH again. As the simulation results show, absolute value of elongation of all the ligaments are lower than 0.2, but these have just little difference compared with the results of E group; positive condyle displacement decreases a little, while negative almost keeps still. Therefore, when BLH is lower than 600mm, the decreasing of the height has minor influence to the elongation of ligaments, but it can decrease positive condyle displacement a little.

Table 2 Combinational table

Number	Height	Width	Forward
A	H1	W1	F1
B	H1	W2	F1
C	H1	W1	F2
D	H1	W2	F2
E	H2	W1	F1
F	H2	W2	F1
G	H2	W1	F2
H	H2	W2	F2

5. Conclusion

Figure 10 depicts the results of parameters. A car model causing minor injuries to the knee joints should have car-front structure as below: the height of bumper is lower than 345mm，the distance between bumper and bonnet leading edge (BLE) is wider than 60mm, the width of bumper is larger than 240mm, the distance between BLE and ground is lower than 600mm. As the analyses indicate, the

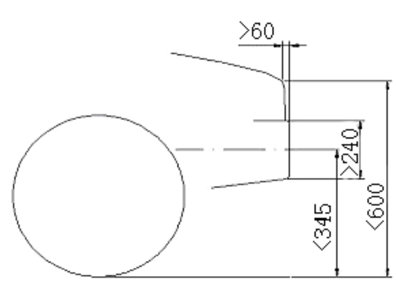

Fig.10 Superior intervals of parameters of car- front structure

protection of knee joints sometimes may at the cost of the fracture of tibia. Too low height of bumper and BLE may influence the assembly and performance of the car, so the research results above have certain limitations in practical application. In conclusion, the design of car-pedestrian safety should consider the specific design requirements and seek for the best combination.

6. References

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