Factors related to road system organisation and its association with mortality due to motor vehicle-pedestrian collisions in Guadalajara Metropolitan Area

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ABSTRACT

Introduction Traffic events are one of the five leading causes of mortality in Mexico. Pedestrians are one of the main road users involved in such incidents and have the highest mortality rate, which is regularly analysed in relation to vehicles and pedestrians, but not the built environment. The purpose of this study was to analyse the elements of the road system organisation that influences the mortality rate of pedestrians hit by motor vehicles in the Guadalajara Metropolitan Area.

Method We designed a case and control study in which the cases were sites where a pedestrian died during 2012. The controls were sites close to where the death occurred, as well as those with road infrastructure characteristics similar to those where the events took place. We obtained the pedestrian data from the death certificates and assessed some of the environmental elements of the road sites. A logistic regression analysis was used to estimate OR; 95% CI.

Results Road system factors related with pedestrian mortality in close locations were: the presence of bus stops on intersections in one street or both, and road system features, such as the presence of traffic islands, vehicle flow and pedestrian flow.

Conclusions According to the urban network theory and multiple theory, the final elements resulted as risk factors due to a fault in connectivity between the nodes. A temporal analysis of urban features will help urban planners make decisions regarding the safety of pedestrians and other road users.

BACKGROUND

Studies on transit events in which pedestrians are injured by a motor vehicle have generally focused on features surrounding the pedestrian, motor vehicle and driver involved. Thus, the environment, and the road infrastructure in particular, are two of the least studied aspects.

In Mexico, 16 179 deaths by transit events were registered in 2016. This placed transit events as one of the five leading causes of death nationwide.[1] In the last decade, the state of Jalisco has been placed as one of the three states with the highest mortality rate. Specifically, Guadalajara Metropolitan Area (GMA) accounted for the 58% of the state deaths.[2 3]

This work is based on three theories that help explain the built environment. The first of these theories is the urban network theory,[4 5] which explains the complex organisation of space by assessing structural elements and their functions through interfering elements, nodes, connections and hierarchies.[6–8] Second, graph theory and probability establish the necessary means to measure road systems. Next, the functionality of these systems is analysed through the complex network theory; specifically, this part of the analysis focuses on the sites where motor vehicle-pedestrian collisions have taken place and caused fatalities.[8]

Similar studies had been conducted in countries such as Canada, the USA, New Zealand and the UK, among others. However, the road system of any of these countries differs from GMA; hence, the interest of this study is to analyse the elements of road systems that impact mortality due to motor vehicle-pedestrian collisions in GMA.

MATERIALS AND METHODS

A case–control study was conducted in which the cases were intersections with registered fatalities due to motor vehicle-pedestrian collisions, with the event occurring between 1 January and 31 December 2012. Controls were those intersections of GMA without fatalities due to motor vehicle-pedestrian collisions during 2012.

We calculated the sample size based on the pedestrian risk of dying when crossing a road without using the pedestrian bridge, estimated as OR >5.0, a proportion of 5.56% of controls with exposition and of 25.00% in cases with exposition, with a confidence level of 95%, a power of 80.00% and a rate of control by case of 1:1. We obtained a minimum sample of 63 cases and 63 controls.

The inclusion criteria for the study cases were intersections where pedestrians from 18 to 65 years old died due to collisions involving a motor vehicle, and where the event occurred between 06:00 and 23:00 day hours during 2012. Elimination criteria were incomplete case information, cyclists, motorcyclists or other non-pedestrian subjects involved and a modified road infrastructure after the event. The latter was established because, over the last 5 years in GMA, there have been a number of

Table 1 Description of records excluded from FOMESE

	n (%)
Event mechanics*	13 (5.44)
Other cause of death or non-pedestrian subject involved	
Strangled	1 (0.42)
Died under beating	1 (0.42)
Cyclist	11 (4.60)
MVC	23 (9.62)
Roll-over	17 (7.11)
Motorcyclist	7 (2.93)
Outside of GMA	30 (12.55)
Out of age range	73 (30.54)
Out of established schedule	23 (9.62)
Insufficient data†	39 (16.32)
Lost record	1 (0.42)
Total	239 (100.0)

*Refers to event kinematics in which the subject was ejected from the vehicle and was hit by a car.
†Insufficient data were the location, date and age.
FOMESE, Forensic Medical Service; GMA, Guadalajara Metropolitan Area.

modifications in the road system organisation; specifically, a new urban rail line and some road changes for cycling transportation inclusion, among other public works in the municipalities of GMA (Guadalajara, Zapopan, Tlaquepaque, Tonalá, Tlajomulco de Zuñiga, El Salto, Juanacatlán, Ixtlahuacán de los Membrillos).

It is worth mentioning that we created the schedule for the study based on the measurements of road sites, which were made at the same time that the event occurred and could also affect the researchers' personal safety in certain areas of GMA.

The measurements taken at the control locations were done at the same day and hour of the week in which the event took place. We did this in accordance with the registered data on the death certificate, with the goal of ensuring that the conditions of the road infrastructure and environmental interactions (ie, the same number of pedestrian flow or street vending stands) were similar to those present at the time of the transit events.

We obtained the data concerning the pedestrian mortality rate in GMA from the Forensic Medical Service (FOMESE). We also obtained the records of deaths caused by transit events with pedestrians involved, and these were verified to include the following information: age and sex of the pedestrian; collision location (street, intersection, neighbourhood and municipality, to obtain the geographical information); and date and time of the event. To confirm the reliability of the reported information, the intersection, neighbourhood and municipality were checked to match the map, and once the location was confirmed, the minimum mapping unit (MMU) was obtained using a digital map of Mexico, version 5.0

We used the spatial analysis theory[9 10] to select the control locations in the study based on the supposition that the proximity to the event location would ensure that the site characteristics were similar. In contrast to distant control locations, assuming that the characteristics would be different from those at the event site. Thus, the controls were selected randomly from intersections where no pedestrian deaths by motor vehicle collision had occurred with roads of the same hierarchy of the case, this characteristic was used as match criteria. In this study, we used a ratio 1:1 case–control based on this theory, one control near to the case and other control with the same street hierarchy but in a different location that could be far away from the case site. For this reason, the statistical analysis was done separated, case-near control and case-far control.

Table 2 Characteristics of transit events with pedestrians involved in GMA, 2012

Event distribution by municipality	n (%)
El Salto	0 (0.0)
Guadalajara	26 (36.0)
Tlajomulco de Zuñiga	0 (0.0)
Tlaquepaque	17 (24.0)
Tonalá	10 (14.0)
Zapopan	19 (26.0)
Zapotlanejo	0 (0.0)
Sex of the pedestrian deceased	
Male	61 (84.72)
Female	11 (18.28)
Age group (years)	
<20	3 (4.0)
20–29	14 (19.0)
30–39	20 (28.0)
40–49	16 (22.0)
50–59	15 (21.0)
60–65	4 (6.0)
Time-lapse of the event (hours)	
6:00–11:59	17 (23.61)
12:00–17:59	19 (26.39)
18:00–23:00	36 (50.00)
Weekday of the event	
Sunday	11 (15.28)
Monday	9 (12.50)
Tuesday	14 (19.44)
Wednesday	12 (16.67)
Thursday	13 (18.06)
Friday	7 (9.72)
Saturday	6 (8.33)
Span of months	
January to April	19 (26.39)
May to August	35 (48.61)
September to December	18 (25.00)
Site of the public road	
Road intersection	71 (98.0)
Street narrowness	1 (2.0)
Total	72 (100.0)

GMA, Guadalajara Metropolitan Area.

From the FOMESE data, we examined a total of 338 records of dead pedestrians during 2012, of these 239 were removed for presenting any of the exclusion criteria previously established (table 1). Later, from the 99 remaining records, 18 were excluded because the exact location could not be extracted from the data described. At the end of the selection process, 72 records were classified as cases.

For controls definition, random intersections were selected in which no pedestrian deaths occurred due to motor vehicle collisions that had connecting roads of the same case hierarchy. Control selection for cases was made choosing two intersections: one with the same MMU where the event occurred and the other from an MMU chosen at random using a random numbers table. Initially, the study showed that there were important environmental differences between those cases in which the death occurred on the ring road in comparison to the selected controls

Table 3 Other features of road intersection

Variable	Case location		Control location (nearby)		Mean difference	P value	Control location (distant)		Mean difference	P value
	μ	DE	μ	DE			μ	DE		
Traffic flow	299.31	241.79	123.82	194.72	175.49 (103.17, 247.81)	<0.001	98.12	107.20	201.19 (139.33, 263.05)	<0.001
Pedestrian flow	18.65	15.15	9.04	7.21	9.61 (5.70, 13.52)	<0.001	11	8.52	7.65 (3.59, 11.71)	<0.001
Parked cars	11.39	10.97	12.28	10.79	−0 to 89 (−4.47, 2.69)	<0.001	12.76	12.28	−1.37 (−5.21, 2.47)	>0.05
Sidewalk width	3.15	2.46	2.03	1.47	1.12 (0.45, 1.79)	>0.05	2.27	1.86	0.88 (0.16, 1.60)	<0.01
Road width	26.08	17.32	16.74	10.67	9.34 (4.59, 14.09)	<0.05	16.54	8.81	9.54 (5.00, 14.08)	<0.001
Traffic island width	2.12	4.00	0.49	1.67	1.63 (0.62, 2.64)	<0.01	1.06	2.68	1.06 (−0.06, 2.18)	>0.05

μ denotes mean; DE denotes standard desviation.

with the aforementioned process. To avoid this selection bias, we modified the selection process for controls for all pedestrian fatalities that took place on the ring road by considering differing features such as width, vehicle flow, road signs and speed limit.

First, of the 1670 MMUs from GMA, we identified 71 that constitute the ring road. From these, an MMU was selected for controls. Next, the intersections from the MMU were enumerated, starting from the upper left corner and continuing unto the right side. After that, we selected the intersection using the random numbers table and picked two controls.

Of the remaining 1599 MMUs, controls were taken for those cases that occurred anywhere else, excluding the ring road. On these, it was possible to choose a control from the same MMU where the case occurred, and the other from a randomly chosen MMU. Afterward, the control intersections from both MMUs were enumerated from west to east and north to south to randomly select the intersection for the study.

The road system features analysed were: road geometric design, signage, infrastructure (bus stops, traffic lights, speed reducers) and the pedestrian subsystem (pedestrian crossing, pedestrian bridge and sidewalks). We considered traffic and pedestrian flow as intervening factors. They were calculated by number of vehicles or pedestrians transit on the intersection in any direction in 5 min.

The statistical analysis was carried out in three stages: (1) means, SD, frequencies and percentages were obtained; and (2) a bivariate analysis was made to obtain OR with 95% CIs. In cases that were not feasible to obtain an OR, we would calculate a Fisher's exact test with a statistical significance of $p \leq 0.05$. The logistic regression was made considering all variables with p value <0.25 during the bivariate analysis. The model was done as saturated model and each variable was evaluated with partial *F* test to analyse its contribution to the model, if p value was >0.05, the variables were eliminated from the model. Finally, the selected variables for the model were those with $p \leq 0.05$. In this model, we did not find any interaction. This analysis was made using IBM SPSS (V.20.0.0).

RESULTS

Pedestrian fatalities occurred mainly in the Guadalajara (36.0%) and Zapopan (26.0%) municipalities. Most of them took place between 18:00 and 23:00 hours (48.61%), from Tuesday to Thursday (54.17%), between May and August (48.61%) and located at an intersection (98.0%). Dead pedestrians were mostly men on a 5.5:1 ratio and older than 30 years (76.0%) (table 2).

When comparing the road features where collisions took place with other locations in the same MMU, it was found that the traffic flow ($p \leq 0.001$), pedestrian flow ($p \leq 0.001$), number of parked cars ($p \leq 0.001$), road width ($p \leq 0.05$) and island width ($p \leq 0.01$) were statistically significant. In general, higher numbers were obtained on locations with dead pedestrians. Also, locations with different MMU were in similar conditions, excepting the number of parked cars and road width (table 3).

In the adjusted analysis, road features associated with pedestrian mortality on locations near to the case location were bus stops on both streets (adjusted OR (aOR) 6.80, 95% CI 2.00 to 23.07) or on one street (aOR 9.18, 95% CI 3.54 to 23.84), the presence of a pedestrian island (aOR 4.45, 95% CI 1.85 to 10.74), a sidewalk wider than 3 m (aOR 3.24, 95% CI 1.35 to 7.76), traffic flow ≥260, vehicles (aOR 15.35, 95% CI 1.84 to 127.9) and pedestrian flow ≥14 subjects (aOR 5.22, 95% CI 2.09 to 13.07) (table 4).

On the locations outside of the MMU with a road system similar to that of the case, a risk of fatality was found on bus stops that were on both streets (aOR 6.5, 95% CI 1.81 to 23.36), on one street (aOR 2.56, 95% CI 1.61 to 5.68), the existence of a pedestrian island (aOR 2.93, 95% CI 1.33 to 6.46) and traffic flow ≥260 vehicles (aOR 3.72, 95% CI 1.06 to 13.09). Additionally, we also found some risk-diminishing features of the road system: a vertical stop sign (aOR 0.19, 95% CI 0.06 to 0.63), crosswalks on both streets (aOR 0.19, 95% CI 0.08 to 0.49) or in one street (aOR 0.28, 95% CI 0.10 to 0.76) (table 5).

DISCUSSION

According to the urban network theory and multiple connectivity theory, the last elements resulted as a risk factor due to a fault in connectivity between nodes. This could be explained because pedestrians tend to walk in a straight line towards their destination, therefore, the bus stop locations concerning businesses, schools, and alike have an influence on the expected behaviour of the pedestrians at the time of crossing the street and, as a consequence, the likelihood of death after a collision.

The protective factors for pedestrian mortality were only found in distant locations from the collision. These elements were marked crosswalks on one or both streets on intersections, the vertical stop signs and the number of parked vehicles, which ranged from 6 to 15 cars on the road. This agrees with the premise from the spatial analysis theory and explains why, for nearby controls, the marked crosswalks were not as significant as the protective factors.[11]

The marked crosswalk was a controversial element in car-pedestrian collisions since some studies reported it as risk factor while others revealed it as a protective factor, and finally, because it did not show any significant association to pedestrian deaths. In support of this study, similar results were obtained in Maine, Vancouver and Düsseldorf.[12–14] Furthermore, in California, the presence of marked crosswalks represented a risk increment of two times more, and another study conducted in Washington reported this element as a risk factor.[15] It has even been mentioned that this risk increase is due to a false sense of security

Table 4 Factors related to road system organisation and its association with mortality due to motor vehicle-pedestrian collisions in Guadalajara Metropolitan Area, 2012

	Case location		Control location (nearby)		Bivariate analysis		Multivariate analysis	
Road system	**n**	**%**	**n**	**%**	**OR**	**(95% CI)**	**aOR**	**95% CI**
Intersection features								
Intersection								
T	27	37.50	28	38.90	1.01	0.48 to 2.12	–	–
Cross	40	55.60	42	58.30	1		–	–
Ways*								
Four	51	10.80	34	47.20	2.41	0.82 to 7.50	–	–
Three	13	18.10	25	34.70	0.84	0.24 to 3.00	–	–
Two	8	11.10	13	18.10	1			
Pot-holes								
In both streets	8	11.10	17	23.60	0.47	0.15 to 1.32	–	–
In one street	26	36.10	17	23.60	1.52	0.67 to 3.52	–	–
None	38	52.80	38	52.80	1			
Intersection infrastructure								
Bus stops								
On both streets	17	23.62	5	6.94	10.77	3.58 to 33.30	6.80	2.00 to 23.07
On one street	37	51.39	10	13.89	11.72	4.88 to 28.16	9.18	3.54 to 23.84
None	18	25.00	57	79.17	1.00			
Pedestrian bridge								
Yes	18	25.00	4	5.56	5.67	1.81 to 17.73	3.16	0.95 to 10.50
No	54	75.00	68	94.40	1			
Speed bump								
On both streets	0	0.00	0	0.00				
On one street	4	5.6	11	15.30	0.32	0.07 to 1.18	–	–
None	68	94.40	61	84.70	1		–	–
Road signs								
Stop signs (horizontal)								
On both streets	5	6.90	3	4.20	1.72	0.31 to 11.75	–	–
On one street	20	27.80	20	27.80	1.04	0.46 to 2.33	–	–
None	47	65.30	49	68.10	1			
Stops signs (vertical)								
On both streets	0	0.00	0	0.00				
On one street	4	5.60	11	15.30	0.32	0.07 to 1.18	–	–
None	68	94.40	61	84.70	1		–	–
Lane markings								
Marked	43	59.90	27	37.5	2.45	1.2 to 5.10	–	–
Not marked	29	40.30	45	62.50	1		–	–
Directional arrows								
Marked	20	27.80	17	23.30	1.79	0.84 to 3.92	–	–
Not marked	52	72.30	55	76.40	1		–	–
Speed limit								
Marked	8	11.20	5	7.00	1.66	0.45 to 6.84	–	–
Not marked	64	88.90	67	93.10	1		–	–
Pedestrian subsystem								
Crosswalks								
On both streets	18	25.00	16	22.20	1.12	0.46 to 2.72	–	–
On one street	14	19.40	16	22.20	0.87	0.34 to 2.20	–	–
None	40	55.60	40	55.60	1			
Cars parked on the sidewalks								
On both streets	12	16.70	6	8.30	2.64	0.82 to 9.44	–	–
On one street	24	33.30	18	25.00	1.77	0.78 to 4.03	–	–
None	36	50.00	48	66.70	1			
Street vending								
On both streets	8	11.10	4	5.60	2.52	0.62 to 12.31	–	–
On one street	24	33.30	17	23.60	1.79	0.80 to 4.08	–	–

Continued

Table 4 Continued

Road system	Case location n	Case location %	Control location (nearby) n	Control location (nearby) %	Bivariate analysis OR	Bivariate analysis (95% CI)	Multivariate analysis aOR	Multivariate analysis 95% CI
None	40	55.60	51	70.80	1			
Continuous sidewalk								
On both streets	43	59.70	42	58.30	1.56	0.67 to 3.70	–	–
On one street	14	19.40	7	9.70	3.00	0.88 to 11.07	–	–
Non-continuous	15	20.80	23	31.90	1			
Cracked, broken or irregular sidewalks								
On both streets	33	45.80	31	43.10	1.62	0.64 to 4.22	–	–
On one street	26	36.10	21	29.20	1.88	0.70 to 5.21	–	–
None	13	18.10	20	27.80	1			
Road infrastructure								
Traffic light								
Yes	25	34.72	11	15.28	2.95	1.32 to 6.60	2.02	0.82 to 4.9
No	47	65.28	61	84.72	1.00		1.00	
Pedestrian island								
Yes	36	50.00	10	13.89	6.20	2.75 to 13.97	4.45	1.85 to 10.74
No	36	50.00	62	86.11	1.00		1.00	
Sidewalk								
≥3 m	35	48.61	15	20.83	4.02	1.74 to 9.30	3.24	1.35 to 7.76
>1.7 m to <3 m	19	26.39	26	36.11	1.26	0.55 to 2.88	1.11	0.47 to 2.64
≤1.7 m	18	25.00	31	43.06	1.00		1.00	
Road features								
Road hierarchy†								
Arterial	26	36.10	7	9.70	2.10	0.68 to 7.06	–	–
Collector	7	9.70	4	5.60	1	0.21 to 5.40	–	–
Minor collector	5	6.90	10	13.90	0.29	0.06 to 1.13	–	–
Subcollector	5	6.90	9	12.50	0.32	0.07 to 1,29	–	–
Local	1	1.4	26	36.10	0.02	0.001 to 0.17	–	–
Access to property	28	38.90	16	22.20	1			
Road materials								
Cobble	1	1.40	2	2.80	0.44	0.01 to 8,86	–	–
Concrete	27	37.50	22	30.60	1.08	0.49 to 2.35	–	–
Paving stone	1	1.40	8	11.10	0.11	0.002 to 0.90	–	–
Dirt	1	1.40	3	4.20	0.29	0.005 to 3.89	–	–
Asphalt	42	58.30	37	51.40	1			
Other road features								
Road width								
≥28 m	34	47.22	18	25.00	4.86	2.10 to 11.26	1.65	0.56 to 4.84
>12 to <28 m	24	33.33	18	25.00	3.33	1.37 to 7.96	1.79	0.63 to 5.08
≤12 m	14	19.44	35	48.61	1.00		1.00	
Parked cars								
≥15	26	36.11	24	33.33	0.86	0.39 to 1.87	0.49	0.19 to 1.23
<15 to >6	17	23.61	25	34.72	0.54	0.24 to 1.23	0.55	0.22 to 1.36
≤6	29	40.28	23	31.94	1.00		1.00	
Traffic flow‡								
≥260	36	50.00	12	16.67	13.33	5.03 to 35.33	15.35	1.84 to 127.9
35–259	27	37.50	20	27.78	6.00	2.38 to 15.14	5.67	0.61 to 52.45
0–34	9	12.50	40	55.56	1.00		1.00	
Pedestrian flow‡								
≥14	37	51.39	16	22.22	5.35	2.33 to 12.36	5.22	2.09 to 13.07
8–13	19	26.39	19	26.39	2.31	0.97 to 5.50	2.18	0.87 to 5.42
0–7	16	22.22	37	51.39	1.00		1.00	

In the multivariate analysis, the variables were adjusted among them.
*Refers to the direction of vehicles going north-south and vice versa, and east-west and vice versa; therefore, if these converge at an intersection, this is called four ways, and so forth.
†The hierarchy is based on the road width, number of lanes and road capacity.
‡Estimated on a 5 min or 300 s lapse.
aOR, adjusted OR.

Table 5 Factors related to road system organisation and its association with mortality due to motor vehicle-pedestrian collisions in Guadalajara Metropolitan Area, 2012

	Case location		Control location (distant)		Bivariate analysis		Multivariate analysis	
Road system	**n**	**%**	**n**	**%**	**OR**	**(95% CI)**	**aOR**	**95% CI**
Intersection features								
Intersection								
T	27	37.50	20	27.80	1.64	0.76 to 3.60	–	–
Cross	40	55.60	49	68.10	1		–	–
Ways*								
Four	51	10.80	41	56.90	2.77	1.02 to 816	–	–
Three	13	18.10	13	18.10	2.21	0.63 to 8.19	–	–
Two	8	11.10	18	25.00	1			
Pot-holes								
In both streets	8	11.10	10	13.90	0.96	0.29 to 0.03	–	–
In one street	26	36.10	16	22.20	1.95	0.86 to 4.52	–	–
None	38	52.80	46	63.90	1			
Intersection infrastructure								
Bus stops								
On both streets	17	23.61	4	5.56	9.44	2.78 to 32.08	6.5	1.81 to 23.36
On one street	37	51.39	28	38.89	2.94	1.40 to 6.17	2.56	1.61 to 5.68
None	18	25.00	40	55.56	1.00		1.00	
Pedestrian bridge								
Yes	18	25.00	72	100.0	–	–	–	–
No	54	75.00	0	0.00	–	–	–	–
Speed bump								
On both streets	0	0.00	4	5.60				
On one street	4	5.6	7	9.70	0.51	0.10 to 2.14	–	–
None	68	94.40	61	84.70	1		–	–
Road signs								
Stop signs (horizontal)								
On both streets	5	6.90	7	9.70	0.49	0.11 to 1.97	–	–
On one street	20	27.80	33	45.80	0.41	0.46 to 2.33	–	–
None	47	65.30	32	44.40	1			
Stops signs (vertical)								
On both streets	4	5.56	13	18.06	0.27	0.08 to 0.86	0.19	0.06 to 0.63
On one street	68	94.44	59	81.94	1.00		1.00	
Lane markings								
Marked	43	59.90	36	50.00	1.47	0.72 to 3.02	–	–
Not marked	29	40.30	36	50.00	1		–	–
Directional arrows								
Marked	20	27.80	29	40.30	0.82	0.40 to 1.67	–	–
Not marked	52	72.30	43	59.70	1		–	–
Speed limit								
Marked	8	11.20	12	16.70	0.62	0.20 to 1.8	–	–
Not marked	64	88.90	60	83.30	1		–	–
Pedestrian subsystem								
Crosswalks								
On both streets	18	25.00	28	38.89	0.37	0.17 to 0.81	0.19	0.08 to 0.49
On one street	14	19.44	21	29.17	0.38	0.16 to 0.89	0.28	0.10 to 0.76
None	40	55.56	23	31.94	1.00		1.00	
Cars parked on the sidewalks								
On both streets	12	16.70	5	6.90	2.90	0.85 to 11.53	–	–
On one street	24	33.30	23	31.90	1.27	0.58 to 2.79	–	–
None	36	50.00	44	61.10	1			
Street vending								
On both streets	8	11.11	1	1.39	11.00	1.32 to 91.48	7.97	0.94 to 68.37
On one street	14	19.44	16	22.22	2.06	0.97 to 4.38	1.37	0.60 to 3.14
None	40	55.56	55	76.39	1.00		1.00	

Continued

Table 5 Continued

Road system	Case location		Control location (distant)		Bivariate analysis		Multivariate analysis	
	n	%	n	%	OR	(95% CI)	aOR	95% CI
Continuous sidewalk								
On both streets	43	59.70	41	56.90	1.67	0.72 to 3.94	–	–
On one street	14	19.40	7	9.70	3.13	0.92 to 11.51	–	–
Non-continuous	15	20.80	24	33.30	1			
Cracked, broken or irregular sidewalks								
On both streets	33	45.80	25	34.70	2.31	0.91 to 6.04	–	–
On one street	26	36.10	24	33.30	1.90	0.73 to 5.08	–	–
None	13	18.10	23	31.90	1			
Road infrastructure								
Traffic light								
Yes	25	34.72	22	30.56	1.21	0.60 to 2.43	0.86	0.40 to 1.87
No	47	65.28	50	69.44	1.00		1.00	
Pedestrian island								
Yes	36	50.00	15	20.83	3.80	1.82 to 7.91	2.93	1.33 to 6.46
No	39	50.00	57	69.44	1.00		1.00	
Sidewalk								
≥3 m	35	48.61	25	34.72	2.26	1.03 to 4.92	1.99	0.90 to 4.41
>1.7 m to <3 m	19	26.39	15	20.83	1.70	0.71 to 4.07	1.94	0.78 to 4.81
≤1.7 m	18	25.00	32	44.44	1.00		1.00	
Road features								
Road hierarchy†								
Arterial	26	36.10	7	9.70	2.23	0.73 to 7.45	–	–
Collector	7	9.70	13	18.10	0.33	0.09 to 1.10	–	–
Minor collector	5	6.90	7	9.70	0.44	0.09 to 1.90	–	–
Subcollector	5	6.90	13	18.10	0.23	0.06 to 0.87	–	–
Local	1	1.4	15	20.80	0.04	0.001 to 0.32	–	–
Access to property	28	38.90	17	23.60	1			
Road materials								
Cobble	1	1.40	0	0.00				
Concrete	27	37.50	21	29.20	1.28	0.59 to 2.79	–	–
Paving stone	1	1.40	6	8.30	0.16	0.003 to 1.48	–	–
Dirt	1	1.40	3	4.20	0.33	0.01 to 4.39	–	–
Asphalt	42	58.30	42	58.30	1			
Other road features								
Road width								
≥28 m	34	47.22	19	26.39	4.47	1.94 to 10.32	2.24	0.81 to 6.20
>12 to <28 m	24	33.33	18	25.00	3.33	1.37 to 7.96	1.79	0.63 to 5.08
≤12 m	14	19.44	35	48.61	1.00		1.00	
Parked cars								
≥15	26	36.11	28	38.89	0.67	0.31 to 1.46	0.41	0.16 to 1.06
<15 to >6	17	23.61	23	31.94	0.53	0.23 to 1.24	0.39	0.16 to 0.96
≤6	29	40.28	21	29.17	1.00		1.00	
Traffic flow‡								
≥260	36	50.00	7	9.72	20.00	6.71 to 59.59	3.72	1.06 to 13.09
35–259	27	37.50	30	41.67	3.50	1.43 to 8.59	1.31	0.29 to 6.02
0–34	9	12.50	35	48.61	1.00		1.00	
Pedestrian flow‡								
≥14	37	51.39	23	31.94	2.41	1.06 to 5.47	1.78	0.72 to 4.42
8–13	19	26.39	25	34.72	1.14	0.48 to 2.72	0.93	0.37 to 2.36
0–7	16	22.22	24	33.33	1.00		1.00	

In the multivariate analysis, the variables were adjusted among them.
*Refers to the direction of vehicles going north-south and vice versa, and east-west and vice versa; therefore, if these converge at an intersection, this is called four ways, and so forth.
†The hierarchy is based on the road width, number of lanes and road capacity.
‡Estimated on a 5 min or 300 s lapse.
aOR, adjusted OR.

when using marked crosswalks,[16] though opposite results were obtained in Chapel Hill, North Carolina,[11] where no statistical association was reported.

The road signs in a study done in North Carolina[17] showed a risk reduction of being hit by a car. The same result was obtained in this study. However, this is different from what was found in a study done in Northeast Washington,[18] where no statistical association was found between road signs. It was found that parked cars were a reducing risk factor, in contrast to what was reported in Auckland[19] and in the Southwestern United States.[20]

As in other studies,[13 21–23] the presence of bus stops was shown to be a risk factor in car-pedestrian collisions. In contrast, in another study, no statistical association was shown.[11] On the other hand, the presence of speed bumps[24] was reported as a protective factor, in contrast to this study, where we did not find any significant association.

In our study, we observed that the pedestrian island did not have all the ideal features for pedestrian safety, in contrast to a study conducted in Flanders, Belgium.[25] This contrast could be due to the planning and features of the street. The presence of the pedestrian island has shown a reduction in car-pedestrian collisions[13 26]; however, in the present study, this increased the risk of death. The increase of vehicle traffic flow increased the risk of car-pedestrian collisions, as reported in other studies.[18 19 22 27–34]

The next factors that increased the risk of dying from a car-pedestrian collision were only significant in nearby locations. These factors were the pedestrian traffic flow, in concordance with other studies,[20 21] and width sidewalks. These results are similar to what was reported by Mueller *et al*,[18] while contrasting with McMahon *et al*[27] and Constant and Lagarde,[26] who reported this latter as a protective factor. With this study, we do not explain the causes or mechanisms of why the width of sidewalks increases the risk, though this could be due to the interactions between various road system features.

The road system features without significant statistical association were the hierarchy of streets, the road width and lane markings. A number of researchers have studied the hierarchy of streets in Canada,[13] England[35]; North Carolina, USA[17]; and South Africa,[36] with all of them concluding that there is a directly proportional relationship between road hierarchy and the risk of car-pedestrian collisions. The road width as a continuous variable was also an element that increased the mortality in car-pedestrian collisions in Washington,[18] Maine,[12] Florida,[37] England[35] and Long Beach.[38] The only study that obtained results similar to our study was Schneider and colleagues.[11] Finally, Donroe *et al*[29] concluded that the lack of lane markings increased the risk of car-pedestrian collisions.

The advantages of this study are that it allows the identification of the elements of the road system that have an influence on pedestrian mortality in one of the biggest metropolitan areas in Mexico. Furthermore, this study involved other variables that had not been previously included in the literature. This is because these types of events are regularly analysed from the perspectives of either the pedestrian or the involved vehicle while location characteristics are often overlooked. Regarding the case–control methodology, in which the cases were the locations with pedestrian fatalities and the controls being locations without fatalities due to car-pedestrian collisions, a disadvantage was not considering other variables for matching, such as vehicle traffic flow or pedestrian traffic flow. Other limitations are that some variables were measured as categorical variables instead of numerical variables, also not considering pedestrian characteristics such as if they had a physical disability, the use of electronic devices or using alcohol or drugs.

What is already known on the subject

- These types of events are regularly analysed from the perspective of either the pedestrian or the involved vehicle while location characteristics are often overlooked.

What this study adds

- This study shows a different methodological option because the cases and controls are locations, not persons.
- In addition, it allows the identification of the elements of the road system that have an influence on pedestrian mortality in one of the biggest metropolitan areas in Mexico.

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