

Traffic Circles – Impact on motor vehicle, cyclist-MV, & pedestrian-MV crashes with injuries

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Abstract

Local street intersections with traffic circles have been found to pose a higher injury risk to cyclists than intersections with stop sign control. An outstanding question is the effect of traffic circles on injuries to people walking and driving. We examined this issue using an Insurance Corporation of BC dataset of 40,626 crashes that occurred at local street intersections in Vancouver from 1996 to 2013 to determine whether traffic circles were associated with injury risk for three types of crashes: motor vehicle (MV); cyclist-MV; and pedestrian-MV. Relative risks were calculated using three comparisons: with vs. without traffic circles; traffic circles vs. intersections within one block (“matched”); and after vs. before traffic circles. For motor vehicle crashes, traffic circles had relative risks of 0.17 to 0.53, resulting in 11 to 46 fewer injuries per year in Vancouver, a city with about 200 traffic circles. For cyclist-MV crashes, traffic circles had relative risks of 2.4 to 4.6, resulting in 10 to 12 more injuries per year. For pedestrian-MV crashes, traffic circles had relative risks of 0.97 to 1.9, resulting in 0 to 2 more injuries per year. These results suggest that traffic circles should not be used as a traffic calming measure along local street bike routes. Safer alternatives (i.e., raised crossings, traffic diversion) should be tried to determine if they are better for all modes of travel.

Résumé

On a constaté que les intersections locales avec les cercles de circulation présentent un risque de blessures plus élevé pour les cyclistes que les intersections avec les panneaux d'arrêt. Une question en suspens est l'effet sur les blessures aux personnes qui marchent et qui conduisent. Nous examinons cette question en utilisant une série de 40 626 accidents survenus à des intersections de rues locales à Vancouver de 1996 à 2013 afin de déterminer si les cercles de circulation étaient associés au risque de blessures pour trois types de collisions: véhicule à moteur (MV); cycliste-MV; et piéton-MV. Les risques relatifs ont été calculés en utilisant trois comparaisons: avec ou sans les cercles de circulation; les cercles de circulation ou les intersections dans un bloc; et après ou avant les cercles de circulation. Dans le cas des collisions MV, les cercles de circulation présentaient des risques relatifs de 0,17 à 0,53, ce qui se traduisait par une réduction de 11 à 46 blessures par année à Vancouver, une ville avec environ 200 cercles de circulation. Pour les collisions cyclistes-MV, ils présentaient des risques relatifs de 2,4 à 4,6, ce qui se traduisait par 10 à 12 blessures de plus par année. Dans le cas des collisions piétons-MV, ils présentaient des risques relatifs de 0,97 à 1,9, ce qui se traduisait par 0 à 2 blessures de plus par année. Ces résultats suggèrent que les cercles de circulation ne devraient pas être utilisés le long des routes locales de vélo. Les alternatives plus sûres (c.-à-d., passages surélevés, détournement du trafic) devraient être essayées pour déterminer si elles sont meilleures pour tous les modes de déplacement.

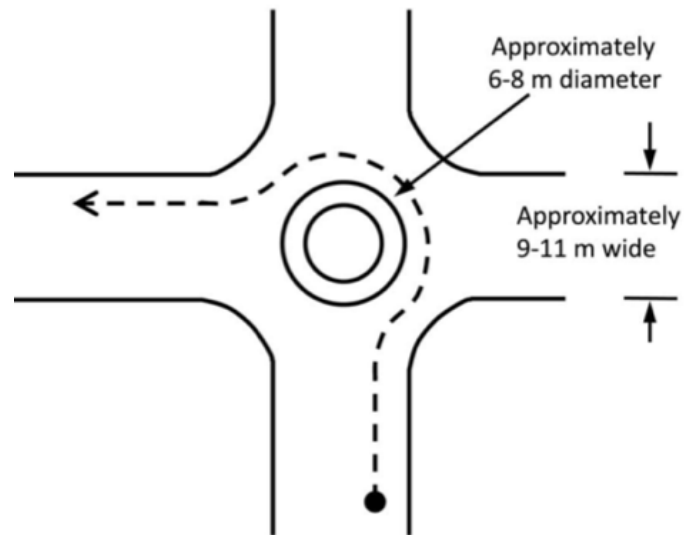
BACKGROUND

In a study of bicycling injuries in Vancouver and Toronto, Canada, local street intersections with traffic circles had an 8-fold increased risk of injury compared to those with two-way and four-way stops (Figure 1).[1] About half the cyclist crashes at traffic circles were with motor vehicles (often related to difficulty understanding who had the right of way) and half were single cyclist crashes (hitting the curb, sliding on the sharp turn).



Figure 1. Above: local street intersection in Vancouver with a traffic circle vs. with a two-way stop. Right: typical dimensions of entering streets and traffic circles.

In Vancouver, traffic circle intersections do not include yield signs. Signage on the circle facing each approach conforms to the only BC Motor Vehicle Act guidance: “driver of a vehicle passing around a rotary traffic island must drive the vehicle to the right of the island.” Circles typically have some vegetation, of varying heights. Photos: Google Streetview



All traffic circles in the study were in Vancouver, were small (Figure 1), and intended for traffic calming. Major street roundabouts common in Europe are considerably larger, have different approach geometry, and have been consistently shown to reduce injury risk for motor vehicle occupants [2,3], but may increase risks for cyclists and pedestrians, potentially because of the large number of conflict points for these vulnerable road users. [4-7] One study found that roundabouts with radii greater than 10 m were safer than smaller circles. [8]

Given the safety benefit of roundabouts for motor vehicle occupants, an outstanding question related to their smaller counterpart, traffic circles, is whether their increased risk observed for people cycling [1] might be mitigated by a benefit to other road users: people in motor vehicles, or people walking. In order to have comparable data for all three injury crash types, data from the Insurance Corporation of BC (ICBC) was used;

it captures injuries resulting from motor vehicle collisions. This study examined whether traffic circles are associated with the risk of injuries for three types of crashes: motor vehicle (MV) only; cyclist-MV; pedestrian-MV.

METHODS

Data Sources

City staff provided data on traffic circles and their dates of installation (and removal, if applicable). Road types, intersections, and bikeways were abstracted from the City of Vancouver Open Data Catalogue to ArcGIS 10.2 (Esri Canada, Toronto). ArcGIS was used to add traffic circles, identify local street intersections one block away from a traffic circle, and calculate slopes of each leg of a local street intersection.

Data were abstracted on 3,631 local street intersections in the City of Vancouver. Of these, 205 now have (or at some point had) traffic circles for intersection control. 1,045 of the local street intersections were on at least one street designated as a bikeway in 2016, as were 137 of the traffic circle intersections (Figure 2).

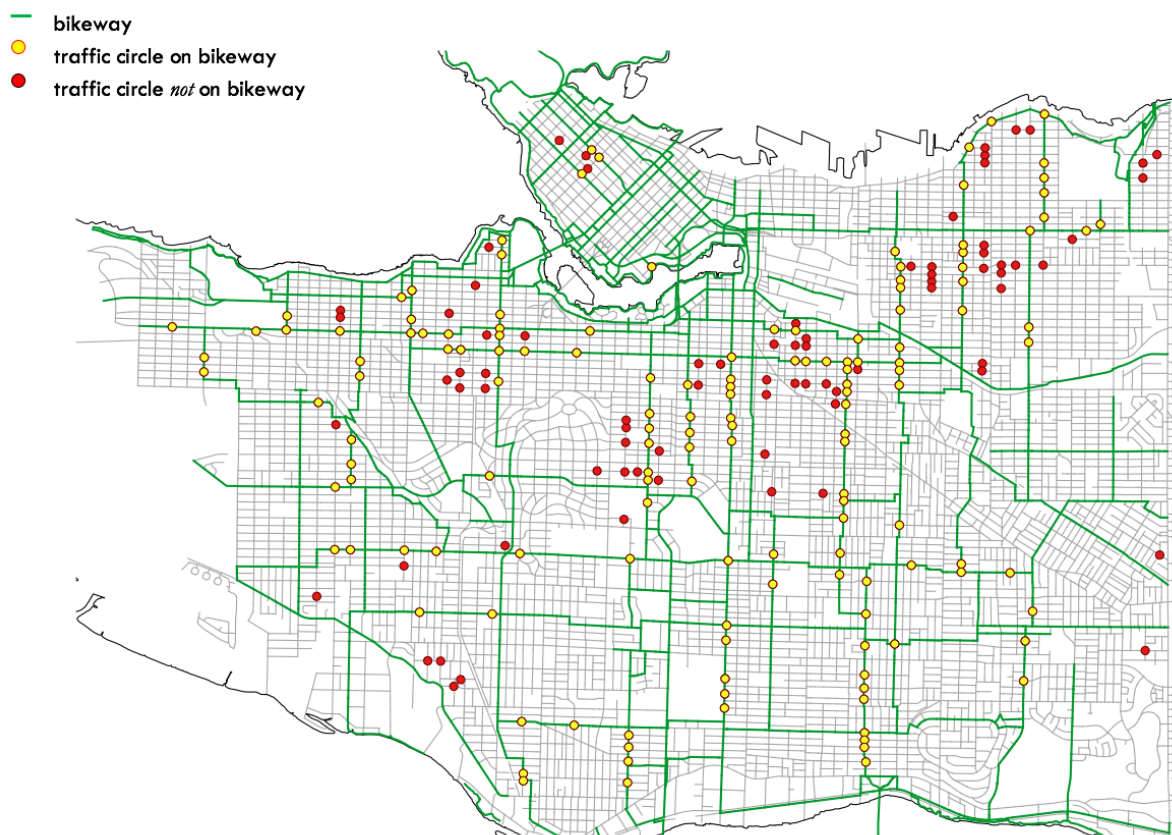


Figure 2. Bikeways and intersections with traffic circles in the City of Vancouver, 2016

Insurance Corporation of BC data on crashes involving motor vehicles were provided by the City. It included all crashes in the City of Vancouver for the 18-year period from 1996 to 2013 inclusive. The data included variables indicating whether the crash was at an intersection and, if so, the cross streets of the intersection, whether the crash involved a cyclist or a pedestrian (all other crashes were deemed motor vehicle only), and the severity of the crash (property damage only, injury, fatality).

Data Linkage

Road data were linked to crash data using variables in each dataset for the names of the cross streets. To maximize matching, multiple checks were performed to detect different street name descriptions and cross street ordering in the two datasets. Linkage was done using PROC SQL in SAS 9.4 (SAS Institute, Cary, North Carolina).

Analyses

Data analyses were done with SAS 9.4 and JMP 13 (SAS Institute, Cary, North Carolina). Descriptive analyses examined the characteristics of the intersections, and tallied the crashes by intersection type, mode, and severity. Inferential analyses examined the relative risks of traffic circle intersections, separately for each type of crash: motor vehicle; cyclist-MV; pedestrian-MV. Note that motor vehicle crashes included those with property damage only and those involving injuries. All cyclist-MV and pedestrian-MV crashes in the dataset involved injuries, therefore comparison analyses reported here are restricted to crashes involving injuries (including fatalities).

Data on exposure (motor vehicle, cyclist, and pedestrian traffic volumes) were sparse for local streets, so could not be used in the analyses. Two substitute methods were used to control for exposure. In all analyses, “intersection-years” was used as the denominator. This is the summation, over all intersections in a given comparison group, of the number of years each intersection was in that group. Crashes that occurred in the year when a traffic circle was installed or removed were not included in the analyses, so these years were not tallied in intersection-years.

The second method to control for exposure was via the comparisons made, each of which involved different spatial and temporal matching, and therefore different advantages and disadvantages. Relative risks of traffic circles were calculated using each of the following three comparisons.

1. With vs. without traffic circles: Crashes with injuries at 187 intersections with traffic circles were compared to those at 2,907 local street intersections without a traffic circle. Note that some intersections had a traffic circle in some, but not other years of the study period.

Advantages:

- This analysis used data on all linked local street intersections, including all traffic circle intersections, so had the largest sample size.
- Crash data were temporally distributed throughout the study period for both types of intersections, so temporal changes in traffic volumes over time are likely to be similar between the comparison groups.

Disadvantages:

- Crash data were not perfectly matched in time because some intersections changed traffic circle status during the study period.

- The spatial distribution of traffic circle intersections is not random throughout the city, so traffic volumes are likely to differ from those of intersections without traffic circles.
- Traffic circle intersections may differ from other local street intersections with respect to other characteristics (e.g., 68% of intersections with traffic circles were on bikeways¹ vs. 26% of those without; 46% of intersections with traffic circles had at least one leg with a downhill grade > 3% vs. 39% of those without).

2. Traffic circle vs. matched intersections: Crashes with injuries at 167 intersections with traffic circles were compared to those at 383 local street intersections within one block of a traffic circle intersection and occurring during the same years that the traffic circle was in place.

On average, there were 2.3 matched intersections per traffic circle, less than the maximum of four possible – one for each leg of the intersection. There were two reasons intersections one block away were excluded. First, where the intersection one block away was an intersection with an arterial or a collector, it was not included because traffic volumes were expected to be much higher than at a traffic circle intersection of two local streets. Second, where the intersection one block away was another traffic circle intersection, it was included as a traffic circle intersection, not a matched intersection.

Advantages:

- Traffic circle intersections and their matched intersections were perfectly matched in time, so temporal changes in traffic volumes are likely to be the same between the comparison groups.
- Traffic circle intersections and their matched intersections were within one block of each other, so spatial distributions of traffic volumes were likely to be very similar.
- Traffic circle intersections and their matched intersections had similar topography: 46% and 45%, respectively, with at least one leg with a downhill grade > 3%.

Disadvantages:

- Traffic circle intersections differed from matched intersections with respect to bikeway status (68% vs. 42% respectively), though less so than in the previous analysis.

3. After vs. before traffic circles: Crashes with injuries after 114 traffic circles were installed were compared to those at the same intersections before they were installed. This analysis was restricted to intersections that had a traffic circle installed during the study period and had at least one year of crash data on either side of the installation year.

Advantages:

- Before and after data were for identical intersections, with the same bikeway status (81% with), and topography (47% with at least one leg with a downhill grade > 3%). Similarly, spatial contributions to traffic volume should be the same in the comparison groups.

Disadvantages:

- Before and after data cannot be matched in time, so were uncontrolled for temporal changes in traffic volumes or other characteristics that changed over time.
- This analysis had the smallest sample size.

¹ In this paper, “bikeway” refers to a local street bikeway. In Vancouver, these are typical local (mainly residential) streets that have one additional feature: cyclist-operated traffic signals where the local street meets an arterial. Bikeways are noted with a bicycle symbol on street signs and on cycle route maps. People cycling in Vancouver may and do ride on other local streets, whether they are bikeways or not.

Relative risks (RR) for all three comparisons were calculated as follows, with confidence intervals calculated using standard methods as described by Morris and Gardner [9]:

$$RR = \frac{\text{Injuries at traffic circles} / \text{Traffic-circle-intersection-years}}{\text{Injuries at comparison intersections} / \text{Comparison-intersection-years}}$$

The proportion of crashes with injuries attributable to traffic circles was calculated as (relative risk-1)/(relative risk). This was used to calculate the estimated annual increase or decrease in injuries associated with traffic circles, based on the relative risks and injuries per intersection-year from the three comparison analyses. Estimated increases and decreases were calculated for 200 intersection-years; since there are ~200 traffic circles in the city, this provides an annual estimate.

RESULTS

The ICBC dataset included crashes in the City of Vancouver over the 18-year period from 1996 to 2013. There were 961,231 crashes in total (53,401 per year on average), 612,523 at intersections. Of these, 40,626 crashes were identified as occurring on local street intersections after linkage to the City of Vancouver road dataset. 8,456 crashes on local street intersections involved injuries, including 2 fatalities (1 pedestrian, 1 cyclist).

The resulting linked dataset included crashes on 2,963 local street intersections (81% of those in the road dataset), including 187 traffic circle intersections (91% of those in the road dataset). Whether the unlinked intersections represent misses in the data linkage or intersections with no crashes during the time period is unknown. Figure 3 illustrates the growth in the number of traffic circle intersections over time since 1976. A large number were installed in the period from 1995 to 2005.

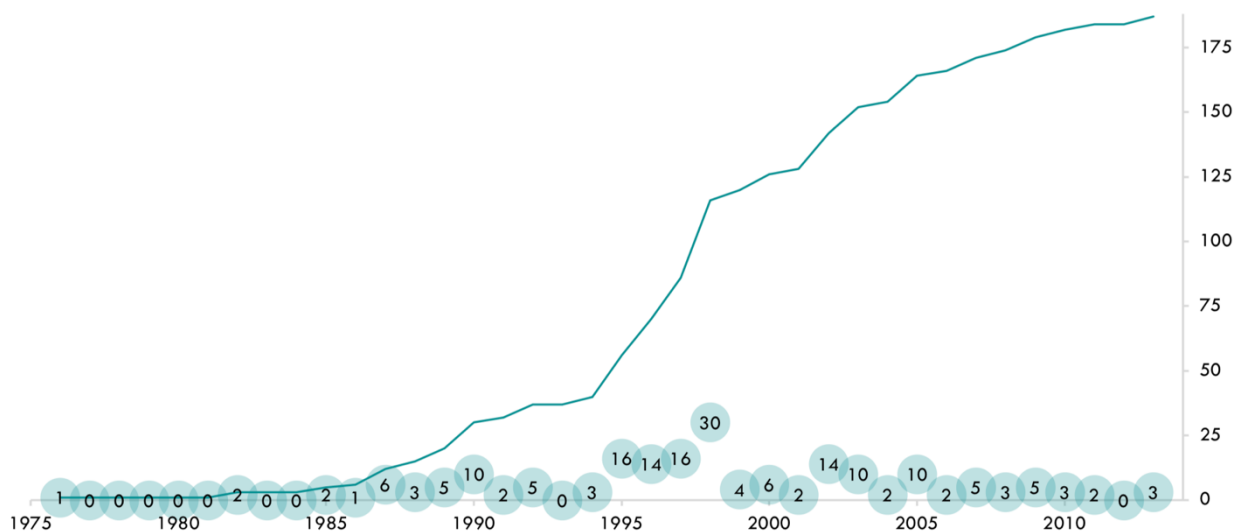


Figure 3. Number of traffic circles installed & cumulative total, by year (187 traffic circles linked to ICBC dataset)

Figure 4 shows the number of crashes with injuries at local street intersections over time, for motor vehicle only, cyclist-MV, and pedestrian-MV crashes. Motor vehicle only crashes declined substantially over the study period, whereas they increased somewhat for cyclist-MV, and stayed about the same for pedestrian-MV. In the most recent 5 years of the data (2009 to 2013) when the traffic circle count was relatively stable, the proportions of local street intersection crashes that were at traffic circles were ~3.5% for motor vehicle, ~26% for cyclist-MV, and ~13% for pedestrian-MV. The proportion of all local street intersections with traffic circles in this period was ~6%.

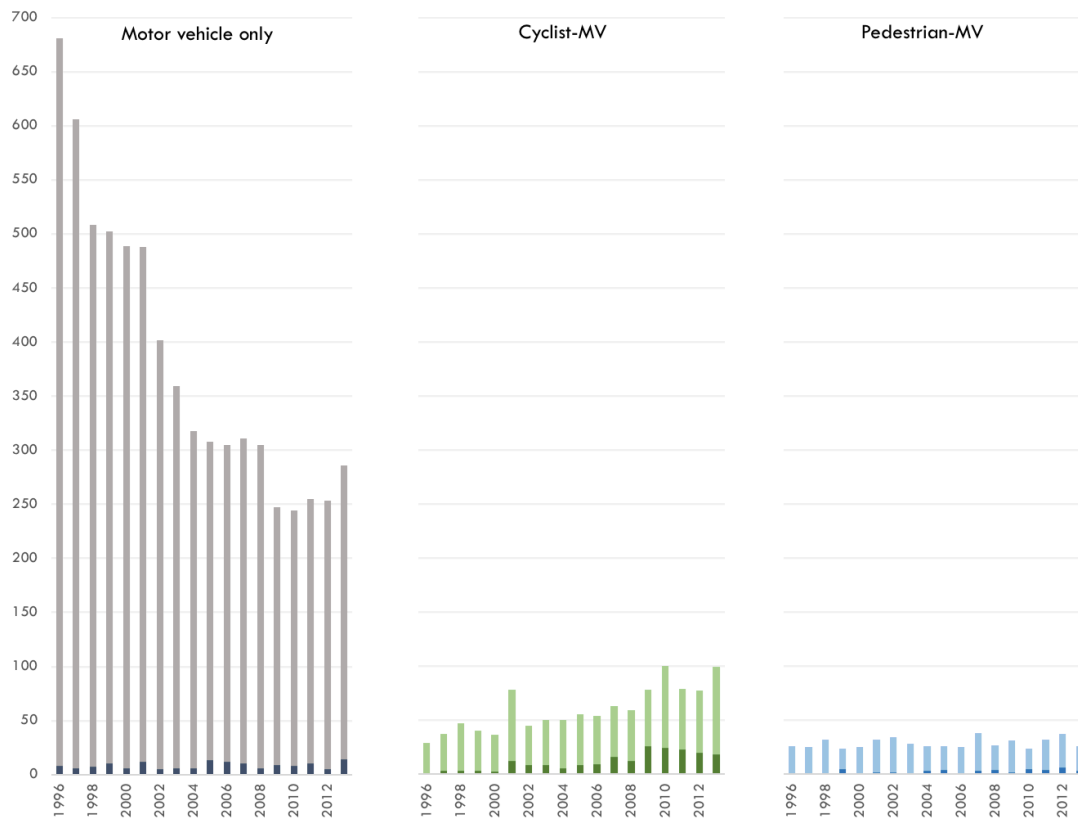


Figure 4. Number of crashes with injuries at local street intersections over time, for motor vehicle, cyclist-MV, and pedestrian-MV crashes (traffic circle crashes in darker shade)

Tables 1, 2, and 3 (page 10) show the results of the three comparisons: with vs. without traffic circles; traffic circle vs. matched intersections; and after vs. before traffic circles. In all comparisons, the risk of motor vehicle crashes with injuries was lower with traffic circles (relative risks of 0.17 to 0.53, all statistically significant), and the risk of cyclist-MV crashes with injuries was significantly higher with traffic circles (relative risks of 2.4 to 4.6, all statistically significant). For pedestrian-MV crashes with injuries, there was a neutral to higher risk with traffic circles (relative risks of 0.97 to 1.9).

DISCUSSION

Figure 5 shows the estimated increases and decreases in the number of crashes with injuries associated with traffic circles. It illustrates quite consistent results for each mode of travel, no matter the comparison made.

- Traffic circles were associated with fewer motor vehicle crashes with injuries. The risk reduction is consistent with research evidence about the effect of converting stop-controlled intersections to single-lane roundabouts on injuries to motor vehicle occupants, with an average crash modification factor of 0.4 (range 0.12 to 0.65).[2,3] The relative risks calculated in this analysis were within this range.
- Traffic circles were associated with more cyclist-MV crashes with injuries. The risk increase is consistent with results of the earlier Vancouver and Toronto cycling injury study.[1] That study found an even higher relative risk, 8.0, because it included cyclist-only in addition to cyclist-MV crashes and these comprised half the traffic circle crashes. This suggests that if cyclist-only crashes were taken into account, the total increase in traffic-circle-associated cyclist injuries would be 20 to 24 annually.
- Traffic circles were associated with zero to slightly more pedestrian-MV crashes with injuries.

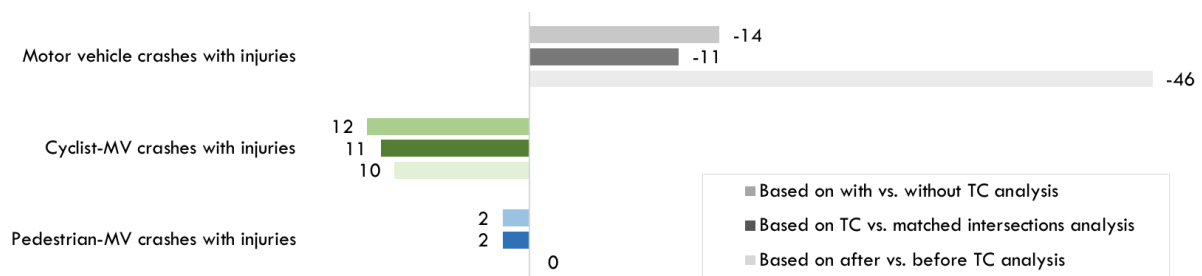


Figure 5. Estimated annual increase or decrease in crashes with injuries associated with traffic circles (TC) in Vancouver based on relative risks in three comparisons

This study did not directly control for motor vehicle, cyclist, or pedestrian traffic volumes, data that is not routinely collected at the thousands of local street intersections in the city. However, two methods of control were used. Intersection-years were used as the denominator in every risk calculation. The second method to control for exposure was via the comparisons made. None was perfectly controlled, but all were differently controlled, so results that were consistent between all three are compelling. The directions of effect were consistent in all comparisons.

A reasonable question is which of the three comparisons is best. Of the three, the second one that compared traffic circles to matched local street intersections is perfectly matched in time and very closely matched in space (one-block proximity). It provides the best control for traffic volumes and other characteristics that might vary between intersections in space and time. Interestingly, the after vs. before comparison has the least comparable results to the other two comparisons. It is likely that the background change in crashes over time (Figure 4), particularly for motor vehicle only crashes, is an important potential confounder of traffic circle risk comparisons, and cannot be controlled in the after vs. before analysis – by definition, this analysis is unmatched in time. Therefore, the after vs. before analysis is likely to have overestimated the benefit of traffic circles for

motor vehicle crashes with injuries, and slightly underestimated the detriment of traffic circles for cyclist-MV and pedestrian-MV crashes with injuries.

Many factors may contribute to crashes and injuries at traffic circles including weather conditions, time of year, and vehicle and cyclist speeds, and it is worth considering whether they might be confounders of the results we observed. The earlier study [1] that originally identified the excess risk of cycling injury at traffic circles used a case-crossover design that completely controlled for weather, time, and personal cycling behaviour; it found similar results. In addition, the second analysis reported here is perfectly matched in time and closely matched in space, making these factors also likely to be well matched in the current analysis. We therefore believe it is unlikely that these factors confounded the results.

On the other hand, base characteristics of traffic circle design (Figure 1) in Vancouver cannot be tested within this dataset. It is reasonable to consider that some of these may contribute to their increased injury risk: poor sightlines owing to signage or vegetation at the circle; curbs around the circles; lack of yield signs at the intersection entrance; small intersection size. It would be useful to evaluate other traffic circle designs to determine whether they are safer. For example, “mountable” traffic circles might solve the problem of single cyclist crashes that result from hitting the curb.

CONCLUSIONS

This study confirmed an excess risk at traffic circles in Vancouver for people cycling, found a slight increase for people walking, and a decrease in risk for motor vehicle occupants – similar in magnitude to the increase for those cycling. Thus the increased risk of traffic circles to people cycling appears to be mitigated in part by a benefit to people in motor vehicles, posing a conundrum for transport engineers.

One approach might be to avoid installing traffic circles along local street bikeways. Raised crossings and traffic diversion are alternative traffic calming measures that have been shown to be safer for vulnerable road users [1,10] and should be tried to determine whether they are better for all modes of travel. Alternative traffic circle designs may also be safer, but this would need verification in injury research.

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Table 1. Comparison of crashes with injuries at 187 local street intersections with a traffic circle (TC) and 2,907 without during study period, 1996-2013 (relative risks in bold are statistically significant)

	Crash count with TC (in 2,554 intersection-yrs)	Crash count without TC (in 50,649 intersection-yrs)	Crashes/intersection-year at intersections with TC	Crashes/intersection-year at intersections without TC	Relative risk (95% CI) with vs. without TC
Motor vehicle	153	6,697	0.060	0.13	0.45 (0.39-0.53)
Cyclist-MV	200	870	0.078	0.017	4.6 (3.9-5.3)
Pedestrian-MV	46	470	0.018	0.0093	1.9 (1.4-2.6)

Table 2. Comparison of crashes with injuries at 168 traffic circle (TC) intersections and 383 local street intersections matched to the traffic circles in time and proximity (within one block), 1996-2013 (relative risks in bold are statistically significant)

	Crash count at TC intersections (in 2,302 intersection-yrs)	Crash count at matched intersections (in 5,293 intersection-yrs)	Crashes/intersection-year at TC intersections	Crashes/intersection- year at matched intersections	Relative risk (95% CI) TC vs. matched intersections
Motor vehicle	139	608	0.060	0.11	0.53 (0.44-0.63)
Cyclist-MV	177	120	0.077	0.023	3.4 (2.7-4.3)
Pedestrian-MV	45	56	0.020	0.011	1.8 (1.3-2.7)

Table 3. Comparison of crashes with injuries after vs. before installation of 114 traffic circles (TC) with at least one year before and after installation in the study period, 1996-2013 (relative risks in bold are statistically significant)

	Crash count after TC (in 1,306 intersection-yrs)	Crash count before TC (in 517 intersection-yrs)	Crashes/intersection-year at intersections after TC	Crashes/intersection- year at intersections before TC	Relative risk (95% CI) after vs. before TC
Motor vehicle	61	143	0.047	0.28	0.17 (0.13-0.22)
Cyclist-MV	114	19	0.087	0.037	2.4 (1.5-3.8)
Pedestrian-MV	22	9	0.017	0.017	0.97 (0.45-2.1)