Diabetes and Driving

Desired data, research methods and their pitfalls, current knowledge, and future research

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The issue of traffic safety of patients with diabetes is rising on political as well as scientific levels. Driving by diabetic patients may be impaired by three factors: hyperglycemia, hypoglycemia, and diabetes complications. Management of diabetic patients is progressively aiming at near normoglycemia (1,2). Consequently, the rate of hypoglycemia and hypoglycemia unawareness has markedly increased (3–8). These factors could pose an increased threat to diabetic patients' fitness to drive. Current legal restrictions regarding diabetes and driving privileges vary throughout the world, but laws are generally prompted by the impending danger of hypoglycemia during driving. To research the various aspects of diabetes and driving, several study methods have been applied. In consideration of dissenting opinions and laws, rules, and regulations, we will discuss in this article the currently available data on diabetes and driving, potential pitfalls in research, and give recommendations for future research.

In modern traffic, the increasing age of drivers (9) and their medical conditions can be risk factors for traffic incidents and accidents. The amounting prevalence of diabetes also leads to an increased number of diabetic drivers. Driving by diabetic patients may be impaired by three factors: hyperglycemia, hypoglycemia, and diabetes complications.

In recent years, it has become apparent that acute hyperglycemia, and possibly also chronic hyperglycemia, may be associated with cognitive function loss (10–15). However, the cognitive dysfunction occurring during hypoglycemia is most striking (16–18). After the Diabetes Control and Complications Trial (1) and the U.K. Prospective Diabetes Study (2), which showed that diabetes complications are reduced with tight glucose control, management of diabetic patients is progressively aiming at near normoglycemia. Consequently, the rate of hypoglycemia has increased. We now know that even a single episode of hypoglycemia leads to impaired hypoglycemia awareness (19). Hypoglycemia unawareness currently affects ~25% of patients with type 1 diabetes (4–6). The incidence of severe hypoglycemia in type 2 diabetes is lower (3,6,7) but may approach the incidence in type 1 diabetes (3,8). Sequellae of diabetes complications (e.g., retinopathy, neuropathy) (20–22) can impair driving capacity; retinopathy is associated with impaired vision, and its treatment with laser coagulation may reduce peripheral vision (23–25). Peripheral neuropathy may interfere with the operation of a vehicle. Eventually, the challenge will be to identify individual diabetic drivers who have an impaired fitness to drive.

LEGAL REGULATIONS— Laws, rules, and regulations regarding medical conditions have to balance individual interests on one side against the general interest of traffic safety on the other side, and therefore the safety risks of granting driving privileges to a certain group of people with an (possibly) increased risk of automotive accidents have to be estimated. Social and economic factors play an important role: young male subjects have higher accident rates (26–28), as do drivers from lower social classes (29–32), and drivers of advanced age are more likely to have fatal accidents (26,33–36). Nevertheless, these groups are not excluded from driving. Likewise, weather conditions, such as night driving or rain, may entail higher risks than the diabetic condition (37,38). Current legal restrictions are generally prompted by the impending danger of hypoglycemia during driving. The possible interference of chronic diabetes complications is also taken into account.

In Europe, many countries have restrictions for diabetic drivers, ranging from more frequent than usual medical examination to denial of driving privileges for certain groups, e.g., patients with hypoglycemia unawareness. The European Union has issued directive 91/439, stating that diabetic patients who are using insulin are excluded from driving trucks, heavy goods vehicles, and buses, except for small trucks in "very exceptional cases (39)." This directive is interpreted differently throughout the European Union (40,41).

Many U.S. states have a restrictive licensing program for drivers with medical conditions (42,43). Utah, for example, has a program that may impose restrictions on speed, geographic area, or time of day. In California, it is mandatory for doctors to report unexpected loss of consciousness due to hypoglycemia to the authorities, which results in revocation of the driver's license. In most states, such reporting is voluntary or permissive. Individuals with diabetes who are treated with insulin are automatically denied an interstate commercial driving license, with the exception of some states (42–44). However, during the past decennium, in 39 of 50 states, waivers were temporarily granted (44).

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Abbreviations: BGAT, blood glucose awareness training.
A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.
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OFFICE-BASED SURVEYS AND QUESTIONNAIRES — Several studies have been published with office-based samples of diabetic patients. In 1980, Clarke et al. (45) found that 40% of 94 insulin-dependent drivers admitted having experienced hypoglycemic symptoms while driving. In the same year, Frier et al. (46) reported that 13.6% of 250 patients with insulin-dependent diabetes had been involved in a driving accident since starting insulin treatment, and 5.2% suspected that hypoglycemia had been a causal factor. Steel et al. (47) reported that only 5 of 120 type 2 diabetic patients had experienced mild hypoglycemia while driving, and none admitted to a driving accident related to hypoglycemia. Eight years after the original survey of Eadington and Frier (48), 20% of their 250 patients admitted to have experienced hypoglycemia while driving. Interestingly, the mileage-adjusted accident rate for the whole group was 5.4 per million miles driven (men 4.9, women 6.3), which was considerably lower than the accident rate for the general population of 10.0 accidents per million miles. Stevens et al. (49) found, among 354 insulin-treated diabetic drivers in Belfast, a similar accident rate of 7.9 per million miles, which was 7.8 in a control group. Since these rates were only calculated for the 24% of case and control subjects who reported accidents, true accident rates must have been lower (49).

Songer et al. (50) reported a trend toward a higher accident rate in 121 insulin-dependent diabetic patients versus 121 case-control subjects in Pittsburgh, Pennsylvania (10.4 vs. 3.9 accidents per 100 drivers per million miles; $P = 0.12$), especially in women. There were no data on type of road, type of vehicle, time of day, severity of accidents, etc., which all may have been confounding factors. In a large multicenter, multinational survey in seven U.S. and four European cities with 313 type 1 and 274 type 2 diabetic drivers, 159 of whom were using insulin, type 1 diabetic drivers reported more crashes and moving violations than type 2 diabetic drivers or nondiabetic spouses (19 vs. 12 and 8%, respectively, $P < 0.001$) (51). However, results were given as percentages of individuals with accidents or mishaps and were not corrected for number of accidents or mileage, since some drivers with diabetes and multiple motor vehicle accidents had substantially reduced their driving. Perhaps the most worrying figures concerned the occurrence of hypoglycemia during driving. Of the type 1 diabetic drivers in the U.S., 31% admitted to have driven in a hypoglycemic stupor during the past 2 years, and 28% experienced hypoglycemia while driving in the past 6 months. These figures were considerably lower for the type 2 diabetic drivers (8 and 6%, respectively). In diabetic drivers from Europe, occurrence was strikingly lower: 4 and 16% for type 1 diabetic subjects, respectively. No hypoglycemic episodes behind the wheel were reported by European type 2 diabetic drivers (51). In most of these studies, essential data on patient, treatment, and mileage is missing, and control groups, if present, were not always well matched. None of the studies provided information on the circumstances or severity of the crash.

HOSPITAL REGISTRY–BASED RESEARCH — In a study in Western Australia, from 1971 to 1979, in 8,623 diabetic patients, overall admission rates of diabetic drivers were not higher than nondiabetic drivers, but there was a significant excess of admissions in diabetic men aged <55 years, both as drivers and as pedestrians (52). Hansotia and Broste (53), studying hospital records of 484 diabetic patients (436 type 2 diabetic subjects, 69.5% using insulin) from Marshfield, Wisconsin, found a slightly elevated accident ratio (1.32; $P = 0.01$). Unfortunately, the accident ratio was not corrected for miles driven. For traffic violations, this ratio was not significantly elevated (1.14; $P = 0.23$) (53). In a Dutch case-control study, prevalence of diabetes was slightly lower among drivers admitted to the emergency room (1.2%) than in the general population (1.3%). The finding that prevalence of diabetes was higher in passengers casts doubt on the validity of the data (54). Most recently, in a study of 11,244 patients in the Scottish Trauma Audit Group database who were admitted to the hospital for ≥3 days, or who died in the hospital as a result of an accident, only 23 patients with insulin-treated diabetes were identified. The road traffic accident rate for insulin-treated patients was estimated at 44.4 per 100,000 people per year, compared with 34.4 for the general population (relative risk 1.29; P = NS) (55).

In addition to the possible methodological problems with studies based on hospital records that will be discussed below, in all of the studies mentioned, information on the driving habits of the patients and particularly on crash variables is very limited or absent, reducing comparability and validity. However, the slightly increased accident rate per number of drivers is a consistent finding in most of these studies (52,53,55).

RESEARCH BASED ON RECORDS OF AUTHORITIES — A number of studies originate from 1970 or earlier (56–59), when traffic was very different from current times and treatment of diabetes differed from current practice. They report inconsistent higher, lower, and equal accident rates among diabetic patients compared with control subjects.

More recent studies include an Icelandic study, in which all drivers in single-car accidents between 1989 and 1991 ($n = 471$) were sent a questionnaire about driving habits, drinking habits, and chronic disorders, including diabetes. Single-car accidents could represent accidents solely due to driver-related factors, such as alcohol and drug use and medical disorders. Incidence of diabetes was very low and similar in the study group and a control group of 999 people chosen at random from the general population (both 0.6%) (60). McGwin et al. (61) studied 447 randomly selected drivers, who were aged ≥65 years and had been involved in one or more road traffic accidents during 1996 in Alabama, by means of telephone interviews. After adjustment for age, sex, race, and annual mileage, the odds ratio (OR) for diabetes was 1.1 (95% CI 0.7–1.9) when compared with both a control group and a drivers-not-at-fault group. Strikingly, among subjects who had been at fault for an accident in the 4 years preceding, the adjusted OR for diabetes was 2.5 (0.9–7.2), while it was only 0.9 (0.5–1.7) among those who had not had an accident in the previous 4 years. This suggests that there is a subgroup of (older) drivers with diabetes that could be at increased risk for road traffic accidents (61). Most recently, the National Highway Traffic Safety Administration linked police crash records of 68,770 drivers to medical and financial information. In drivers known for diabetes (and other metabolic conditions; number not given) with an unrestricted driving license, the relative risk for at-fault accidents was 1.44 ($P \leq 0.05$). In drivers with restricted driver's licenses because of metabolic conditions, the relative risk was 3.56 (P = NS) (62).

Taken together, although various studies find an increased accident rate among diabetic subjects, other studies do not or even show a lower rate. Some studies had relatively small numbers of diabetic patients. The most methodologically accurate study by McGwin et al. (61) on drivers aged >65 years indicates that there might be specific subgroups of diabetic patients that are at increased risk.

INSURANCE RECORD–BASED RESEARCH — Koepsell et al. (63) reviewed the records of a group health insurance in Washington state, identifying drivers aged >65 years who were injured in a road traffic incident during a 2-year period, comparing them with 446 case-control subjects not involved in an accident. A total of 234 cases were identified, of which only 26 were known for diabetes. The authors found a 2.6-fold increased injury risk in older diabetic drivers. In the six insulin-treated patients, the OR was 5.8 (95% CI 1.2–28.7). The OR was 3.1 for 12 patients using oral hypoglycemic agents (not statistically significant) and 0.9 for diet alone. Interestingly, patients with both diabetes and coronary heart disease had an OR of 8. It must be noted that the number of diabetic patients was extremely low. Clearly, the number of diabetic patients was low, although the study may indicate a trend (63). The Danish Diabetes Association, offering all members free collective accident insurance, reported that the risk of any accident was significantly lower in the diabetic group compared with two control groups (0.7 per 1,000 person-years vs. 4.5 and 5.5, respectively). Only one car accident was reported (64).

DRIVING SIMULATOR STUDIES — Two driving simulator studies, in which hypoglycemia was induced by means of a hyperinsulinemic clamp, have been performed by the group of Cox et al. (65,66). In a group of 25 type 1 diabetic patients, driving 4 min in a low-fidelity driving simulator, they found that driving performance was not disrupted at mild hypoglycemia (3.6 mmol/l). During moderate hypoglycemia (2.6 mmol/l), driving performance was reduced, with significantly more swerving, spinning, time over the midline, and time off the road. In addition, there was more compensatory very slow driving. Strikingly, only 50% of the subjects with reduced driving performance stated that they would not drive under similar conditions in everyday life (65). In a second simulator study, 37 type 1 diabetic patients drove 30 min during progressive hypoglycemia, from 4.0 to <2.8 mmol/l. When subjects felt hypoglycemic, they were given the opportunity to self-treat the hypoglycemia by drinking a (placebo) glucose drink or to discontinue driving. Diminished driving performance was observed at all glucose levels (4.0–3.3, 3.3–2.8, and <2.8 mmol/l), although this was only seen for a limited number of parameters, with no consistent pattern. During hypoglycemia, 11 subjects treated themselves and 7 subjects stopped driving. Thus, only 32% of patients took corrective action, whereas 79% detected hypoglycemia <2.8 mmol/l. This indicates that even in an experimental setting, only a relatively small percentage of diabetic patients take appropriate action on experiencing hypoglycemia during driving (66). However, the use of a low-fidelity, fixed-base, non–mock-up (no model of a real car around the simulator) driving simulator is probably not appropriate to assess complex aspects of driving (67). Furthermore, in such a complex study (awareness of impending hypoglycemia, intravenous lines, electroencephalogram-cap, questions posed during driving) a control group is essential for validity.

BLOOD GLUCOSE AWARENESS TRAINING — Cox et al. (68) have also developed blood glucose awareness training (BGAT), a patient education program designed to teach patients to more accurately estimate blood glucose levels (68–70). Remarkably, after 4 years of follow-up, accident rates per million miles driven were 6.8 in the BGAT group versus 29.8 in the diabetic control group ($P = 0.01$), presumably due to an increased awareness of when not to drive (70). During long-term follow-up, the number of traffic violations was significantly reduced from baseline. However, there was no clinically relevant improvement in patients' avoidance of driving with low blood glucose levels (48–51%). The rate of road traffic accidents was not mentioned. Similarly, in a Dutch study on BGAT, the decision not to drive during hypoglycemia improved significantly ($P = 0.01$), and patients were less often involved in a traffic accident (0.6 vs. 0.2 accidents per patient per year; $P = 0.04$) (71,72). BGAT may well be a relatively easy and effective method to reduce traffic violations and accidents in diabetic patients.

COMMERCIAL TRUCK DRIVING — Since chances of injury, the number of injuries, and the severity of injuries are higher in trucks (73,74), stern restrictions have been imposed on driving privileges for vocational drivers with diabetes (39–41,44). Based on various assumptions, Songer and Lave (75) have estimated that if diabetic patients would be licensed to drive commercial motor vehicles, mild and moderate hypoglycemia would increase the amount of accidents 6.1-fold for insulin-dependent diabetic patients and 4.1-fold for non–insulin-dependent diabetic patients, resulting in an additional 42 accidents per year in the U.S. The risks of diabetic drivers with a history of severe hypoglycemia would be increased nearly 20-fold. However, they also estimate that if these latter diabetic subjects are excluded, the relative risk drops to 3.7 and 2.7, respectively, and the number of additional accidents per year to 20 (75). In a companion report, the same authors conclude that given the fact that other higher risks are generally accepted (e.g., driver's licenses from the age of 16 years, allowing some unsafe motorways, etc.), the additional risks from insulin-using individuals are well within the accepted range of risk (76). A Canadian research group merged a number of databases of the Quebec Automobile Insurance Society, providing information on driving licenses, accidents, traffic violations, and medical conditions of >20,000 license holders, 1,198 of whom were commercial motor vehicle drivers who responded to a telephone survey (77). The number of diabetic drivers remains unclear. Strikingly, in each of six different regression models, diabetic drivers in straight trucks had a significantly higher number of road traffic accidents. Since this was not found in articulated trucks, it could be that the physically and medically fittest drivers were selected for the largest (articulated) trucks (77). In an extension of this study, Laberge-Nadeau et al. (78) analyzed the severity of road traffic accidents of commercial motor vehicle drivers, and no significant association between diabetes and crash severity was found for either type of truck. In 2000, the group again reports, on what appears to be the same cohort during the same period, that only drivers with a license for single (unarticulated) trucks, not using insulin and without diabetes complications, had an increased relative risk of 1.76 (95% CI 1.06–2.91). All other subgroups of diabetic truck drivers had relative risks of ~1 (0.65–1.02), and therefore insulin use was not associated with higher crash risk. The previously suggested "healthy workers effect" is supported by the fact that the percentage of drivers holding the license that is actually driving commercially is similar in the control group and in the group of diabetic drivers in good health. This percentage is considerably lower in the group of diabetic drivers with complications or using insulin (79).

Although the suggested explanation is plausible, other more methodological problems remain. First, about one-third of the known drivers were not included in the studies for various reasons. Second, a number of variables, including mileage, working hours, and number of hours behind the wheel, were obtained through a telephone survey. It could be that because of their medically restricted driving licenses, diabetic drivers were more reluctant to admit to driving more miles or longer hours, thus influencing results. However, the studies clearly indicate that an increased risk for (a subset of) diabetic truck drivers could very well exist.

OLDER DIABETIC DRIVERS

— It has been well established that older age is associated with poorer driving performance (80), a higher number of road traffic accidents per mile driven, and a higher likelihood of injury or death (33–36). Moreover, cognitive functioning seems to decline more rapidly in older diabetic patients than in healthy subjects (81,82). The two largest studies on diabetes (61,63) and driving in the elderly have been discussed above. Koepsell et al. (63) found a 2.6-fold increase in injury risk for diabetic drivers, which was even higher (OR 5.8) for patients treated with insulin or oral hypoglycemic agents (3.1) and for drivers with a duration of diabetes >5 years (3.9) (63). McGwin et al. (61) only found an association with accident involvement among diabetic subjects already involved in a road traffic accident in the previous 4 years but found no increased risk for the whole group of elderly diabetic drivers nor for treatment modality. Forrest et al. (83) reported a clear and significant association between diabetes and driving cessation in 1,768 women aged ≥71 years (OR 2.53 [95% CI 1.57–4.07]). This implies that older diabetic drivers are more likely to give up driving than those who do not have diabetes. One may argue that older diabetic drivers adequately self-regulate their driving pattern. These results are confirmed by Gallo et al. (84) who found that in 589 subjects aged ≥60 years, driving cessation was (slightly) more likely in drivers with diabetes (1.37 [1.03–1.83]). In this group, there was no association between diabetes and road traffic accidents or violations (0.88 [0.50–1.53]) (84).

ACCIDENT FREQUENCY DUE TO MEDICAL CONDITIONS

— In British and American research, it was shown that roughly 95% of road traffic accidents are attributable to human errors or defects from the vehicle, the road, or the environment (85,86). Various European studies indicate that only 0.4–3% of fatal accidents were caused by medical conditions (87–89). Epilepsy appears to be the most common cause (38%), with insulin-treated diabetes to be the cause in 18% and acute myocardial infarction and stroke each in 8%. No cause could be established in 21% (86).

Harsch et al. (90) found in 450 randomly selected type 1 and type 2 diabetic German patients that symptomatic hypoglycemia during driving was rare, with an occurrence of 0.19–8.26 per 100,000 km driven or 0.02–0.63 per year driven. The incidence increased significantly with the "strictness" of treatment, with odds approximately fourfold higher during intensified insulin treatment and continuous subcutaneous insulin infusion than during oral treatment. Traffic accidents due to hypoglycemia occurred 0.01–0.49 times per 100,000 km driven or 0.007–0.01 per year driven. Strikingly, there was no difference in accident rate between treatment modalities (90). Given the fact that the diagnosis of hypoglycemia can be quite difficult, it may well be that episodes of hypoglycemia causing a road traffic accident have remained unrecognized or have been wrongfully diagnosed (91). Nevertheless, it can be concluded that only a very small proportion of road traffic accidents are caused by a medical condition in general and by diabetes in particular.

DESIRED DATA

— To objectively and accurately consider the relationship between diabetes and driving ideally, valid data should be available on the following aspects of driving in patients with diabetes: accident rate, driving performance, the effect of diabetes-related factors, and the possibility of modification of certain aspects.

Ultimately, whether patients with diabetes cause more accidents seems paramount. However, the mere accident rate does not provide sufficient information. Nature and severity of accidents are important parameters. Data should be corrected for relevant variables, including age, sex, driving experience, miles driven per year, and road type. In patients with diabetes, there may also be other confounding factors, including type of diabetes, treatment modality, and hypoglycemia awareness. Patients may impose restrictions to themselves, e.g., on driving frequency, distance, or on conditions (night time, bad weather, etc.). Moreover, the relation between accidents on the one hand and diabetes proper and glycemic status during the accident on the other hand should be assessed. Furthermore, certain (subclinical) diabetes complications could negatively influence driving performance and could increase the accident risk. This is evident for retinopathy, cataract, and neuropathy, but in recent years, it has also become known that in patients with diabetes, the brain may suffer changes similar to the effect of aging (81,82). Therefore, data on driving performance as such are equally important. Patients with diabetes are by no means a homogenous group. Treatment, incidence of hypoglycemia, diabetes complications, and hypoglycemia awareness can vary considerably between groups but also between individuals. For these reasons, it is important to identify subgroups of patients who are at increased risk. Finally, after identification of the factors that negatively influence driving performance and accident risk in patients with diabetes, the next step will be to investigate whether and how these factors can be positively modified.

RESEARCH METHODS AND PITFALLS

— To research the various aspects of diabetes and driving, several study methods have been applied, each of which entails potential strengths and biases. Most frequently, accident rates have been analyzed in various samples of diabetic patients.

Office-based research

In office-based samples (usually outpatients from a general or diabetes clinic), the possibility of selection biases exists. These may be related to the type of clinic, the selection of patients by physicians, and willingness and opportunity of patients to participate. Finally, there could be a "survivor bias" (patients having had a fatal accident cannot participate in the study).

Hospital and authority record–based research

Some studies (52–62) have focused on samples of subjects who had recently experienced road traffic accidents. These subjects may have been identified in hospital and emergency room records (52–55) or records of police and other authorities (56–62). Records of emergency room and hospital admission could also carry a "survivor bias" or the opposite, where patients in a certain group could have lighter road traffic accidents not requiring transportation to an emergency room. Moreover, in countries and states where health personnel is obligated to report disease-related traffic accidents (e.g., California), patients who have had a collision because of hypoglycemia will be reluctant to be transported to a hospital. Police records could be more representative, although in countries where police presence after an accident is not mandatory, biases could occur. Only three studies have been performed involving insurance records (63,64,77–79), which are most likely to be representative and complete. Perhaps for commercial reasons, insurance companies have been reluctant to cooperate in scientific research. In all studies with authority-based records, there is a potential bias in reporting of the incidence of diabetes to the authority by the patient, as this is not mandatory in many countries. Patients who are most likely to experience problems with driving are most likely to not report their diabetes to the insurance company or licensing authority.

Questionnaires

In many (retrospective) studies, information is obtained through questionnaires, filled out by the drivers themselves (45–51,70,72,83,84). This can cause a recall bias on the one hand and a bias of subjectivity on the other hand. Often, subjects filling out questionnaires tend to neglect negative experiences or describe occurrences in a more positive fashion (92). The value of questionnaires is therefore limited.

Driving simulator research

Driving simulation studies have potential advantages over other types of studies since they examine driving performance, specifically, circumstances as urban driving, highways, but also weather conditions can be simulated in a standardized manner. This research method relies on comparative measurements. Thus, it cannot be claimed that simulator results have absolute validity but only that differences found between conditions or groups represent differences that exist in reality. Therefore, it is an indirect measure of the relative risk of road traffic accidents. However, good correlation has been shown (67,93). When using driving simulation as a research tool, it is of importance to utilize a suitable driving simulator and appropriate programming. A high-fidelity driving simulator, where reality is closely approximated, is required to assess more complex aspects of driving, like driving performance. A low-fidelity simulator can be used be used to research other hypotheses, for example, concerning behavior and decision making of patients with diabetes (67).

CONCLUSIONS — When performing research on the relationship between diabetes and driving, several study designs can be applied, each of which entails potential strengths and biases. Evaluation of the available research on diabetes and driving is difficult. Most older studies have either found no association between diabetes and traffic accidents or a small, usually not statistically significant, increase of the relative risk. More recent U.S. research, however, indicated a clear trend, frequently statistically significant, toward a slightly increased risk of road traffic accidents in diabetic drivers. The increase of the relative risk in some studies was only found in specific subgroups of diabetic patients, not consistent throughout various studies. Overall, the available studies indicate that road traffic accidents directly caused by diabetes seem to be relatively rare occurrences. However, without a doubt, hypoglycemia during driving does occur and can cause traffic accidents. If any trend can be distilled, current knowledge may point toward a slightly increased risk of road traffic accidents for drivers with diabetes. However, no subgroup that is particularly at risk has been unequivocally defined.

The appraisal of potential risks of participation in traffic of a certain group of people, versus the social aspects of denying participation, may be influenced by society, media, and experts, but final appraisal should be performed by the legislators.

Recommendations for future research

At this point in time, to increase current understanding, to support decisions on legislation concerning diabetes and driving, and to tailor legislation to specific subgroups at risk, three types of research would be most helpful. First, there must be a comparison of a large, multicenter, multinational, prospective follow-up study on the rates of traffic accidents and incidents of patients with diabetes to a well-matched control group from the general population. The study should be performed in countries or states where reporting diabetes to a central authority is mandatory and where all traffic accidents and violations are registered by either police or insurance companies, including all relevant information. Also, relevant diabetes-related information should be available to identify specific subgroups at risk for road traffic incidents or accidents, with a specific focus on older drivers. Information of particular relevance may include therapy (hypoglycemic drugs, insulin, or insulin pump), duration of diabetes, diabetes complications, and self-monitoring of blood glucose, specifically before and during driving. On the other hand, information on age and socioeconomic factors should be available, including school education, income, alcohol use, and drug abuse. It might well be that the latter socioeconomic factors may prove to be more relevant for traffic accidents and violations than diabetes per se. When possible, data on commercial vehicle drivers should be collected as well. Second, regarding glucose awareness, programs such as BGAT are potentially very useful, and their implementation in clinical practice should be considered. Future research should focus on their long-term efficacy and the necessity of repetitive glucose awareness instruction; in addition, its use in specific subgroups such as patients with neuropathy, hypoglycemia unawareness, or (future) insulin pump users may be studied. Third, research on driving performance of various groups and subgroups of patients with diabetes should be performed, preferably in a well-validated state-of-the-art driving simulator. It should primarily focus on driving performance and on the influence of hypoglycemia and hyperglycemia. Subsequently, specific subgroups of patients with diabetes with impaired driving performance should be identified. If future research would indicate that hyperglycemia itself is associated with decreased driving performance, screening for (unknown) diabetes might be considered, for example, in specific groups such as commercial drivers or drivers over a certain age. Other driving simulator studies may investigate the impact of BGAT on driving performance. Finally, when subgroups of patients who are at increased risk of road traffic incidents and accidents have been identified, research should subsequently focus on altering factors that influence the increased risk, including behavioral, pharmacological, and technical possibilities.

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