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Driving Safety after Spinal Surgery: A Systematic Review

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This study aimed to assess driving reaction times (DRTs) after spinal surgery to establish a timeframe for safe resumption of driving by the patient postoperatively. The MEDLINE and Google Scholar databases were analyzed according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) Statement for clinical studies that investigated changes in DRTs following cervical and lumbar spinal surgery. Changes in DRTs and patients' clinical presentation, pathology, anatomical level affected, number of spinal levels involved, type of intervention, pain level, and driving skills were assessed. The literature search identified 12 studies that investigated postoperative DRTs. Six studies met the inclusion criteria; five studies assessed changes in DRT after lumbar spine surgery and two studies after cervical spina surgery. The spinal procedures were selective nerve root block, anterior cervical discectomy and fusion, and lumbar fusion and/ordecompression. DRTs exhibited variable responses to spinal surgery and depended on the patients' clinical presentation, spinal level involved, and type of procedure performed. The evidence regarding the patients' ability to resume safe driving after spinal surgery is scarce. Normalization of DRT or a return of DRT to pre-spinal intervention level is a widely accepted indicator for safe driving, with variable levels of statistical significance owing to multiple confounding factors. Considerations of the type of spinal intervention, pain level, opioid consumption, and cognitive function should be factored in the assessment of a patient's ability to safely resume driving.

Keywords: Reaction time; Driving; Anterior cervical discectomy and fusion; Fusion; Spine

Introduction

The driving reaction time (DRT) is defined as the amount of time, in the order of milliseconds or seconds, at which a driver can adequately react to a stimulus which requires them to brake emergently [1]. Although DRTs can vary depending on variables such as the mental processing time, movement time, and device response time, there are standard or safe ranges reported [2,3]. Thus, a standardized postoperative DRT might represent an objective indicator of the ability of a patient to safely resume driving after spinal surgery.

However, studies that have described changes in DRT after spinal interventions are numbered and the methodology used is not well standardized. Differences in patients' initial presentation and pathology, anatomical level

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of the lesion and the number of spinal levels affected, nature of surgical intervention, pain medication consumption, and baseline driving skills are some of the factors that limit the generalizability of the conclusions. Although there is no definitive single objective measure or guideline that can verify the ability of a patient to safely resume driving after spinal surgery, DRT is accepted in the orthopedic and neurosurgery literature as the best available and studied quantifiable indicator for safe driving.

Herein, we provide an up-to-date review on postoperative driving recommendations following spinal surgery, based on changes in DRTs. We also discuss the limitations of the currently available published literature and the potential improvements that can be brought about in future studies.

Materials and Methods

1. Search methodology for identification of studies

A retrospective literature review was performed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines with use of a Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist (Fig. 1) [4,5]. The PubMed/MEDLINE and Google Scholar databases were analyzed for studies published as of May 1, 2016. The following search terms were used: "driving reaction time" [All Fields] AND "spinal surgery" [All Fields], OR "driving" [All Fields] AND "reactiontime" [All Fields] AND "spinal surgery" [All Fields] OR "automobile driving, reactiontime, spine" [MeSH Terms]. The retrieved studies were saved for further review if they satisfied the following inclusion criteria: (1) cervical or lumbar spinal surgery and (2) preoperative and postoperative DRT. Studies that analyzed orthopedic procedures not involving the spine and studies that did not report DRT measurements were excluded. A manual search of the reference lists of the saved articles was performed to identify additional articles for inclusion.

2. Procedure

The apparatus used to determine preoperative and postoperative DRT in five of the six reviewed studies was a

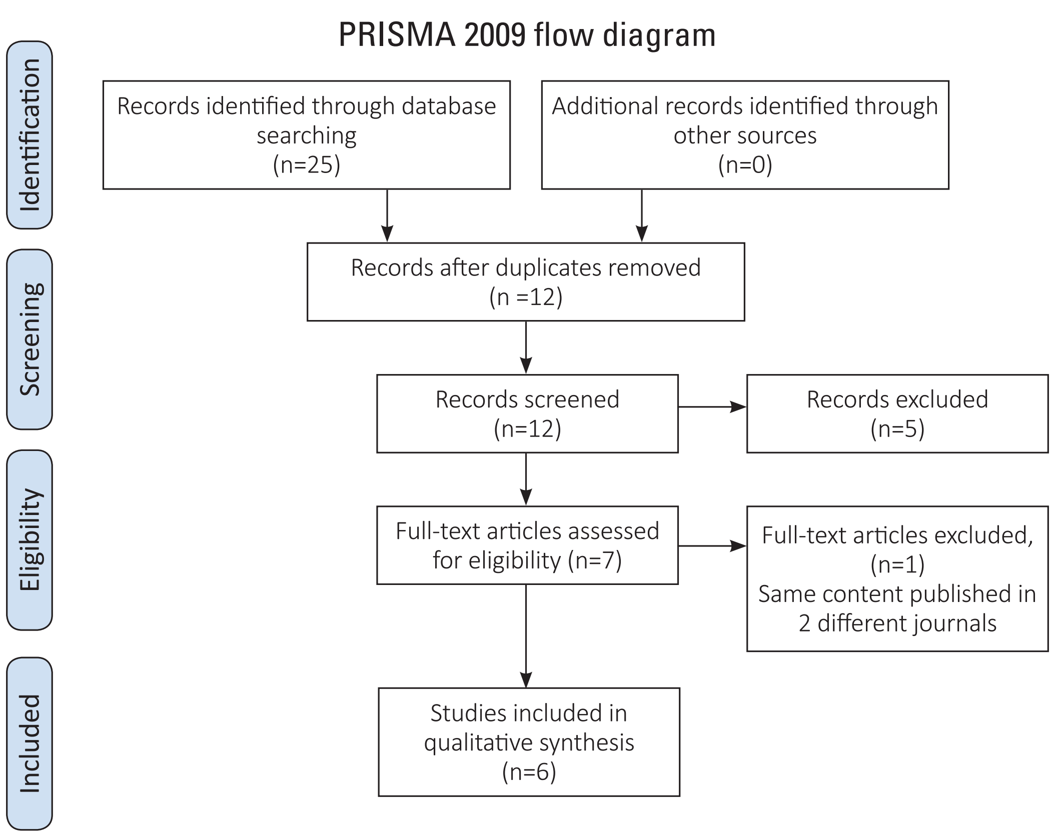

Fig. 1. Flow diagram according to Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). Data from Moher et al. PLoS Med 6: e1000097 [5].

custom-made in-office driving simulator test that measured drivers' perceptions and reaction times [2,3,6-8]. The stimulator allowed users to stimulate normal driving habits with an adjustable car seat fixed on a frame with hanging pedals. Once the patient fully depressed the accelerator pedal, a green indicator light would appear in front of the patient. Then, after 5–10 seconds with the accelerator still fully depressed, an observer (unannounced to the patient) would trigger a red light signal to appear in front of the patient. The patients were previously instructed to push the brake pedal as quickly as possible once they noted the red signal. The time lapse between turning on of the red signal indicator and the application of the brakes was measured in milliseconds and recorded as DRT.

DRT was reportedly measured using a commercial computer instrumentation and software (Vericom Reaction Timer, Rogers, Minnesota, United States) [9,10]. Similarly, the simulation started when the patient depressed the accelerator pedal for a predetermined amount of time, which correlated to a speed of 35–65 mile/hr (mph) on the system. The software then recorded the reaction time to five different on-road stimuli. Herein, the patients were tested preoperatively and postoperatively at 2–3, 6, and 12 weeks following spinal surgery.

3. DRT relationship to pain

Since pain may induce a "reflex inhibition" on muscles, it could theoretically increase DRT [11]. The studies which included pain assessments used the visual analog scale (VAS) for pain; pain was scored on a scale of 0 (no pain) to 10 (very severe pain). Data on analgesic intake was evaluated as a potential confounding influence on DRT.

Results

1. Search results

Overall, 12 studies that investigated DRTs post cervical and/or lumbar spinal surgery were identified. After a review of the titles and abstracts, seven relevant full text papers were assessed in detail. One article was excluded because it was published in two different journals [8]. Consequently, six studies met our inclusion criteria and were included in this review (Table 1) [2,3,6-9]. Among these studies, three studies had reviewed the changes in DRT after lumbar spinal intervention, after cervical spinal surgery in one study, and after cervical or lumbar spinal surgery in one study. The range of procedures reviewed included selective nerve root block [2], anterior cervical discectomy and fusion (ACDF) [6], lumbar fusion and/or decompression [3,7,9], and posterior sequestrectomy or subtotal discectomy [12].

2. Reaction time

The optimal DRT consistent with safe driving is debatable because of the multiple variables that may affect its calculation. Different road authorities have suggested safe DRT, ranging between 700 and 1,500 ms [2]. In an on-road study of normal drivers, the median reaction time in an emergency was found to be 660 ms (range, 300–1,200) [13]. Several factors are considered when calculating a safe DRT such as driver's age and gender and cognitive load [14-16]. These factors may confound the two elements that make up DRT: the neurological or mental reaction time and movement or foot transfer time [3,17]. The effects of general anesthesia on reaction times do not persist longer than 24 hours. Therefore, it was not considered in our assessments of DRT [18]. Contrarily, spinal pathologies and degenerative spinal diseases may cause a delay in the neural signal transfer, resulting in longer DRT [12]. The lack of a universally accepted safe DRT value and the multiple confounders that may influence it have led many clinical researchers to compare pre-procedural DRTs as a guide to post-procedural DRTs.

3. DRT following cervical spinal procedures

Although cervical disc herniation without myelopathy does not directly influence the lower extremities, DRT may be prolonged because of reflex inhibition of the muscles induced by pain [11]. There is very limited literature on the time by which post–spinal surgery DRT returns to preoperative times for patients who undergo cervical surgery [6,9]. Patients who received ACDF for cervical radiculopathy reportedly had a significant improvement in their pre- and postoperative DRT at the time of discharge and upon follow-up [6]. Despite the small sample size of 12 and the short follow-up period, it was concluded that it was safe for the patients to resume driving at the time of discharge.

Scott et al. [9] studied the optimal time to return to driving in 37 patients who underwent spinal procedures

Table 1. Summary of the methods, results, conclusions, and limitations of driving reaction time studies

Study	Design and methods	Location	Comparison groups	DTR findings	Correlation with pain	Conclusions	Limitations
Al-khayer et al. (2008) [2]	Prospective Custom-built car simulator	Lumbar	20 Radiculopathic patients (10 right, 10 left) undergoing SNRB versus 20 age- and sex-matched normal subjects.	Statistically significant increase in DRTs immediately, and two weeks after SNRB. After 6 weeks, the differences in DRT were no longer significant.	The correlation between leg pain (VAS) and the DRT was insignificant.	No recommendation on when to resume driving.	1) Small sample size 2) Limited number of DRTs measurement post-SNRB. 3) Data on patients' functional status, narcotics usage, and pain duration before SNRB were not obtained. 4) Did not investigate the difference between the two DRT sub-periods: reaction time and movement time.
Liebensteiner et al. (2010) [3]	Prospective Custom-built car simulator	Lumbar	21 Primary lumbar fusion versus 31 age-matched healthy subjects.	No significant difference in pre versus immediate postoperative DTR. DTR is significantly reduced during 3 months of follow-up. No correlations between driving skill and DRT	Moderate to high correlations were found between the VAS rating of back pain and DRT	Safe to resume driving after discharge following lumbar fusion.	1) The small sample size permitted no comparisons between the different types of lumbar fusion or approaches. 2) Short postoperative follow-up period. 3) Did not investigate the difference between the two DRT sub-periods: reaction time and movement time.
Lechner et al. (2013) [6]	Prospective Custom-built car simulator	Cervical	12 ACDF (cervical radiculopathy) versus 31 healthy subjects.	Significant improvement in DRT immediately after ACDF.	VAS for arm and neck pain showed significant improvement. Comparison of duration of pain before surgery and DRT revealed no correlation.	Safe to resume driving after discharge for the patients undergoing ACDF surgery. Pain med has no impact on DRT.	1) Small sample size 2) Limited number of DRTs measurements (only 2 postoperative measurments). 3) Did not investigate DRT in different age groups 4) Did not investigate the difference between the two DRT sub-eriods: reaction time and movement time.
Thaler et al. (2012) [8]	Prospective Custom-built car simulator	Lumbar	49 Posterior sequestrectomy or subtotal discectomy (nerve root compression versus) 31 age-matched healthy subjects.	Statistically significant improvement in DRT postoperatively at discharge. No statistical difference in DRT between different levels.	No correlation was found between VAS for leg or back pain and DRT	Safe to resume driving after discharge, for the patients undergoing lumbar discectomy.	1) Small sample size 2) Limited number of DRTs measurements (only 2 postoperative measurements). 3) Did not investigate the difference between the two DRT sub-periods: reaction time and movement time.

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Table 1. Continued

Study	Design and methods	Location	Comparison groups	DTR findings	Correlation with pain	Conclusions	Limitations
Scott et al. (2015) [9]	Prospective Computer software	Cervical and Lumbar	37 Patients (23 lumbar & 14 cervical) versus 14 Healthy subjects. Cervical patients were subdivided into anterior versus posterior approach and myelopathic versus nonmyelopathic Lumbar patients were subdivided into decompression versus fusion with or without decompression, and single-level versus multilevel surgery	Cervical and lumbar surgery showed no significant differences between pre- and postoperative DRT Only the patients having single-level procedures had a significant improvement from a preoperative DRT at 2 to 3 weeks. None of the other subgroups had a difference in the DRT.	No correlation between the preoperative and postoperative DRTs and VAS score. No correlation between the DRT and opioid use either pre- or postoperatively.	Single-level lumbar fusion who are not taking opioids can return to driving as early as 2 weeks	1) Small sample size 2) Did not investigate the difference between the two DRT sub-periods: reaction time and movement time. 3) Sex and age unmatched control sample and high rate of patient attrition. 4) Study population is relatively heterogeneous 5) Measured the speed at which the patient can compress a pedal and not the strength with which they are able to do so, and thus the results may not be generalizable.
Liebensteiner et al. (2016) [7]	Prospective Custom-built car simulator	Lumbar	38 Patients (17 underwent monosegmental instrumented posterolateral fusion; 14 underwent polysegmental instrumented posterolateral fusion; 7 had other procedures e.g., Anterior lumbar interbody fusion or circumferential fusion).	Increased DRT at the time of discharge (1 week) after lumbar spinal fusion decreased at 3 months postoperatively. No statistically significant changes in DRT in relation to the number of levels A tendency towards statistical significance for the influence of patients' driving frequency on DRT.	Moderate and positive correlation coefficients were calculated for VAS back pain and postoperative DRTs.	Recommend driving abstinence until 3 months after lumbar fusion surgery.	1) The small sample size permitted no comparisons between the different types of lumbar fusion or approaches. 2) Did not investigate the difference between the two DRT s ub-periods: reaction time and movement time. 3) Postoperative increase in DRT was statistically just a trend (possibly type 2 error).

DTR, driving reaction time; VAS, visual analogue scales; SNRB, selective nerve root block; ACDF, anterior cervical discectomy and fusion.

(23 underwent cervical, and 14 underwent lumbar procedures); patients were subdivided into cervical surgery patients via anterior (n=5) and posterior (n=9) surgical approaches and myelopathic (n=11) versus nonmyelopathic (n=3) patients. Lumbar surgical patients were subdivided into single-level (n=9 patients) versus multilevel (n=14) and decompression alone (n=11) versus fusion with or without decompression (n=12). There was a general trend of increased DRT following the surgery; however, these values did not reach statistical significance in

either postsurgical cervical or lumbar patients. Only the patients who underwent single-level lumbar intervention demonstrated a statistically significant improvement in postoperative DRT at 2–3 weeks over their respective preoperative DRT. The other subgroups did not demonstrate a significant difference in pre- and postoperative DRT. Scott et al. concluded that patients who undergo a single-level lumbar fusion and are not on opioids may resume driving as early as 2 to 3 weeks following surgery.

The tendency for postoperative increase in DRT, which is in contrast to that reported previously [6], was attributed by Scott et al. [9] to two factors: the heterogeneity of the patient sample pool in conjunction with the inclusion of more patients with myelopathy and chronic pain who were less likely to have immediate postoperative symptom resolution. Even though Scott et al. demonstrated increased postoperative DRTs, the mean difference between the preoperative and postoperative DRTs was quite negligible (0.031 seconds). This would reflect a 3-foot increase in the total stopping distance if a driver were traveling at 70 mph.

Notably, the posterior cervical surgical approach and multilevel lumbar surgery groups demonstrated the greatest increase in postoperative DRT. These findings may have been secondary to the more extensive surgeries and the likelihood that these patients had more pre- and postoperative pain that required greater doses of opioids for pain control.

Table 1 summarizes the methods, results, conclusions, and limitations of the studies which involved cervical spinal procedures.

4. DRT following lumbar spinal procedures

Scott et al. [9] studied the changes in DRT following lumbar surgery in 23 subjects and found no statistical significance; 11 patients underwent surgery, which involved decompression alone, while 12 received fusion with or without decompression intervention. They further evaluated DRT changes associated with single-level versus multilevel lumbar intervention. Only the patients who underwent single-level procedures showed a significant improvement in postoperative DRT at 2–3 weeks compared to their preoperative DRT. None of the other lumbar surgery subgroups demonstrated a statistically significant difference in DRTs. The group that received decompression alone demonstrated improvement in postoperative DRTs that approached statistical significance. Similar results were reported previously [12], wherein the postoperative DRT actually improved compared with the preoperative DRT among patients who underwent lumbar disk surgery for radiculopathy.

In 2010, Liebensteiner et al. [3] conducted a study on 21 consecutive patients who had primary lumbar fusion. In contrast to Al-khayer et al. [2] study, Liebensteiner et al. found no significant difference between preoperative and immediate postoperative DRT at the time of discharge (approximately 7 days) post lumbar intervention. However, the authors did demonstrate a statistically significant improvement in postoperative DRT at the 3-month follow-up visit. Subsequently, since there was no significant statistical difference between pre- and immediate postoperative DRT, Liebensteiner et al. concluded that it is safe to resume driving after discharge from the hospital following lumbar fusion.

The original study by Liebensteiner et al. in 2009 had some shortcomings (short postoperative follow-up period, a small and non-uniform sample size, and the inability to study the effects of different types of fusion surgery). In 2016, Liebensteiner et al. [7] repeated the study with a greater and more homogeneous sample size. The authors extended their previous study to include 38 patients, which were subdivided into subgroups based on the number of lumbar levels fused. The authors identified no statistically significant changes in DRT in relation to the number of levels fused irrespective of the type of lumbar surgery, or age of the patient. There difference approached statistical significance (p=0.051) after accounting for preoperative driving frequency (ever, seldom, sometimes, often, very often). In contrast to that in their prior study, the authors found increased DRT at the time of discharge (1 week) after lumbar spinal fusion and noted a statistically significant difference in DRT which decreased at 3 months postoperatively.

The authors opined that it may be safe to resume driving at 3 months after lumbar fusion surgery. Of note, the patients were not tested between the time of discharge (1 week) and the postoperative follow-up visit at 3 months. Since Liebensteiner et al. [7] noted no significant difference between the pre and postoperative DRT after the various types of lumbar fusion interventions, their recommendations might be valid for the majority of types of lumbar fusion.

Unlike all other lumbar DRT studies, Thaler et al. [12]

showed a statistically significant improvement in DRT at discharge after posterior sequestrectomy or subtotal discectomy for lumbar radiculopathy [2,7,9,18]. The study population comprised largely of patients who had a neurological impairment of the foot (31 of 42 patients; 73.8%). Their study endorses Scott et al. [9] findings that the shortest DRT is achieved by individuals who moved only their foot for the purpose of applying the brake and not their entire leg [19]. Despite the differences in DRT regarding the level of disc herniation and the affected muscles, Thaler et al. [12] found, no meaningful difference. As such, recommendations according to the affected muscles or levels cannot be made. The dramatic improvement in DRT in the study sample was likely due to minimal surgical dissection and the resolution of radicular pain. Thus, Thale et al. concluded that it is safe to resume driving after hospital discharge in the case of patients with right or left paresis caused by lumbar disc herniation post decompression.

Al-khayer et al. [2] performed a prospective study on 20 patients who received nerve blocks of the lumbar spinal nerves. They found statistically significant increase in DRTs immediately, and two weeks after right lumbar nerve root blocks. After 6 weeks, the differences in DRT were no longer significant. However, Al-khayer et al. [2] do not provide clear recommendations as to the optimal time for resumption of driving by the patients. The significant postoperative increase in DRT may have resulted from direct application of local anesthetics to the nerve root, which would explain the differences compared to DRT after lumbar fusion in the previously mentioned studies [7,9,18].

Discussion

1. DRT relation to pain and pain medication

The inhibitory effect of pain on reflexes seems to be one of the most important confounders that influence DRT, and prolong the foot transfer time on the pedal [3,6,11]. Moreover, the sensation of pain might have an impact on monitoring visual acuity, which is an important determinant of the reaction to visual stimuli [6]. Moreover, certain spinal diseases such as radiculopathy may cause a delay in the neuron transfer time which increases DRT.

Scott et al. [19] concluded that pain influences muscle performance and therefore DRT. Liebensteiner et al. [3] demonstrated high and moderate correlation between back pain assessed on VAS with pre- and postsurgical DRTs at approximately 7 days. Interestingly, for unknown reasons the correlation between DRT and back pain appeared to disassociate 3 months after the surgery. Remarkably, Liebensteiner et al.'s [7] study conducted in 2016 demonstrated no significant correlation between VAS and DRT 7 days after surgery. This finding could be attributed by the administration of relatively higher doses of analgesic medication in the immediate postoperative period. Ultimately, findings by Liebensteiner et al. emphasize the hypothesis that pain prolongs DRT. On the contrary, Alkhayer et al. [2] investigated leg pain and DRT before and after lumbar nerve root blocks, and recorded no significant correlation. Similarly, Thaler et al. [12] found no correlation between VAS scores for leg or back pain and DRT. A similar finding was reported for patients who underwent ACDF in a different study by Lechner et al. [6].

The effect of analgesics, especially opioids on driving ability has been discussed by numerous studies [3,9,12,20-22]. The literature suggests that analgesics may not have a significant effect on DRT, and studies do not recommend a abstinence from driving for patients who receive opioids for postoperative pain control after spinal surgery [3,6,12]. Though, driving is a complex task that requires mental alertness and a variety of cognitive functions. Data related to driving while on acute or chronic prescription strength analgesics is a controversial trending topic among many health professionals, drivers, and law enforcement authorities. Wilhelmi and Cohen [20] performed an extensive literature review and concluded that although there is psychomotor impairment following acute administration of opioids or an increase in opioid dosage; the level of impairment diminishes with chronic, stable opioid usage. We recommend individual patient evaluation focused on age, type of pain medication and frequency of use, history of opioid consumption, and other factors that might affect driving abilities.

2. DRT correlation with driving frequency

Studies have found increased DRT after total knee arthroplasty in patients with more driving experience [1]. However, Liebensteiner et al. [3,7] could not establish a significant correlation between driving frequency and DRT after spinal surgery in both of their studies. Further assessment of the effect of driving frequency on DRT after spinal surgery in future studies is recommended.

3. Recommendations and timing

Recommendations on resuming driving following spinal surgery should be tailored to the spinal procedure and spinal levels involved. The relatively small sample sizes in studies that evaluated DRTs after surgical interventions at varying levels limits the scope for generalized conclusions. The recommendations provided here are based solely on DRT changes. Other factors that affect the driving ability should be evaluated individually including in the context of narcotic usage.

Based on the available evidence we recommend the following: (1) for patients undergoing single-level lumbar spinal fusion, resumption of driving as early as 2 weeks is acceptable; (2) for patients who undergo multilevel lumbarspinal fusion, it is safe to resume driving 3 months after the surgery; (3) for patients who have paresis from lumbar disc herniation, it is safe to continue driving after hospital discharge; (4) for patients undergoing ACDF for cervical radiculopathy, it is safe to resume driving after hospital discharge.

4. Limitations

Despite taking efforts to create a driving simulator that reliably tests emergency braking, the complexity of real driving cannot be simulated in its entirety. Another universal limitation common to DRT studies is their small sample sizes and the relatively short and infrequent postoperative follow-up times. None of the reviewed studies assessed the individual components that make up DRT: reaction time and movement time. The movement time varies according to the different braking kinematics used by drivers. Scott et al. [19] measured DRT in healthy subjects and found the best DRTs in subjects who solved the task by only moving the foot, in contrast to lifting the entire leg from the floor by hip flexion.

Additionally, the number of DRT measurement at frequent intervals post-treatment is limited. In retrospect, additional measurements could have helped achieve more precise estimates of the time needed for DRTs to be restored to the normal or preoperative levels. This would have helped assess the optimal time for resumption of driving more accurately. Furthermore, data on patients' functional status, narcotics usage, and pain duration before intervention were not obtained in the majority of the studies, and could have had an effect on understanding more clearly the changes observed in DRT.

Conclusions

To date, scientific evidence of the patients' ability to safely resume driving after spinal surgery is rather limited. Furthermore, there is no single universally accepted postoperative DRT that has been deemed "safe" for resumption of driving; however, a return to preoperative values might be an acceptable indicator for safe driving. Nonetheless, driving is a complex task and considerations of patients' age, pain medication usage and cognitive function should be factored and the timing to return to driving should be tailored to each case. This review attempts to provide some evidence for driving safety after specific spinal procedures. Future prospective studies should be performed with longer duration of follow-up in a larger sample of patients, assessment of individual DRT components (movement and reaction time) in different patient subgroups (cervical and lumbar levels), and involve considerations of the patients' functional status and narcotics usage.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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