Increased population density of neurosurgeons associated with decreased risk of death from motor vehicle accidents in the United States

Clinical article

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Object. Motor vehicle accidents (MVAs) are a leading cause of death and disability in young people. Given that a major cause of death from MVAs is traumatic brain injury, and neurosurgeons hold special expertise in this area relative to other members of a trauma team, the authors hypothesized that neurosurgeon population density would be related to reduced mortality from MVAs across US counties.

Methods. The Area Resource File (2009–2010), a national health resource information database, was retrospectively analyzed. The primary outcome variable was the 3-year (2004–2006) average in MVA deaths per million population for each county. The primary independent variable was the density of neurosurgeons per million population in the year 2006. Multiple regression analysis was performed, adjusting for population density of general practitioners, urbanicity of the county, and socioeconomic status of the county.

Results. The median number of annual MVA deaths per million population, in the 3141 counties analyzed, was 226 (interquartile range [IQR] 151–323). The median number of neurosurgeons per million population was 0 (IQR 0–0), while the median number of general practitioners per million population was 274 (IQR 175–410). Using an unadjusted analysis, each increase of 1 neurosurgeon per million population was associated with 1.90 fewer MVA deaths per million population (p < 0.001). On multivariate adjusted analysis, each increase of 1 neurosurgeon per million population was associated with 1.01 fewer MVA deaths per million population (p < 0.001), with a respective decrease in MVA deaths of 0.03 per million population for an increase in 1 general practitioner (p = 0.007). Rural location, persistent poverty, and low educational level were all associated with significant increases in the rate of MVA deaths.

Conclusions. A higher population density of neurosurgeons is associated with a significant reduction in deaths from MVAs, a major cause of death nationally. This suggests that the availability of local neurosurgeons is an important factor in the overall likelihood of survival from an MVA, and therefore indicates the importance of promoting neurosurgical education and practice throughout the country.

Key Words • motor vehicle crash • area resource file • trauma • neurosurgeon population density

Abbreviations used in this paper: IQR = interquartile range; MVA = motor vehicle accident; TBI = traumatic brain injury.

Injuries from trauma are among the leading causes of death and disability in the US, with MVAs comprising the vast majority of those events.1,20 Traumatic brain injuries, in turn, comprise the leading cause of death in MVAs.4 Health care costs for patients with TBI present a significant economic burden due to several factors, including prolonged hospitalizations, inpatient and outpatient rehabilitation, and long-term care requirements.2,23 Although the contribution of general practitioners in improving health care outcomes has been widely recognized, the impact of neurosurgical care in public health improvement has not been investigated.3

Neurosurgery in the US has largely functioned as a tertiary care specialty, provided mainly by large urban city hospitals, contributing to an uneven distribution of neurosurgeons throughout the country.24 Transfer of patients with acute TBIs to neurological facilities may result in a critical delay in providing timely intervention, potentially contributing to disability and death from MVAs.10

One feature of the US Affordable Care Act, passed
in May 2010, was the incentivization of primary care to improve public health care outcomes. Surgical fields, including neurosurgery, are currently not provided with the same incentives under this Act, despite having a potentially large effect on outcomes after MVAs. A recent study using the Area Resource File, a national health resource information database, demonstrated that increased population density of general surgeons is associated with reduced mortality from MVAs, likely as a result of the availability of acute trauma teams. Given that a major cause of death from MVAs is TBI, and neurosurgeons hold special expertise in this area relative to other members of a trauma team, we postulated that neurosurgeon population density within a given geographical area would be related to reduced mortality from MVAs. The purpose of the present study was to investigate this hypothesis and quantify any relationship between the availability of neurosurgeons and reduction in death from MVAs.

Methods

Study Design

We performed a retrospective analysis of the Area Resource File (2009–2010), which includes county-level public health data on all US counties. The primary outcome variable was the 3-year (2004–2006) average in MVA deaths per million population for each county. The primary independent variable was the density of neurosurgeons, calculated as the number of neurosurgeons per 1 million population in the year 2006. Data on the number of neurosurgeons were reported from the American Medical Association Physician Master File to the Area Resource File.

Statistical Analysis

Multiple linear regression analysis was performed using SAS statistical software (SAS version 9.2, SAS, Inc.), adjusting for population density of general practitioners (general internal medicine, family medicine, and general practitioners per 1 million population in the year 2006, reported by the American Medical Association Physician Master File), urbanicity of the county (with rural counties defined as having rural-urban continuum level ≥ 4), and socioeconomic status of the county (including measures of persistent poverty and low educational level, as defined by the US Department of Agriculture-Economics Research Service). Persistent poverty counties were defined as those in which 20% or more of the residents were poor as measured by the most recent census. Counties with low educational levels were defined as those in which 25% or more of the residents 25–64 years old had neither a high school diploma nor a general educational development (GED) certificate. A probability value < 0.05 was considered statistically significant.

Results

A total of 3141 counties were analyzed, with 2051 classified as rural, 622 as low educational level, and 386 as persistent poverty. The mean and median number of annual MVA-related deaths per million population was 255 ± 162 and 226 (IQR 151–323), respectively. The mean number of neurosurgeons in a county was 6 ± 18 and the maximum was 372, with most counties not having any neurosurgeons (median 0, IQR 0). The mean and median number of general practitioners per million population was 314 ± 231 and 274 (IQR 175–410), respectively.

On unadjusted analysis, each increase of 1 neurosurgeon per million population was associated with 1.90 fewer MVA deaths per million population (95% CI –1.33 to –0.69; p < 0.001; Table 1). On multivariate analysis, adjusting for urbanicity, socioeconomic status, and general practitioner population density, each increase of 1 neurosurgeon per million population was associated with 1.01 fewer MVA deaths per million population (95% CI –1.33 to –0.69; p < 0.001; Table 2). Similarly, each increase of 1 general practitioner per million population was associated with 0.03 fewer MVA deaths per million population (95% CI –0.06 to –0.01; p = 0.007; Table 2).

Additional subset analyses found that the relationship between neurosurgeon population density and MVA deaths existed both in rural areas (regression coefficient –1.14, 95% CI –1.87 to –0.40; p = 0.002; Table 3) and in urban areas (regression coefficient –0.80, 95% CI –1.04 to –0.56; p < 0.001; Table 3).

Discussion

In the US, MVAs are the leading cause of death for those 1–34 years old. A greater likelihood of fatal outcomes in MVAs has been observed in rural areas, This observation has been attributed to various factors including, among others, delayed time to medical response and limited access to trauma resources. Several studies have sought to demonstrate the former by identifying an association between injury-related death and prehospital resources. However, the differences in the types of early intervention implemented, as well as the varied response times, have contributed to inconsistent results.

It has also been shown that trauma systems have a beneficial impact on patient outcomes. The independent contribution of hospital-based resources, however,

**TABLE 1: Univariate unadjusted analysis for 3-year (2004–2006) average MVA deaths per million population in a county according to urbanicity, low educational level, persistent poverty, number of neurosurgeons, and number of general practitioners**

<table>
<thead>
<tr>
<th>Variable*</th>
<th>Regression Coefficient (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>neurosurgeons per million population (2006)</td>
<td>–1.90 (–2.22 to –1.59)</td>
</tr>
<tr>
<td>general practitioners per million population (2006)</td>
<td>–0.06 (–0.08 to –0.03)</td>
</tr>
<tr>
<td>persistent poverty (2004)</td>
<td>125.61 (108.86–142.36)</td>
</tr>
<tr>
<td>low educational level (2004)</td>
<td>92.20 (78.30–106.10)</td>
</tr>
<tr>
<td>rural county (2003)†</td>
<td>96.51 (85.06–107.97)</td>
</tr>
</tbody>
</table>

* All p values < 0.001.
† Rural county defined as having a rural-urban continuum level ≥ 4.

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has not been extensively studied. A health system can be described as comprising 3 domains: structure (buildings, equipment, human capital), process (triage, operational algorithm), and outcomes. The contribution of providers, both in the structure and the process domains of this model, demonstrates their important role in outcomes. Several lines of evidence point to the value of accessibility to appropriate health systems in the outcomes after MVAs. Clark and Cushing\(^6\) demonstrated that knowing the mean distance between hospitals in a region allows for a fairly accurate estimate of the per capita mortality rate from vehicle crashes. Maio et al.\(^{16}\) have shown that in Michigan, 52% of the deaths from MVAs could be attributed to medical resource availability. In another study in the counties of Alabama, Melton et al.\(^{19}\) demonstrated that counties with 24-hour availability of a general surgeon, neurosurgeon, orthopedic surgeon, CT scanner, and operating room had decreased MVA-related mortality. Finally, Chang et al.\(^{5}\) have demonstrated that the population density of general surgeons is significantly associated with reduced risk of deaths from MVAs throughout the US.

Given the strong relationship between head injuries and overall morbidity and death from trauma,\(^{23}\) the potentially important role of neurosurgeons in trauma outcomes comes into focus. As demonstrated in this study, there is considerable disparity in the population density of neurosurgeons practicing among various counties throughout the country. Most counties have no local neurosurgical availability, likely due to a concentration of neurosurgeons around tertiary care centers. The present study demonstrates, however, that the population density of neurosurgeons is significantly associated with reduced risk of deaths from MVAs, and thus underserved areas may benefit significantly from access to a local neurosurgeon.

These data suggest that an increase of 1 neurosurgeon would be associated with 1 fewer MVA deaths per 1 million population. By comparison, the data also demonstrate that an increase of 33.3 primary care providers would be required to have an equivalent effect on the same outcome, whereas a recent study\(^7\) suggested 6.3 general surgeons would be needed for this effect.\(^4\) These data suggest a considerable effectiveness of neurosurgical providers in reducing MVA-related death, and that availability of neurosurgeons may be an important factor in overall likelihood of survival from an MVA. In addition, the current study does not analyze the potential effect of neurosurgeon population density on morbidity after MVAs, which may clearly be improved by early neurosurgical intervention, such as intracranial pressure management and intracranial clot evacuation. Many such neurosurgical interventions affecting both morbidity and death could potentially be performed in local hospitals with subsequent transfer to more specialized centers if necessary. The data in this study demonstrate a public health benefit of neurosurgical services, and as such present a valuable corollary to previous literature that has focused on rates of surgical procedures while failing to address whether this, in fact, improves public health outcomes.\(^{3,9}\)

Attempts to improve neurosurgeon accessibility locally in underserved areas would likely benefit from multiple strategies, including educational support, medical malpractice reform, and protection of reimbursement, in addition to the development of more effective trauma services in the community. The Affordable Care Act, passed in 2010, attempts to improve primary care provision by incentivizing primary care at the level of residency training and physician reimbursement. The important role of the neurosurgeon in the trauma team with respect to TBI, the significant contribution of TBI to overall nationwide

### Table 2: Multivariable adjusted analysis for 3-year average MVA deaths per million population in a county

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rural County</th>
<th>Urban County</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression Coefficient (95% CI) p Value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept†</td>
<td>206.79 (194.90–218.67) &lt;0.001</td>
<td>214.69 (202.93–226.45) &lt;0.001</td>
</tr>
<tr>
<td>neurosurgeons per million population (2006)</td>
<td>–1.01 (–1.33 to –0.69) &lt;0.001</td>
<td>–0.80 (–1.04 to –0.56) &lt;0.001</td>
</tr>
<tr>
<td>general practitioners per million population (2006)</td>
<td>–0.03 (–0.06 to –0.01) 0.007</td>
<td>–0.08 (–0.12 to –0.05) &lt;0.001</td>
</tr>
<tr>
<td>persistent poverty (2004)</td>
<td>77.91 (59.40–96.42) &lt;0.001</td>
<td>87.17 (58.61–115.74) &lt;0.001</td>
</tr>
<tr>
<td>low educational level (2004)</td>
<td>38.64 (23.26–54.02) &lt;0.001</td>
<td>87.17 (58.61–115.74) &lt;0.001</td>
</tr>
<tr>
<td>rural county (2003)</td>
<td>71.30 (59.37–83.23) &lt;0.001</td>
<td>71.86 (53.29–90.42) &lt;0.001</td>
</tr>
</tbody>
</table>

* Adjusted for urbanicity, low educational level, persistent poverty, number of neurosurgeons, and number of general practitioners.
† Mean of the MVA deaths per million population in a county from a linear regression model.

### Table 3: Multivariable adjusted analysis for 3-year average MVA deaths per million population in a rural county and an urban county

<table>
<thead>
<tr>
<th>Variable</th>
<th>Rural County</th>
<th>Urban County</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression Coefficient (95% CI) p Value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>intercept†</td>
<td>277.89 (264.29–291.49) &lt;0.001</td>
<td>214.69 (202.93–226.45) &lt;0.001</td>
</tr>
<tr>
<td>neurosurgeons per million population (2006)</td>
<td>–1.14 (–1.87 to –0.40) 0.002</td>
<td>–0.80 (–1.04 to –0.56) &lt;0.001</td>
</tr>
<tr>
<td>general practitioners per million population (2006)</td>
<td>–0.02 (–0.05 to –0.01) 0.114</td>
<td>–0.08 (–0.12 to –0.05) &lt;0.001</td>
</tr>
<tr>
<td>persistent poverty (2004)</td>
<td>80.82 (67.35–104.28) &lt;0.001</td>
<td>87.17 (58.61–115.74) &lt;0.001</td>
</tr>
<tr>
<td>low educational level (2004)</td>
<td>26.89 (6.37–47.42) 0.010</td>
<td>71.86 (53.29–90.42) &lt;0.001</td>
</tr>
</tbody>
</table>
mortality and health care costs, and the scarcity of neurosurgeons throughout vast areas of the country, suggest an added importance of promoting neurosurgical practice. The present study has several limitations. It is retrospective in nature, and although an association is demonstrated between neurosurgeon population density and reduced MVA deaths, a causal relationship cannot be proven by the data. As discussed above, it does not account for the additional effect of neurosurgeons on MVA morbidity, which may be significant. In addition, other markers of the overall quality of the trauma care system (such as specialist equipment and multidisciplinary staffing) were not consistently available in the Area Resource File, and therefore we cannot control for these potential confounders. The study design also cannot control for counties with no neurosurgeons that have immediate neurosurgical availability from other counties. However, the presence of those counties may not affect the observed difference because the effect of neurosurgical availability in neighboring counties may well also affect counties with large neurosurgical availability. Similarly, it is possible that the observed results are spurious and arise from more severe MVAs occurring further away from neurosurgical centers. This possibility remains unlikely, especially as the effect of neurosurgeon population density on outcomes remains true whether the counties are rural or urban. Another limitation of this study is that it cannot answer whether there is a critical population density of neurosurgeons after which mortality decreases, an interesting question for future investigation.

Furthermore, rates of neurosurgical interventions were not available to us, and therefore this study is unable to answer which aspects of neurosurgical management may be most effective in reducing mortality from MVAs. This is of particular interest because there is some literature to suggest that, at least for spine surgery, surgeon population density is not necessarily related to rates of surgical procedures. Finally, the study provides a county-level analysis, and therefore we cannot be certain about the effect of neurosurgeon population density on outcomes on an individual patient level. Other individual characteristics such as age, alcohol use, accident details (such as speed and vehicle deformity), and injury severity, which have previously been shown to influence MVA mortality, are not considered in our analysis because these data were not available.

Conclusions

Motor vehicle accidents are a major cause of death in the US. A higher population density of neurosurgeons is associated with a significant reduction in deaths from MVAs across US counties. These data suggest that availability of local neurosurgeons may be an important factor in the overall likelihood of survival from MVAs, and therefore indicates the importance of promoting neurosurgical education and practice throughout the country.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Desai, Ball. Acquisition of data: Desai. Analysis and interpretation of data: Desai, Bekelis. Drafting the article: Desai, Bekelis. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Desai. Statistical analysis: Zhao. Study supervision: Ball.

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