

Patterns of Traumatic Brachial Plexus Injuries: A Nationwide Study of Geographic, Demographic, and Socioeconomic Factors in England and Wales

Abstract

Introduction:

Traumatic brachial plexus injuries (TBPIs) are severe, life-altering injuries associated with significant functional impairment. While previous studies have highlighted mechanisms of injury, there is limited research on the geographical and socioeconomic factors influencing TBPI incidence. This study examines TBPI patterns across England and Wales, identifying demographic risk factors and geographic "hotspots".

Methods:

A retrospective cohort study was conducted using data from the Trauma Audit and Research Network (TARN) and the STATS-19 road traffic accident database from January 2010 to March 2022. Patients with confirmed TBPIs meeting TARN inclusion criteria were analysed. Cases were categorised into vehicular collisions (VCs) and non-vehicular injuries (NVIs). Key variables included age, sex, injury mechanism, Index of Multiple Deprivation (IMD) scores, and urban-rural classification. Geographic distribution was assessed to identify high-incidence regions.

Results:

A total of 1,003 TBPI cases were identified: 601 (60%) vehicular and 402 (40%) non-vehicular related injuries. VC TBPIs were more frequent in young males (median age: 35 years), whereas NVIs occurred more in older females (median age: 63 years), mainly due to falls <2m. Higher IMD scores were associated with penetrating injuries. Urban "hotspots" for penetrating injuries included cities in Greater London, Greater Manchester, and West Yorkshire.

Discussion:

This study describes geographic and socioeconomic patterns of TBPIs across England and Wales. Although less frequent than other trauma entities, TBPIs carry a high per-patient burden due to upper-limb paralysis and neuropathic pain, with substantial indirect costs. The identification of demographic profiles and regional clustering provides an epidemiological baseline to inform clinicians and major trauma services.

Highlights

- 1) TBPIs predominantly affect younger males in vehicular collisions and older females following low-level falls.
- 2) Penetrating TBPIs in urban areas were strongly associated with high deprivation and male sex.
- 3) Single carriageways and high-speed zones accounted for most vehicular TBPI incidents.
- 4) Regional clustering of TBPIs underscores the need for targeted trauma service planning and access to specialist care.
- 5) Linking trauma and road safety data can guide resource allocation and improve care in high-risk areas.

Keywords

Brachial plexus, Trauma, Epidemiology

Introduction

Traumatic brachial plexus injuries (TBPIs) are severe, life-altering injuries characterised by long-term physical disability, chronic pain, and psychological challenges for the affected individuals [1]. The consequences of TBPIs extend beyond the individual to impact their families and the wider community. The economic burden of such injuries exceeds \$1.1 million per patient in the US [2]. The cost in the UK is unknown but is expected to be of a similar magnitude. This underscores the substantial societal and healthcare cost associated with TBPIs, highlighting the importance of understanding and mitigating the risks associated with these injuries. Although TBPIs are less common than some other traumatic conditions, the loss of upper-limb function and refractory neuropathic pain can markedly reduce independence and quality of life.

In recent years, there has been growing concern over an increase in TBPI incidence, partly attributed to the rising rates of high-speed road traffic collisions (RTCs) [3]. Although trauma care has advanced significantly, efforts to prevent trauma have received comparatively less attention, aside from key interventions such as the implementation of mandatory seatbelt legislation in the UK in 1983 [4] and the progressive integration of airbags into vehicles since the late 1980s [5]. Studies from other regions also indicate that socioeconomic factors, particularly low socioeconomic status, are associated with a higher incidence of trauma [6]. However, there is limited contemporary data within the UK examining the incidence of TBPIs, the mechanisms of injury, and the influence of social deprivation on these patterns.

This study aims to address these gaps by examining the geographical variation in TBPI incidence across England and Wales, utilising data from both the Trauma Audit and Research Network (TARN) [7] and the STATS-19 [8] database. By exploring associations between TBPI incidence and socioeconomic indicators, this study seeks to identify high-risk populations and geographic “hotspots” of TBPIs, with the goal of informing clinicians and service planning at major trauma centres.

Methods

Study Design

This cohort study was conducted in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines [9]. Prospectively captured data were utilised from the TARN database [7] for the period between January 2010 and March 2022. Duplicate entries (from patients transferred between hospitals) were identified and merged and any entries without a valid postal outcode were excluded

prior to analysis. The dataset was subsequently divided into cases involving a vehicular collision (VC) and non-vehicular injuries (NVIs).

The TARN database provided comprehensive records on patients with traumatic injuries across England and Wales. Inclusion criteria for TARN required that patients met at least one of the following criteria: Hospital stay of three days or more, admission to critical care, trauma resulting in death, transfer for specialist or high dependency care (excluding rehabilitation services). A diagnosis of a TBPI is made by clinicians at the receiving major trauma centre. Only confirmed injury diagnoses recorded by trained, experienced coders are included in the TARN database which ensures consistency.

To enrich the TARN dataset, cases involving a VC were subsequently matched with corresponding records from STATS-19 based on casualty demographics including, age sex, casualty home postal outcode and date and time of the incident. STATS-19 is a database of all RTCs resulting in personal injury, documented either by police at the roadside or reported within 30 days by a member of the public [8]. STATS-19 provides additional details on the accident circumstances, vehicles involved, a casualty record and any contributory factors relevant to the accident.

Rural Urban Classification

For each NVI, the casualty home postal outcode was assigned a proportion of urbanity, according to the Rural Urban classification [10]. For VCs, the outcode of the incident location was used to assign a proportion of urbanity.

Index of Multiple Deprivation

Indices of multiple deprivation (IMD) are a measure of deprivation specific to lower level super output areas (LSOAs), each representing a geographic area with a population of approximately 1500 [11]. The English IMD ranks each area from 1 (most deprived) to 32,844 (least deprived), with lower ranks indicating greater deprivation. The indices consider weighted factors to calculate each index as follows: income (22.5%), employment (22.5%), education and skills training (13.5%), health deprivation and disability (13.5%), crime (9.3%), barriers to housing and services (9.3%) and living environment (9.3%). Using the same techniques that the Office for National Statistics use to aggregate LSOA IMD scores and ranks to local authorities, LSOA IMD scores and ranks were aggregated to postal outcodes [11]. Following adjustments to allow for comparison between countries of the United Kingdom, as described by Abel et al [12], a 2019 time-period appropriate IMD rank was assigned to each NVI case.

142

143 Discordance from Home

144 For VCs, the road distance from the casualty's home postal outcode to the incident
145 location was calculated by measuring the distance between the centroids of the postal
146 outcode areas using the Open Source Routing Machine (OSRM) package [13].

147

148 Analysis

149 All analyses were descriptive. Continuous variables are reported as medians and
150 interquartile ranges (IQR). Categorical variables are presented as counts with
151 percentages.

152

153 Ethical Considerations

154 Existing ethical approval for the use of anonymised registry data was obtained under
155 Section 251 of the National Health Service Act 2006, with data securely stored on a
156 University of Manchester server [7].

157

158 **Results**

159 Demographics

160 A total of 1,003 TBPI cases were identified during the study period, with 601 (59.9%)
161 resulting from VCs and 402 (40.1%) NVIs. The median age for patients in the NVI cohort
162 was 63 years (IQR: 41-77). This was older than the VC cohort, with a median age of 35
163 years, (IQR: 25-48). The male-to-female ratio also differed between groups, with a higher
164 proportion of males among VCs (n=521/601, 86.7%) compared to the NVI cohort
165 (n=235/402, 58.4%).

166

167 Vehicular Collision TBPIs

168 A mean frequency of 47 TBPIs caused by VCs occurred annually during the study period.
169 A possible COVID-19-related significant drop in frequency was observed between 2021
170 and 2022 compared to all other years (23.0 vs 51.6). No differences were found between
171 the median age of males (35.2, IQR:25.2 – 47.3) and females (36.6, IQR:28.0-50.5) in this
172 cohort.

173

174 Overall, 62.4% (n=375/601) of VC cases from the TARN database were matched with the
175 STATS-19 database (**Supplementary Material 1**). From the STATS-19 matched cohort, a

difference in frequency of TBPIs based on road speed limit was observed with the most common speed limits resulting in injury being 30mph (n=151/601) and 60mph (n=106/601). **Figure 1** displays the count of different road speed limits associated with TBPIs by vehicle type. Motorcycles over 500cc and cars demonstrated a greater variation across road speed limits.

Single carriageways accounted 76.5% (n=460/601) of cases. Over a quarter (n=178/601) of TBPIs occurred at a T or staggered junction, over one-fifth (n=133/601) occurred on wet or damp road conditions, over one-fifth (n=136/60) involved a manoeuvre around a bend and two-thirds (n=416/601) occurred in daylight. Alcohol and/or drug use was reported in 11.1% (n=67/601) of cases.

A measure of discordance from home postal outcode prior to a VC demonstrated a median distance of 7.1km (IQR: 0.0–20.9) (**Figure 2**). On average, females (median: 7.8km, IQR: 0.0-27.2) were further away from their home location compared to males (median: 7.1km, IQR: 0.0-21.0) at the time of a TBPI.

Figure 3 displays the geographic distribution of VC TBPIs across England and Wales. For VC TBPIs, suitable exposure denominators were unavailable at a resolution aligned to incident location and study period; maps therefore display case counts (event burden). Peterborough had the highest number of cases (n=15/601) over the 12-year data collection period followed by Guildford (n=13/601). In Peterborough, 87% (n=13/15) of the cases were on single carriageways with a speed limit of 60mph and over 73% (n=11/15) involved a motorcycle. The central region of England, including Sheffield (n=10/601), Derbyshire (n=8/601), Leicestershire (n=9/601), Birmingham (n=10/601), Coventry (n=8/601) and Oxford (n=11/601) accounted for approximately 10% (n=56/601) of VC TBPIs.

The median proportion urbanity for VCs (89.0%, IQR: 45.4-99.6) was lower than for NVIs (median: 98.3%, IQR: 79.1-100.0). No differences were identified between vehicle type and the urbanity of the area in which the injury occurred.

Non-vehicular TBPIs

A mean of 33 NVI cases occurred annually, with minimal variation during the COVID-19 pandemic. Males (median age: 52, IQR: 31-71) were 17 years younger than females (median age: 72, IQR 58-82) at the time of injury. Elderly individuals from the cohort (65

years of age or over) had a lower deprivation rank (median: 1019, IQR: 609.8 - 1786.5) at the time of a TBPI than those under 65 years of age (median: 1408, IQR: 766.5-1885.0). Over 75% (n=305/402) of the cohort resided in a postal outcode with an urban percentage of over 75%.

Mechanisms of NVIs are summarised in **Figure 4**. The most common mechanism was a fall of less than 2m, accounting for 56.0% (n=225/402) of cases. An older age distribution was found to sustain a fall of less than 2m (median age: 73, IQR: 60-82) compared to the age distribution for all other mechanisms of injury combined (median age: 42, IQR: 25-62). Females (77.2%, n=129/167) were more likely to experience a fall of less than 2 metres compared to males (40.9%, n=96/235). Of the male cohort, the most common mechanisms of injury were falls of less than 2m (n=96/235), falls of greater than 2m (n=46/235) and stabbings (n=43/235). 84.3% (n=43/51) of all stabbings and 67.7% (n=46/68) of all falls greater than 2m occurred in the male cohort.

Over 15% (n=56/402) of injuries were due to penetrating trauma, such as a stabbings or shootings. Those individuals sustaining penetrating TBPIs (median IMD: 1687, IQR: 977-2082) lived in areas with higher deprivation ranks compared to those sustaining non-penetrating mechanisms of TBPIs (median IMD: 1147, IQR: 574-1755). Penetrating TBPIs occurred in individuals that lived in areas with a higher urban percentage compared to non-penetrating mechanisms of injury (100% vs 97.6%). The most common casualty postal outcodes for penetrating mechanisms of injury was Manchester (n=4/56), followed by Huddersfield (n=3/56), South-East London (n=3/56) and East London (n=3/56). These postal outcodes combined accounted for over one-fifth (n=13/56) of casualty's sustaining penetrating TBPIs. No significant associations were found between deprivation ranks and length of stay, complications or survival.

Figure 5 shows the geographic distribution of NVIs across England and Wales normalised by the population of the area. The casualty home area with the highest TBPI cases per million of the population was Bournemouth (35.5 cases per million), followed by Oxford (19.0 cases per million) and Swansea (16.1 cases per million). In Bournemouth, 58% (n=10/17) of cases were female, the median age of the cohort was 70 years (IQR:), all cases (n=17/17) involved a fall, and over 70% (n=12/17) involved a concurrent bony injury (either a fracture, subluxation or dislocation).

Discussion

This study provides valuable insights into the geographical and demographic patterns of TBPIs across England and Wales, revealing distinct differences in injury mechanisms, socioeconomic associations, and urban-rural distributions. By leveraging data from the TARN and STATS-19 databases, we were able to identify important associations between TBPI occurrence and factors such as age, sex, deprivation levels, and accident location, which carry significant public health implications.

Our study has demonstrated that NVIs occur in a younger cohort of males compared to females and that this cohort has a higher level of social deprivation. In turn, we have also demonstrated that these individuals are more likely to sustain penetrating brachial plexus injuries compared to other mechanisms of injury. This is in keeping with previous studies which have shown populations living in socioeconomically deprived areas have a higher incidence of penetrating trauma, but this is not associated with case fatality [6,14]. In deprived urban areas, social determinants such as unemployment, poor housing conditions, limited access to recreational facilities, and higher crime rates likely increase individuals' exposure to violence and injury. Future studies could explore whether similar patterns are present in other developed countries with comparable socioeconomic structures.

Interestingly, while global studies have reported higher trauma incidence in rural regions [1,15], our findings indicate a higher frequency of NVIs in urban areas. This discrepancy may reflect specific socio-cultural and environmental factors within the UK, where densely populated urban settings are associated with increased exposure to mechanisms of injury like falls and stabbings.

The most common mechanism of NVIs was a fall of less than 2m and this mechanism of injury was more likely in older females as demonstrated by the cohort of cases from Bournemouth. Bournemouth is a coastal retirement destination with a comparatively older resident population compared to other parts of England and Wales [16]. This aligns with studies showing that falls are a primary cause of injury in this demographic, driven by age-related factors such as reduced balance [17]. The high association with a concurrent bony injury suggests a potential causative factor for their TBPI also shown from previous studies [18].

Our study's findings align with prior research demonstrating that TBPIs frequently result from VCs, particularly in younger males [19,20]. The reduction in VC TBPIs in 2021 is likely

due to the effects of the COVID-19 pandemic lockdown which ran from January to July 2021, and is in keeping with previous studies [21,22].

An interesting finding from analysing the discordance from home was that males were involved in VCs closer to home. This may be explained by the higher likelihood for males to engage in high-risk activity such as motorcycle use, speeding and substance misuse compared to female counterparts [19,23]. Linking healthcare data with road safety data, as this study does, offers a richer perspective on injury mechanisms.

The distribution of VC-related TBPIs revealed notable geographic patterns, with Peterborough and Guildford identified as areas with the highest number of cases. Peterborough and Guildford lie on major transport corridors linking high-speed A-roads and motorways. In Peterborough, the predominance of single carriageways with a 60mph speed limit and the high proportion of motorcycle involvement aligns with known risk factors for severe trauma in rural areas. These findings suggest that the central region of England, including urban centres such as Birmingham and Oxford, accounted for a significant proportion of VC TBPIs. This clustering may be partly explained by the region's role as a major transport hub, with high-density road networks and significant commuter traffic. The mix of urban centres and high-speed rural roads likely contributes to the elevated TBPI risk.

The identification of geographic “hotspots” from our study suggests that specialist services such as nerve surgery and neurorehabilitation may need to be more readily available in high-incidence regions to improve access and reduce delays in care.

Moreover, the high proportion of NV TBPIs occurring in older adults, particularly due to low-level falls, raises concerns about age-related disparities in trauma care. Previous qualitative studies have highlighted potential differences in the aggressiveness and intensity of treatment due to implicit age bias, even when injury severity is comparable [24]. This underscores the need for further research and policy attention to ensure that treatment decisions are based on clinical need rather than age alone.

Limitations

This is a retrospective study, and this inherently introduces bias related to data availability. The reliance on TARN and STATS-19 data introduces potential biases due to variable reporting standards across trauma centres and police jurisdictions. While

compliance in data submission has improved since the establishment of major trauma centres in 2012, discrepancies remain in data completeness across centres and regions.

Inclusion in the TARN database is subject to specific severity criteria, which introduces a severity bias where the dataset may overrepresent more severe injuries while underestimating the true incidence of TBPIs across the population. Milder TBPIs from closed injuries and certain mechanisms may lead to spontaneous reinnervation and are therefore unlikely to be captured [25]. This may skew the identified patterns toward higher-acuity cases.

Additionally, not all cases in the TARN database could be matched to corresponding STATS-19 records, potentially limiting the generalisability of our findings. In analysing VC TBPIs, the study focused on the injured individual rather than external contributing factors, such as the role of other drivers on the road which may have played a significant role but was not accounted for.

This study used area-based IMD ranks rather than individual-level deprivation data, which may introduce ecological fallacy of socioeconomic status [26]. Another limitation for the NVI cohort is the assumption that the TBPI occurred within the casualty's home postcode region. Some individuals may have sustained their injuries in a different location due to travel or other factors, potentially affecting the accuracy of geographic and socioeconomic associations.

Conclusion

This study provides a comprehensive analysis of TBPIs across England and Wales, demonstrating distinct geographical and demographic patterns influenced by socioeconomic factors. TBPIs were most prevalent among younger males involved in VCs and older females sustaining falls at home, with higher deprivation ranks associated with penetrating injuries in urban areas. The integration of trauma and road safety data enhances understanding of injury mechanisms. These findings characterise who, where and how TBPIs occur in England and Wales across vehicular and non-vehicular contexts. The patterns by age, sex, deprivation rank and urbanity provide an epidemiological baseline for clinicians, commissioners and researchers. Future research should explore individual-level socioeconomic factors and expand this approach to other populations to refine prevention strategies and reduce the burden on healthcare systems.

Tables & Figures

Supplementary Table 1 – Number of VC cases from TARN database matched with the STATS-19 database by year

Figure 1 – Speed limit counts by vehicle type

Figure 2 – Discordance from home postal outcode (km) at the point of a TBPI-sustaining vehicle collision

Figure 3 - Geographical distribution of vehicular collision TBPIs across England and Wales

Figure 4 – Frequency of non-vehicular injury mechanisms

Figure 5 - Geographic distribution of non-vehicular TBPIs across England and Wales normalised by the population of the area

385 **References**

- 386 [1] Li G-Y, Xue M-Q, Wang J-W, Zeng X-Y, Qin J, Sha K. Traumatic brachial plexus injury: a
387 study of 510 surgical cases from multicenter services in Guangxi, China. *Acta*
388 *Neurochir (Wien)* 2019;161:899–906. <https://doi.org/10.1007/s00701-019-03871-y>.
- 389 [2] Hong TS, Tian A, Sachar R, Ray WZ, Brogan DM, Dy CJ. Indirect Cost of Traumatic
390 Brachial Plexus Injuries in the United States. *J Bone Joint Surg Am* 2019;101:e80.
391 <https://doi.org/10.2106/JBJS.18.00658>.
- 392 [3] Warwick CE, Hems T. Traumatic brachial plexus injuries: a national review of
393 epidemiology in the Scottish population over a 10-year period. *J Hand Surg Eur Vol*
394 2024;49:905–11. <https://doi.org/10.1177/17531934231209661>.
- 395 [4] Thirty years of seatbelt safety. GOVUK n.d.
396 <https://www.gov.uk/government/news/thirty-years-of-seatbelt-safety> (accessed
397 November 7, 2024).
- 398 [5] Williams RF, Croce MA. Are Airbags Effective in Decreasing Trauma in Auto
399 Accidents? *Adv Surg* 2009;43:139–45. <https://doi.org/10.1016/j.yasu.2009.03.003>.
- 400 [6] Corfield AR, MacKay DF, Pell JP. Association between trauma and socioeconomic
401 deprivation: a registry-based, Scotland-wide retrospective cohort study of 9,238
402 patients. *Scand J Trauma Resusc Emerg Med* 2016;24:90.
403 <https://doi.org/10.1186/s13049-016-0275-7>.
- 404 [7] TARN Foundation Website – The TARN Foundation – n.d.
405 <http://tarnfoundation.org.uk/> (accessed August 3, 2024).
- 406 [8] What does STATS19 record about casualties? n.d.
407 <https://roadsafety.network/kb/casualty-fields-stats19/> (accessed August 3, 2024).
- 408 [9] Vandenbroucke JP, von Elm E, Altman DG, Gøtzsche PC, Mulrow CD, Pocock SJ, et
409 al. Strengthening the Reporting of Observational Studies in Epidemiology
410 (STROBE): explanation and elaboration. *Epidemiol Camb Mass* 2007;18:805–35.
411 <https://doi.org/10.1097/EDE.0b013e3181577511>.
- 412 [10] 2011 Rural Urban Classification. GOVUK 2021.
413 <https://www.gov.uk/government/statistics/2011-rural-urban-classification>
414 (accessed October 26, 2024).
- 415 [11] English indices of deprivation 2019. GOVUK n.d.
416 <https://www.gov.uk/government/statistics/english-indices-of-deprivation-2019>
417 (accessed November 9, 2024).
- 418 [12] Abel GA, Barclay ME, Payne RA. Adjusted indices of multiple deprivation to enable
419 comparisons within and between constituent countries of the UK including an
420 illustration using mortality rates. *BMJ Open* 2016;6:e012750.
421 <https://doi.org/10.1136/bmjopen-2016-012750>.
- 422 [13] Project OSRM n.d. <https://project-osrm.org/> (accessed November 4, 2024).
- 423 [14] Snell DT, Lockey PD, Thompson DJ. Socioeconomic status is associated with
424 mechanism and intent of injury in patients presenting to a UK Major Trauma
425 Centre. *Injury* 2023;54:497–501. <https://doi.org/10.1016/j.injury.2022.11.023>.
- 426 [15] Keeves J, Ekegren CL, Beck B, Gabbe BJ. The relationship between geographic
427 location and outcomes following injury: A scoping review. *Injury* 2019;50:1826–38.
428 <https://doi.org/10.1016/j.injury.2019.07.013>.

- [16] Warnes AM. Cities and Elderly People: Recent Population and Distributional Trends. *Urban Stud* 1994;31:799–816. <https://doi.org/10.1080/00420989420080681>.
- [17] Hsu W-L, Chen C-Y, Tsao J-Y, Yang R-S. Balance control in elderly people with osteoporosis. *J Formos Med Assoc* 2014;113:334–9. <https://doi.org/10.1016/j.jfma.2014.02.006>.
- [18] Hardie CM, Jordan R, Forker O, Fort-Schaale A, Wade RG, Jones J, et al. Prevalence and risk factors for nerve injury following shoulder dislocation. *Musculoskelet Surg* 2023;107:345–50. <https://doi.org/10.1007/s12306-022-00769-4>.
- [19] Killer crashes: fatal road traffic accidents in the UK - PubMed n.d. <https://pubmed.ncbi.nlm.nih.gov/20159105/> (accessed August 6, 2024).
- [20] Suroto H, Antoni I, Siyo A, Steendam TC, Prajasari T, Mulyono HB, et al. Traumatic Brachial Plexus Injury in Indonesia: An Experience from a Developing Country. *J Reconstr Microsurg* 2022;38:511–23. <https://doi.org/10.1055/s-0041-1735507>.
- [21] Yasin YJ, Grivna M, Abu-Zidan FM. Global impact of COVID-19 pandemic on road traffic collisions. *World J Emerg Surg* 2021;16:51. <https://doi.org/10.1186/s13017-021-00395-8>.
- [22] Ebrahim Shaik Md, Ahmed S. An overview of the impact of COVID-19 on road traffic safety and travel behavior. *Transp Eng* 2022;9:100119. <https://doi.org/10.1016/j.treng.2022.100119>.
- [23] Santamariña-Rubio E, Pérez K, Ricart I, Rodríguez-Sanz M, Rodríguez-Martos A, Brugal MT, et al. Substance use among road traffic casualties admitted to emergency departments. *Inj Prev J Int Soc Child Adolesc Inj Prev* 2009;15:87–94. <https://doi.org/10.1136/ip.2008.019679>.
- [24] Conn LG, Nathens AB, Scales DC, Vogt K, Wong CL, Haas B. A qualitative study of older adult trauma survivors' experiences in acute care and early recovery. *CMAJ Open* 2023;11:E323–8. <https://doi.org/10.9778/cmajo.20220013>.
- [25] Noland SS, Bishop AT, Spinner RJ, Shin AY. Adult Traumatic Brachial Plexus Injuries. *JAAOS - J Am Acad Orthop Surg* 2019;27:705. <https://doi.org/10.5435/JAAOS-D-18-00433>.
- [26] Sedgwick P. Understanding the ecological fallacy. *BMJ* 2015;351:h4773. <https://doi.org/10.1136/bmj.h4773>.