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ORIGINAL PAPER

ELDERLY IN NEUROSURGERY

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Highlights

- Author-defined age thresholds show an overall upward trend in neurosurgical literature.
- Definitions vary across geographic regions and neurosurgical disease categories.
- Assessment of older patients should incorporate frailty and functional status.

Abstract

Background: Chronological age remains an important factor in neurosurgical decision-making; however, the age threshold used to define patients as "elderly" has varied over time, across geographic regions, and between disease entities. The aim was to examine how author-defined chronological thresholds for elderly populations have evolved in the neurosurgical literature. **Material and Methods:** A systematic PubMed review of neurosurgical literature published 1970–2025 was conducted using predefined search terms related to elderly patients. Studies were included only if they provided an explicit numerical chronological threshold defining an "elderly" population. Each publication was treated as a single unit of analysis. Extracted data included publication year, geographic region, disease category, and the author-defined age threshold. Descriptive statistics, temporal trend analyses, and subgroup analyses were performed. **Results:** Of 927 screened articles, 408 met the inclusion criteria. The author-defined chronological threshold was mean ± standard deviation 67.5±8.9 years (median: 65 years, range: 34–99 years). Author-defined age thresholds showed an overall upward trend over time. Regional differences were observed, with increasing thresholds in Europe, North America, and Japan, whereas an overall declining trend was observed in Asia excluding Japan. Disease-specific analyses showed variation between neurosurgical categories, including higher thresholds in spinal than cranial studies. **Conclusions:** The chronological threshold used to define patients as "elderly" in neurosurgical literature is dynamic and context-dependent, varying over time, across regions, and between disease categories. These findings highlight the limitations of fixed chronological age cut-offs. Assessment of older neurosurgical patients should therefore incorporate individual factors such as frailty, physiological reserve, and functional status rather than rely on chronological age alone. Med Pr Work Health Saf. 2026;77(4)

Key words: neurosurgery, elderly patients, life expectancy, age threshold, biological age, surgical decision-making

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INTRODUCTION

Neurosurgical treatment decisions require assessment of the expected benefits and risks of available interventions [1,2]. The patient's clinical condition, functional status, comorbidities, and goals of care are relevant to the selection of an appropriate treatment strategy [2,3].

Assessment of perioperative risk is especially relevant in patients undergoing brain tumor surgery or spinal procedures [3,4]. Chronological age is one component of this assessment, but patients of the same age may differ substantially in physiological reserve and functional status [2].

Biological processes associated with aging and cellular senescence may also influence brain tumor progression and drug resistance [5]. Chronological age therefore provides only a partial description of the factors relevant to treatment decisions.

Definitions of older age are also influenced by social and cultural context. The United Nations uses an age threshold of >60 years, while acknowledging that local circumstances may lead to different classifications [6].

Advances in treatment and changes in population health provide additional context for the use of chronological thresholds in clinical research.

The aim of this study was to examine how author-defined chronological thresholds used to identify elderly populations have changed over time in the neurosurgical literature. Publications were analyzed by publication period, geographic region, and disease category.

MATERIAL AND METHODS

A systematic PubMed search was conducted using specific search parameters with keywords such as: "neurosurgery" AND "elderly," "neurosurgery" AND "old patient," or "neurosurgery" AND "advanced age," covering the period 1970–2025. For further analysis, only papers with available English abstracts were included. The search terms were selected to identify publications focusing explicitly on elderly populations. Eligibility required an author-defined numerical age threshold, allowing trends in published definitions to be examined without attempting to capture every study of older patients. Abstracts were reviewed to determine how the authors define advanced or old age. If the abstract did not specify this, the full paper was retrieved and examined for the information. Papers lacking a definition of elderly age were excluded. If the elderly age was defined as a range, the median value within that range was recorded.

For all papers meeting the inclusion criteria, data were recorded, including the publication year, country, world region, and the specific disease or disease group addressed. The publication year was noted to track temporal trends in the assessment of seniority onset, serving as a broad indicator of medical progress. A geographical analysis was conducted to explore potential cultural differences. Additionally, focusing on specific medical conditions aimed at determining whether there are selective changes related to disease severity. Anatomical groups were not mutually exclusive; a publication could contribute to both the cranial and spinal groups.

Country regions were grouped into Europe and North America, Asia, and the "Rest of the world." The "Rest of the world" category was created because there were few papers from other continents. Japan was analyzed separately due to the high volume of papers.

Ethics

This study analyzed published literature and did not include individual patient data.

Statistics

Descriptive statistics were used to summarize author-defined age thresholds at the publication level. Measures of central tendency were the arithmetic mean (M) and median (Me); measures of dispersion included the standard deviation (SD), minimum and maximum values (min––max), and interquartile range (IQR), where applicable. Each publication contributed equally to the analysis. Statistics were calculated for the full dataset and subgroups defined by geographic region and disease category. Scatter plots with fitted linear regression models were used to display temporal trends. Box-and-whisker plots summarized threshold distributions, and stacked column plots showed the number of publications in threshold categories by decade. Results were reported as M±SD or as Me with the range or IQR, as appropriate. Analyses were performed using MATLAB R2024b (MathWorks, Natick, MA, USA), R ver. 4.4.2 (R Foundation for Statistical Computing, Vienna, Austria), and Python ver. 3.10.10 (Python Software Foundation, Beaverton, OR, USA).

RESULTS

Of 927 screened articles, 408 publications met the inclusion criteria and were included in the analysis (Figure 1).

The author-defined age threshold was M±SD 67.5±8.9 years (Me = 65 years, range: 34–99 years). Author-defined age thresholds showed an overall upward trend over time. Life expectancy data were obtained from Our World in Data [7] and are shown for descriptive comparison (Figure 2).

Temporal patterns differed across geographic regions. An upward trend was observed in Europe and North America and in Japan, whereas a declining trend was observed in Asia excluding Japan (Figure 3).

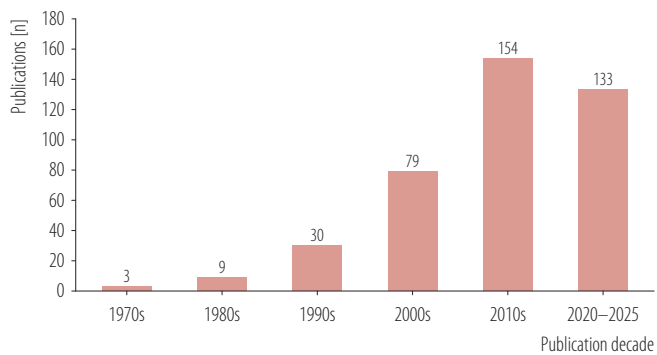


Figure 1. Distribution of 408 neurosurgical publications identified in the worldwide PubMed dataset by publication decade, 1970–2025; the final period (2020–2025) covers 6 years

The median age threshold was higher in spinal than in cranial studies (Me = 68 years vs. Me = 65 years). The corresponding mean thresholds were M±SD 68.15±8.20 years and 67.43±9.06 years, with ranges of 45–90 years and 34–99 years, respectively (Figure 4). Anatomical groups could overlap.

The author-defined age thresholds for benign and malignant tumors were Me = 72.5 years and Me = 67.5 years, respectively, in spinal studies, and Me = 65 years in both cranial groups. Cranial studies grouping tumors irrespective of malignancy had a median threshold of 60 years (Figure 5).

For neurotrauma and chronic subdural hematoma, the age thresholds were M±SD 67.60±8.25 years and 66.11±11.42 years, respectively; Me = 65 years in both groups. For spinal fractures excluding C2 fractures, the threshold was M±SD 67.79±3.67 years and Me = 68 years. For spondylosis, the corresponding values were M±SD 68.96±6.91 years and 67.5 years. Thus, the median threshold was slightly lower for spondylosis than for spinal fractures (Figure 6).

For cerebrovascular disorders, the author-defined age threshold was M±SD 68.3±9.5 years and Me = 67.5 years. Mean thresholds were M±SD 70.1±7.3 years for aneurysmal subarachnoid hemorrhage, M±SD 63.3±5.8 years for unruptured aneurysm, M±SD 66.9±13.7 years for ischemic stroke, and M±SD 65.6±7.3 years for spontaneous intracerebral hematoma. The median threshold was 70 years for subarachnoid hemorrhage and 65 years for each of the other 3 groups (Figure 7).

Other disease and treatment categories are presented in Figure 8. Median thresholds ranged from 50 years for epilepsy to 85 years for chronic pain treatment.

DISCUSSION

International classifications use chronological thresholds to describe older populations. The United Nations definition of over 60 years is one example [6]. Such thresholds are conventional classifications rather than biological boundaries. Individuals of the same chronological age may differ substantially in physiological reserve, multimorbidity, functional status, and frailty [2].

The purpose of the present study was not to determine when old age begins from a biological or clinical perspective, nor to identify the most appropriate age threshold for individual neurosurgical conditions. Rather, the aim was to investigate how the author-defined chronological threshold used to identify an "elderly" population has evolved in neurosurgical lit-

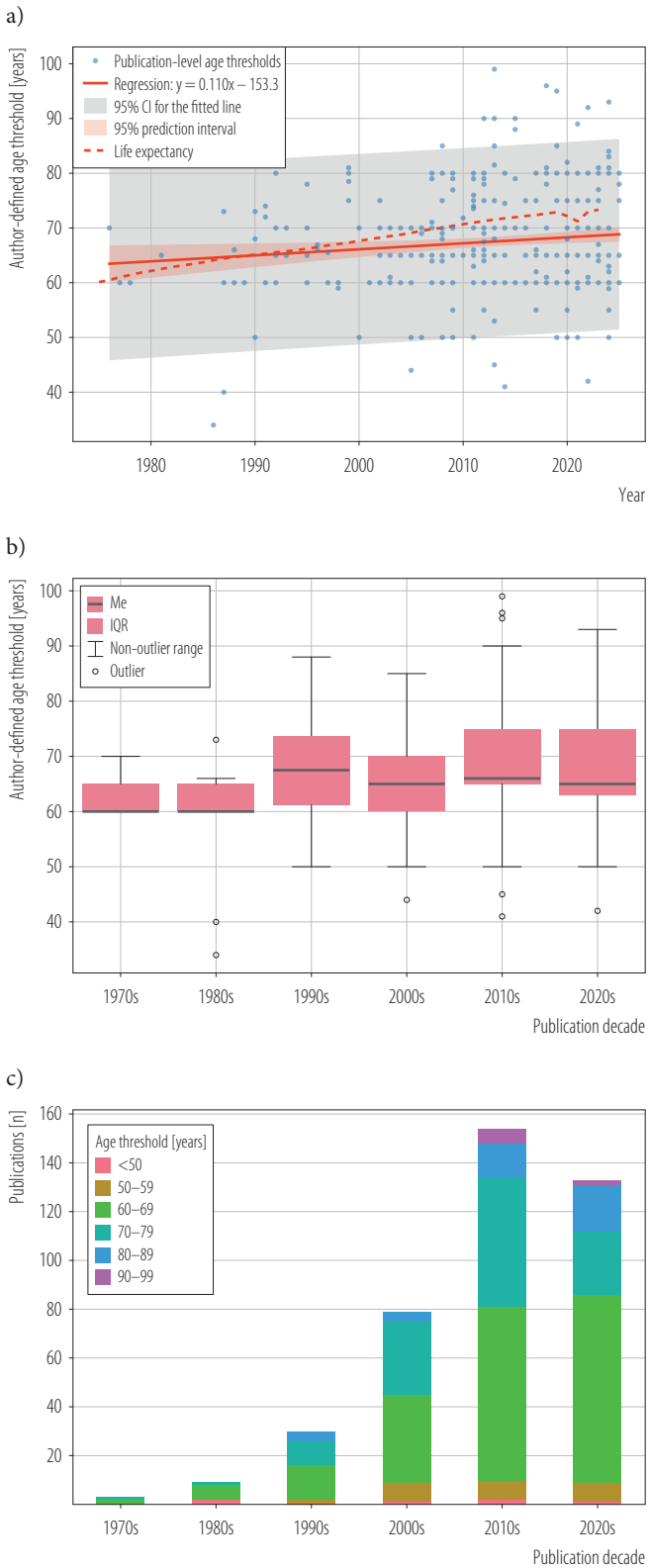


Figure 2. Temporal distribution of author-defined age thresholds for elderly populations in the worldwide neurosurgical PubMed dataset, 1970–2025 (N = 408): a) publication-level thresholds with fitted linear regression and life expectancy for descriptive comparison, b) age-threshold distributions by publication decade, c) publication counts by age-threshold category and publication decade

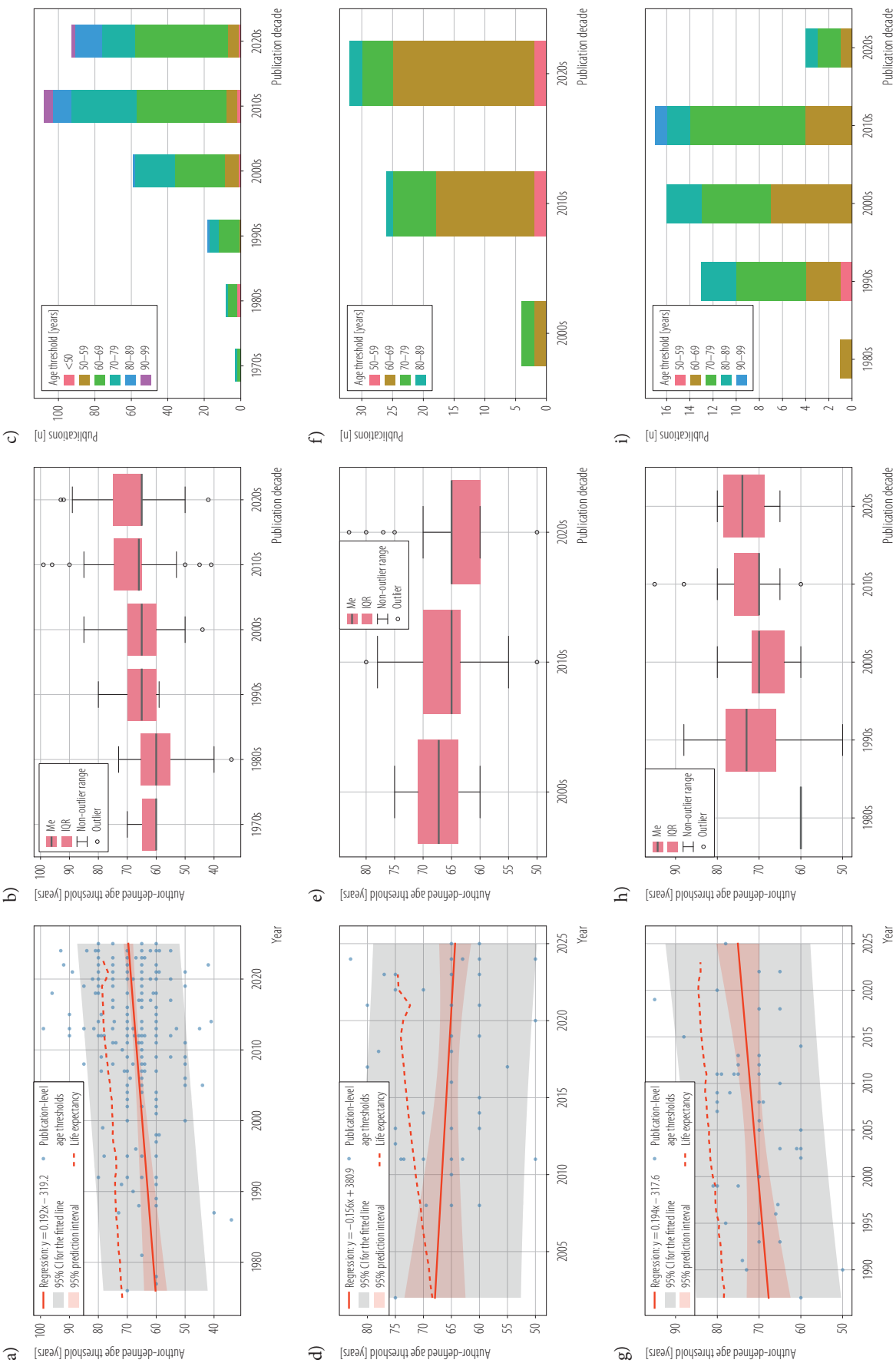


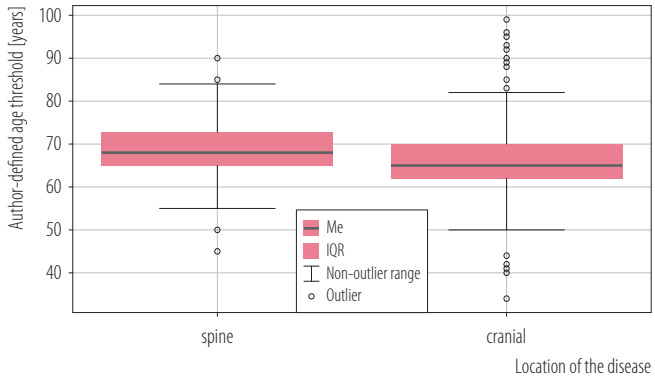
Figure 3. Temporal and geographic distribution of author-defined age thresholds for elderly populations in the neurosurgical PubMed dataset, 1970–2025: a) Europe and North America, publication-level thresholds with fitted linear regression and life expectancy for descriptive comparison, b) Europe and North America, age-threshold distributions by publication decade, c) Europe and North America, publications counts by age-threshold category and publication decade, d) Asia (excluding Japan), publication-level thresholds with fitted linear regression and life expectancy for descriptive comparison, e) Asia (excluding Japan), age-threshold distributions by publication decade, f) Asia (excluding Japan), publications counts by age-threshold category and publication decade, g) Japan, publication-level thresholds with fitted linear regression and life expectancy for descriptive comparison, h) Japan, age-threshold distributions by publication decade, i) Japan, publications counts by age-threshold category and publication decade

erature over time. Such thresholds are operational definitions adopted for the purposes of individual studies and should not be interpreted as biological boundaries between middle and old age.

The fitted temporal trend indicates an overall upward shift in the chronological age thresholds used by authors to define elderly populations over the past 5 decades. This trend occurred in parallel with increasing life expectancy and major developments in medicine, perioperative care, and neurosurgical treatment. However, the present study was not designed to determine which factors caused this change, and these parallel developments should therefore be regarded as possible contextual influences rather than direct causal explanations.

The apparent decline in life expectancy during the COVID-19 pandemic did not visibly alter the longer-term upward trend in the published age thresholds. One possible explanation is that the pandemic represented a relatively short disruption within a much longer demographic process. In addition, neurosurgical activity during this period, similarly to many other areas of medicine, was focused predominantly on urgent and necessary procedures [8]. Nevertheless, the present analysis does not allow the independent effect of the pandemic on the terminology used in neurosurgical studies to be determined.

Geographical differences were also observed. Asia was the only major region in which the chronological threshold used to define elderly populations showed a different temporal pattern from that observed in Europe and North America. The reasons for this divergence remain uncertain. Demographic structure, healthcare organization, research traditions, and cultural factors



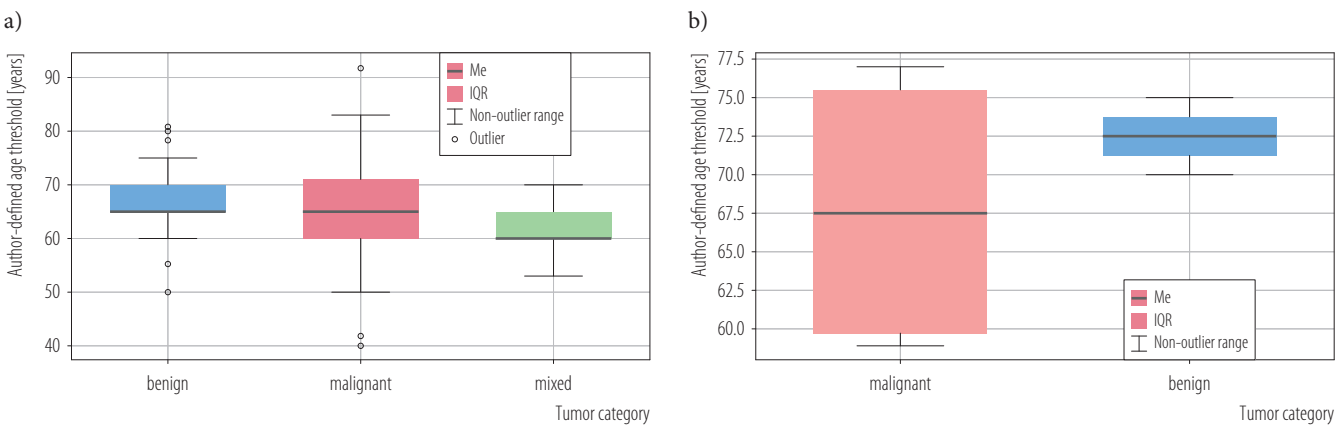
Age thresholds: spinal studies Me = 68 years (range: 45–90 years), cranial studies Me = 65 years (range: 34–99 years).

Figure 4. Distribution of author-defined age thresholds for elderly populations in spinal and cranial studies in the worldwide neurosurgical PubMed dataset, 1970–2025

may influence the chronological boundaries adopted in clinical studies. These factors, however, should not be considered medical indicators of aging and were not directly analyzed in the present study.

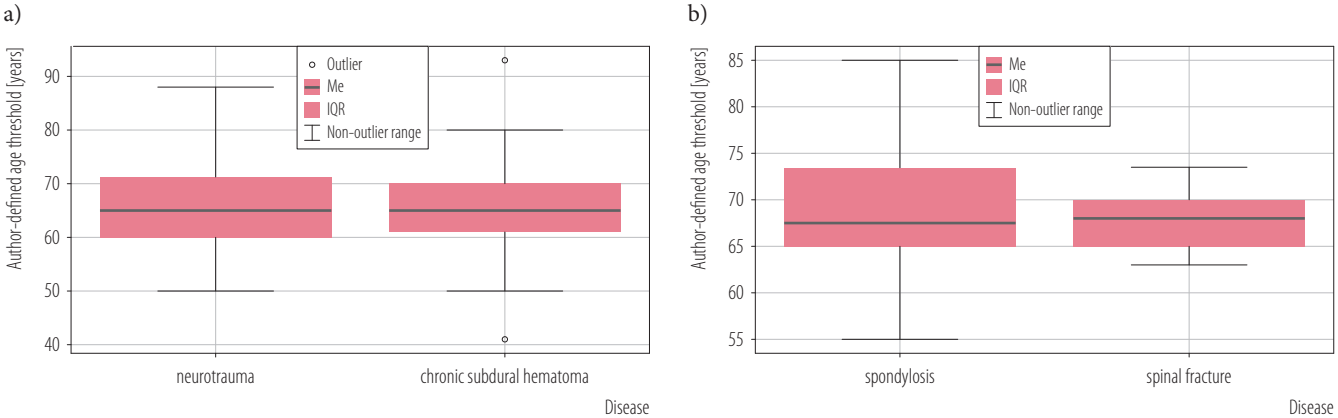
Japan represented a particularly distinctive group because of the large number of studies focusing on older neurosurgical populations and the relatively high age thresholds used in recent publications. Published work describes post-war changes in diet and cardiovascular epidemiology in Japan [9,10], which may have influenced the populations studied and the terminology adopted in clinical research. However, the present analysis does not establish the reasons for the higher thresholds observed in Japanese publications.

The analysis also demonstrated differences between disease categories. Spinal studies had a higher median



Age thresholds: cranial studies – Me = 65 years for both benign and malignant tumors and Me = 60 years for the mixed category; spinal studies – Me = 72.5 years for benign tumors and Me = 67.5 years for malignant tumors.

Figure 5. Distribution of author-defined age thresholds for elderly populations by tumor category in the worldwide neurosurgical PubMed dataset, 1970–2025: a) cranial tumors classified as benign, malignant, or mixed; b) malignant and benign spinal tumors



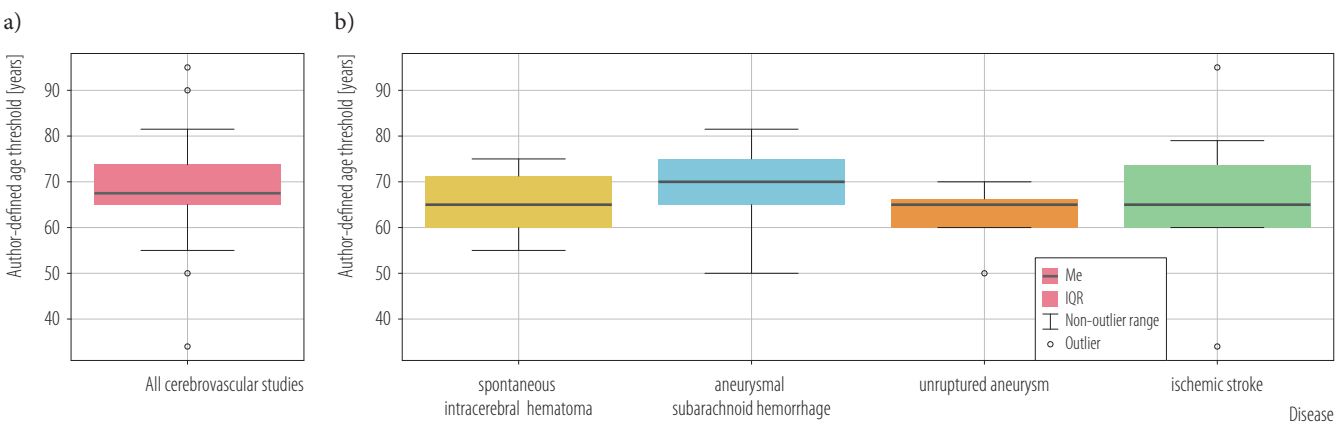
Age thresholds: neurotrauma M±SD 67.60±8.25 years, Me = 65 years; chronic subdural hematoma M±SD 66.11±11.42 years, Me = 65 years; spondylosis M±SD 68.96±6.91 years, Me = 67.5 years; spinal fractures excluding C2 fractures M±SD 67.79±3.67 years, Me = 68 years.

Figure 6. Distribution of author-defined age thresholds for elderly populations in traumatic and degenerative conditions in the worldwide neurosurgical PubMed dataset, 1970–2025: a) neurotrauma and chronic subdural hematoma, b) spondylosis and spinal fractures excluding C2 fractures

threshold than cranial studies. In tumor studies, the median threshold was higher for benign than malignant spinal tumors, whereas benign and malignant cranial tumors had the same median threshold. These differences concern the operational definitions adopted by investigators; they do not establish that biological aging begins at different ages in different disease categories.

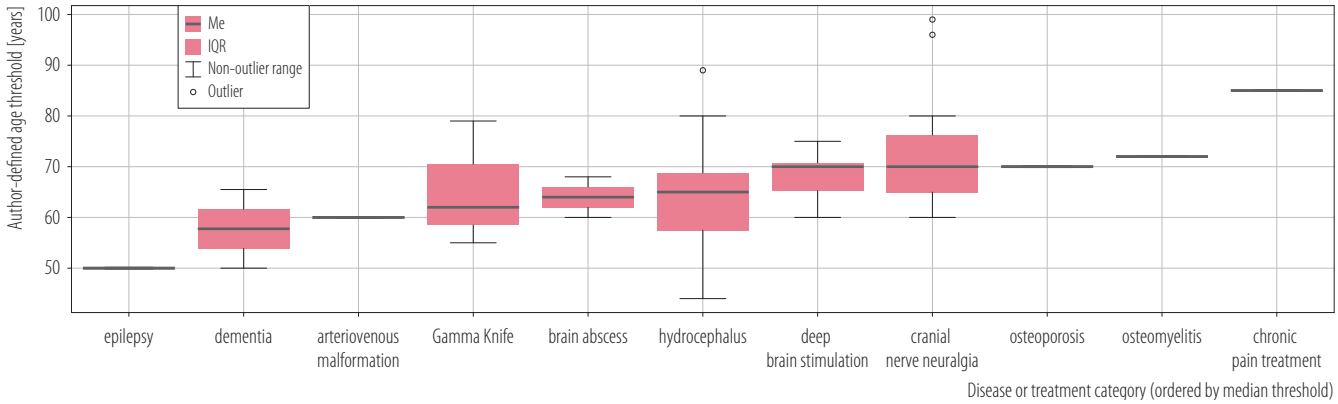
Differences in perioperative risk, expected treatment benefit, severity of complications, and capacity for recovery may contribute to the selection of different age thresholds in different neurosurgical fields. Prospective reporting has demonstrated the relevance of postoperative adverse events in skull base surgery and across neurosurgical practice [11,12]. Frailty provides additional prognostic information beyond chronological age, including for mortality after major neurosurgical complications [13]. Frailty does not define old age itself, but may influence treatment decisions and the characterization of older study populations.

Differences between acute and chronic conditions provide additional clinical context. Acute intracranial injuries are associated with sudden physiological stress and limited opportunity for adaptation, whereas chronic lesions may allow greater compensatory adjustment over time. Outcome differences between acute and chronic subdural hematomas illustrate the clinical relevance of this distinction [14]. In the present dataset, both groups had a median age threshold of 65 years, although dispersion was greater in chronic subdural hematoma studies. Frailty and preoperative functional status are relevant to the selection of older patients for neurosurgery [15]. In spinal disorders, selected octogenarians



Age thresholds: overall M±SD 68.3±9.5 years, Me = 67.5 years; aneurysmal subarachnoid hemorrhage Me = 70 years; the other 3 groups Me = 65 years.

Figure 7. Distribution of author-defined age thresholds for elderly populations in cerebrovascular studies in the worldwide neurosurgical PubMed dataset, 1970–2025: a) all cerebrovascular studies, b) spontaneous intracerebral hematoma, aneurysmal subarachnoid hemorrhage, unruptured aneurysm, and ischemic stroke



Age thresholds: epilepsy Me = 50 years, dementia Me = 57.8 years, arteriovenous malformation Me = 60 years, Gamma Knife Me = 62 years, brain abscess Me = 64 years, hydrocephalus Me = 65 years, deep brain stimulation Me = 70 years, cranial nerve neuralgia Me = 70 years, osteoporosis Me = 70 years, osteomyelitis Me = 72 years, and chronic pain treatment Me = 85 years.

Figure 8. Distribution of author-defined age thresholds for elderly populations in other disease and treatment categories in the worldwide neurosurgical PubMed dataset, 1970–2025

undergoing adult spinal deformity surgery may achieve functional outcomes comparable to those in younger groups [16]. These clinical observations provide possible context for differences in published definitions without establishing their causes.

In neuro-oncology, author-defined age thresholds differed between anatomical and tumor categories. These findings concern operational definitions of elderly study populations and do not identify a biological onset of old age. The natural history, treatment goals, expected survival, and treatment burden differ between benign and malignant disease. Meningioma surgery in older patients is associated with increased perioperative morbidity, although selected patients may improve neurologically [17]. Outcomes in patients aged ≥80 years also depend on their preoperative condition and the period of follow-up [18]. Short-term outcome studies of elderly patients with brain tumors further illustrate the importance of clinical status and tumor pathology [19]. Glioblastoma and its treatment have been associated with accelerated brain aging [20], and frailty is relevant to prognosis in brain tumor patients [21,22]. These differences may influence how investigators define older study populations.

Cerebrovascular studies showed heterogeneous threshold distributions. Age-related differences in presentation, treatment, and outcomes have been described in ischemic stroke [23]. Brain frailty, including imaging markers such as white matter changes and atrophy, provides information relevant to functional outcomes after thrombolysis [24,25]. Reperfusion treatment in older populations also requires consideration of clinical selection and treatment context [26]. Blood–brain barrier injury and hemorrhagic transformation are relevant complications of ischemic stroke and reperfusion therapy [27,28]. These observations provide clinical context but do not establish why investigators selected particular age thresholds.

Hemorrhagic cerebrovascular diseases form a heterogeneous group. In patients undergoing decompressive hemicraniectomy for spontaneous intracerebral hemorrhage, age was not independently associated with in-hospital mortality or poor outcome [29]. Comparisons of rehabilitation after ischemic and hemorrhagic stroke also demonstrate the relevance of functional outcomes beyond the initial disease classification [30]. These findings illustrate why a single chronological boundary has limited applicability across different cerebrovascular conditions.

Taken together, the broad distribution of thresholds across publication periods, geographic regions, and disease categories demonstrates that the term “elderly” has not been used as a uniform biological category in neurosurgical literature. Instead, it has functioned as a context-dependent, author-defined chronological classification.

This distinction is central to the interpretation of the findings. The median values presented in this study summarize the central tendency of the chronological thresholds selected by authors within particular periods or groups of publications. They do not represent the median age of the patients included in those studies, nor do they identify a biological age at which an individual becomes old.

The variability observed across time and clinical contexts also highlights the limitations of chronological age as a stand alone clinical criterion. Frailty, functional

status, multimorbidity, and physiological reserve provide information that is different from chronological age and may be more relevant to individual neurosurgical decision-making [21,22]. Therefore, while chronological thresholds remain useful for describing study populations, they should not be regarded as sufficient measures of biological vulnerability or treatment eligibility.

Limitations of the study

The principal aim of this study was to examine the evolution of the chronological threshold used by authors to define an "elderly" population in neurosurgical literature. The study was not designed to determine a biological threshold for old age, to establish the optimal age cut-off for individual neurosurgical conditions, or to determine an age beyond which treatment becomes ineffective.

The unit of analysis was the individual publication. Each included publication contributed the chronological age threshold adopted by its authors to define an elderly population. Consequently, the analysis reflects publication-level trends in the use of the term "elderly" rather than the age distribution of the underlying patient populations.

Each publication contributed equally to the analysis irrespective of sample size or methodological quality. This approach was consistent with the study objective, because the phenomenon of interest was the definition adopted by the authors rather than the number of patients represented by a particular study. Nevertheless, it limits the interpretation of the results. The reported medians should therefore be regarded as summaries of published chronological thresholds and not as estimates of population-level or biological old age.

The literature search was limited to PubMed and to predefined search terms intended to identify studies explicitly focusing on elderly populations. Some studies examining outcomes in older patients may not have used an explicit numerical threshold or may not have identified the population as elderly in a way captured by the search strategy. Such publications may therefore have been missed.

Substantial heterogeneity existed between study designs, disease categories, geographic regions, and publication periods. The chronological threshold selected by individual authors may have been influenced by convention, study design, epidemiology, clinical risk, local healthcare practice, or other contextual factors. The present analysis cannot determine the relative contribution of these influences.

Finally, biological, clinical, demographic, or cultural mechanisms discussed in relation to observed differences between groups represent possible contextual explanations derived from existing literature. They were not directly tested in the present study and should not be interpreted as causal determinants of the chronological thresholds used by individual authors.

CONCLUSIONS

Author-defined chronological thresholds used to identify elderly populations in neurosurgical literature showed an overall upward temporal trend across the study period.

Author-defined thresholds differed across geographic regions, disease categories, and neurosurgical subspecialties. Differences were observed between spinal and cranial studies and between selected tumor and cerebrovascular categories. These patterns were not uniform across all subgroups.

These findings do not identify a biological age at which old age begins. Rather, they demonstrate that "elderly" has been used in neurosurgical literature as a context-dependent chronological classification whose numerical boundary has changed over time and has varied according to the clinical and research setting.

The wide range of published thresholds underscores the limited value of a single chronological cutoff as a universal representation of aging in neurosurgical patients. Chronological age should therefore be distinguished from biological vulnerability, which is more appropriately assessed using factors such as frailty, physiological reserve, multimorbidity, and functional status.

Future studies should consider more precise reporting of the rationale for chronological age thresholds used to define elderly populations and should increasingly incorporate validated measures of frailty and physiological reserve when evaluating treatment risk and outcomes in older neurosurgical patients.

AI USE

Grammarly and ChatGPT (OpenAI) were used to assist with language editing and editorial revision. The authors reviewed and approved the final manuscript and remain responsible for its content.

AUTHOR CONTRIBUTIONS

Research concept: Dariusz Szarek

Research methodology: Dariusz Szarek, Ireneusz Skawina, Marcin Magdziarz

Collecting material: Dariusz Szarek, Marcin Magdziarz
Statistical analysis: Marta Elżbieta Magdziarz, Marcin Magdziarz
Interpretation of results: Dariusz Szarek, Ireneusz Skawina, Marcin Magdziarz
References: Dariusz Szarek, Marcin Magdziarz

REFERENCES

1. Greenberg SM, Ziai WC, Cordonnier C, Dowlatshahi D, Francis B, Goldstein JN, et al. 2022 guideline for the management of patients with spontaneous intracerebral hemorrhage: a guideline from the American Heart Association/ /American Stroke Association. Stroke. 2022;53:e282–e361. https://doi.org/10.1161/STR.0000000000000407.
2. De Simone B, Chouillard E, Podda M, Pararas N, Carvalho Duarte G de, Fugazzola P, et al. The 2023 WSES guidelines on the management of trauma in elderly and frail patients. World J Emerg Surg. 2024;19:18. https://doi.org/10.1186/s13017-024-00537-8.
3. Nayak L, Iwamoto FM. Primary brain tumors in the elderly. Curr Neurol Neurosci Rep. 2010;10:252–8. https://doi.org/10.1007/s11910-010-0110-x.
4. Liu C, Guo C, Meng F, Zhu Z, Xia W, Liu H. Perioperative risk factors related to complications of lumbar spine fusion surgery in elderly patients. BMC Musculoskelet Disord. 2023;24:573. https://doi.org/10.1186/s12891-023-06689-z.
5. Zhang C, Neha, Zhang J, Dhaha P, Li X, Mishra SK, et al. Aging and senescence: key players in brain tumor progression and drug resistance. Drug Resist Updat. 2025; 81:101228. https://doi.org/10.1016/j.drup.2025.101228.
6. United Nations High Commissioner for Refugees. Older persons [Internet]. Geneva: UNHCR; 2025 [cited 2026 Oct 29]. Available from: https://emergency.unhcr.org/protection/persons-risk/older-persons.
7. Our World in Data. Life expectancy [Internet]. Oxford: Global Change Data Lab; 2025 [cited 2026 Oct 29]. Available from: https://ourworldindata.org/grapher/life-expectancy.
8. Szarek D, Miękisiak G, Szmuda T, Fercho J, Pettersson S, Kipiński L. The impact of the COVID-19 pandemic on the number of brain tumor surgeries in Poland: a national database study. Adv Clin Exp Med. 2023;32:1299–309. https://doi.org/10.17219/acem/161726.
9. Teramoto T. Is "The Japan diet" cardioprotective? J Atheroscler Thromb. 2017;24:388–9. https://doi.org/10.5551/jat.ED061.
10. Sekikawa A, Miyamoto Y, Miura K, Nishimura K, Willcox BJ, Masaki KH, et al. Continuous decline in mortality from coronary heart disease in Japan despite a continuous and marked rise in total cholesterol: Japanese experience after the seven countries study. Int J Epidemiol. 2015;44:1614–24. https://doi.org/10.1093/ije/dyv143.
11. Grutza M, Bächler H, Haux D, Lenga P, Suchorska B, Scherer M, et al. Prospective analysis of 30-day postoperative adverse events in skull base surgery: insights into risk factors and mitigation strategies from a neurosurgical tertiary care center. Neurosurg Rev. 2026;49:16. https://doi.org/10.1007/s10143-025-03944-w.
12. Dao Trong P, Olivares A, El Damaty A, Unterberg A. Adverse events in neurosurgery: a comprehensive single-center analysis of a prospectively compiled database. Acta Neurochir (Wien). 2023;165:585–93. https://doi.org/10.1007/s00701-022-05462-w.
13. Paiz CC, Owodunni OP, Courville EN, Schmidt M, Alunday R, Bowers CA. Frailty predicts 30-day mortality following major complications in neurosurgery patients: the risk analysis index has superior discrimination compared to modified frailty index-5 and increasing patient age. World Neurosurg X. 2024;23:100286. https://doi.org/10.1016/j.wnsx.2024.100286.
14. Kuhn EN, Erwood MS, Oster RA, Davis MC, Zeiger HE, Pittman BC, et al. Outcomes of subdural hematoma in the elderly with a history of minor or no previous trauma. World Neurosurg. 2018;119:e374–e382. https://doi.org/10.1016/j.wneu.2018.07.168.
15. Adebola O. Do we need a neurosurgical frailty index? Surg Neurol Int. 2024;15:134. https://doi.org/10.25259/SNI_50_2024.
16. Kato S, Taniguchi Y, Kawamura N, Sato Y, Onishi Y, Nakayama Y, et al. Outcomes of adult spinal deformity surgery in octogenarians – How old is too old? Eur Spine J. 2026;35(2):388–94. https://doi.org/10.1007/s00586-025-09716-w.
17. Ahmeti H, Borzikowsky C, Hollander D, Röcken C, Jansen O, Synowitz M, et al. Risks and neurological benefits of meningioma surgery in elderly patients compared to young patients. J Neurooncol. 2021;154:335–44. https://doi.org/10.1007/s11060-021-03832-5.
18. Rautalin I, Schwartz C, Niemelä M, Korja M. Mortality of surgically treated 80-year-old or older intracranial meningioma patients in comparison to matched general population. Sci Rep. 2021;11:11454. https://doi.org/10.1038/s41598-021-90842-y.
19. Tantawy MF, Nazim WM. Brain tumor surgery in the elderly: a single institution experience of short-term outcome – a retrospective case study. Egypt J Neurol Psychiatr Neurosurg. 2021;57:96. https://doi.org/10.1186/s41983-021-00350-z.
20. Ainslie AP, Klaver M, Voshart DC, Gerrits E, den Dunnen WFA, Eggen BJL, et al. Glioblastoma and its treat-

ment are associated with extensive accelerated brain aging. Aging Cell. 2024;23:e14066. https://doi.org/10.1111/acel.14066.
21. Torres-Perez P, Álvarez-Satta M, Arrazola M, Egaña L, Moreno-Valladares M, Villanua J, et al. Frailty is associated with mortality in brain tumor patients. Am J Cancer Res. 2021;11(6):3294–303.
22. Qureshi HM, Tabor JK, Pickens K, Lei H, Vasandani S, Jalal MI, et al. Frailty and postoperative outcomes in brain tumor patients: a systematic review subdivided by tumor etiology. J Neurooncol. 2023;164:299–308. https://doi.org/10.1007/s11060-023-04416-1.
23. Fonarow GC, Reeves MJ, Zhao X, Olson DM, Smith EE, Saver JL, et al. Age-related differences in characteristics, performance measures, treatment trends, and outcomes in patients with ischemic stroke. Circulation. 2010;121:879–91. https://doi.org/10.1161/CIRCULATIONAHA.109.892497.
24. Frol S, Zupan M, Nogueira RG. The impact of brain frailty on acute reperfusion therapies in acute ischemic stroke – a narrative review. Interv Neuroradiol. 2025 Oct 27. Epub ahead of print. https://doi.org/10.1177/15910199251389057.
25. Loewen SP, Singh N, Alhabli I, Bala F, Buck B, Benali F, et al. Brain frailty and functional outcomes after thrombolysis for acute ischemic stroke. JAMA Netw Open. 2025;8(9):e2534941. https://doi.org/10.1001/jamanetworkopen.2025.34941.
26. Sudre J, Venditti L, Ancelet C, Chassin O, Sarov M, Smadja D, et al. Reperfusion therapy for acute ischemic stroke in older people: an observational real-life study. J Am Geriatr Soc. 2021;69:3167–76. https://doi.org/10.1111/jgs.17394.
27. Maier B, Desilles JP, Mazighi M. Intracranial hemorrhage after reperfusion therapies in acute ischemic stroke patients. Front Neurol. 2020;11:599908. https://doi.org/10.3389/fneur.2020.599908.
28. Hong JM, Kim DS, Kim M. Hemorrhagic transformation after ischemic stroke: mechanisms and management. Front Neurol. 2021;12:703258. https://doi.org/10.3389/fneur.2021.703258.
29. Poblete RA, Zheng L, Arenas M, Vazquez A, Yu D, Emanuel BA, et al. Older age is not associated with worse outcomes following decompressive hemicraniectomy for spontaneous intracerebral hemorrhage. J Stroke Cerebrovasc Dis. 2019;28:104320. https://doi.org/10.1016/j.jstrokecerebrovasdis.2019.104320.
30. Perna R, Temple J. Rehabilitation outcomes: ischemic versus hemorrhagic strokes. Behav Neurol. 2015;2015:891651. https://doi.org/10.1155/2015/891651.

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