Brain and Spine 5 (2025) 104156

Contents lists available at ScienceDirect

Brain and Spine

journal homepage: www.journals.elsevier.com/brain-and-spine

Knowledge, interest and perspectives on Artificial Intelligence in Neurosurgery. A global survey

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ARTICLE INFO

Handling Editor: Dr W Peul

Keywords:
Artificial intelligence
Neurosurgery
Machine learning
Deep learning
Big data
Global survey

ABSTRACT

Introduction: Artificial Intelligence (AI) applications in healthcare are growing exponentially. The field of neurosurgery is particularly suited to implement AI solutions given its technology-driven nature. It is of paramount importance to understand the basics of AI to make informed decision on how to shape current and future applications.
Research question: What is the level of confidence, knowledge and the attitude of the global neurosurgical community towards AI basic concepts and applications?
Material and methods: A 24-item survey was designed and distributed. The survey results reported on level of knowledge, confidence and interest in AI, perspectives and attitude towards the application of AI technologies in neurosurgery. The potential influence of demographics and work-related environment features on AI knowledge was investigated.
Results: We received a total of 250 responses from 61 countries. The correct definition of 'Machine Learning', 'Deep Learning' and main Big Data features were identified by respectively 42%, 23% and 23% of the respondents. The survey unveiled a strong interest and a positive attitude towards the introduction of AI in the neurosurgical practice. The main concerns included trustworthiness and liability, the main barriers to implementation were considered lack of funding, infrastructure, knowledge and multidisciplinary collaboration.
Discussion and conclusion: There is a low familiarity with basic AI concepts in the neurosurgical community. Nevertheless, there is a strong interest and a positive attitude towards AI implementation. The systematization of training and the production of educational resources will be key in guaranteeing a successful implementation of AI in the evolving history of neurosurgery.

1. Introduction

Artificial intelligence (AI) applications in healthcare are on the rise and projected to grow over the coming years (Manickam et al., 2022; Yu et al., 2018). Some example of AI applications include the improvement of hospital services flow, infection disease detection, risk-screening tools and control and use of clinical and genetic data for common and rare disease diagnosis and management (Haug and Drazen, 2023).

Neurosurgery, as a technology-driven field, is well-suited for the implementation of AI solutions (Zoli et al., 2022; Boaro et al., 2022a). Advancements in the development of visualization tools, navigational systems and intraoperative techniques, are a few examples of neurosurgical areas in which technology plays a central role toward improving patient outcomes, reducing risks and maximizing efficiency (Mishra et al., 2022; Boaro et al., 2022b; Di Domenico et al., 2023; Walker et al., 2019). Some areas ideally suited to be impacted by AI in neurosurgery include anatomical or pathological structures segmentation, surgical trajectory planning, operating room implementation of augmented reality and robotics, clinical outcome prediction and follow-up personalization (Boaro et al., 2022a).

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https://doi.org/10.1016/j.bas.2024.104156
Received 8 October 2024; Received in revised form 28 November 2024; Accepted 8 December 2024
Available online 9 December 2024

While the common understanding of current clinical technological applications as operative microscopes or neuro navigation systems is established and widespread due to their daily utilization, AI concepts are relatively new to healthcare providers while, at the same time, carrying potentially game-changing, clinical, organizational and ethical implications (Keskinbora, 2019; Aung et al., 2021; Chen and Decary, 2020). Therefore, it is of paramount importance for neurosurgeons to understand basic AI concepts, to be able to communicate effectively with AI developers and to use these solutions in the day-to-day practice (Zoli et al., 2022; Awuah et al., 2024).

With this work, supported by the European Association of Neurosurgical Societies (EANS) Emerging Technologies and Innovations in Neurosurgery Task Force, we explored the level of confidence and knowledge of the global neurosurgical community with AI basic concepts as well as its attitude and perspectives towards opportunities and challenges in AI development and integration into clinical practice.

2. Methods

We conducted a cross-sectional study using a newly designed online survey to explore the perceived and actual knowledge of neurosurgeons regarding basic AI concepts, along with attitudes and perspectives toward AI development and integration into clinical practice.

The 24 items survey was developed as a collaborative effort of the Departments of Neurosurgery at the Universities of Verona and Leiden, and reported following the Checklist for Reporting Results of Internet E-Surveys (CHERRIES) (details in Supplementary Table 1) (Eysenbach, 2004).

To identify relevant survey items, we conducted a targeted literature review of systematic reviews and original research articles, followed by a consensus among health researchers with expertise in AI and medicine. A small sample of healthcare professionals evaluated the first draft of the questionnaire for clearness, comprehensibility and possible mistakable phrases and their feedback was implemented (Hengstler et al., 2016; Liyanage et al., 2019; Haan et al., 2019; Pinto dos Santos et al., 2019).

The survey included three different sections. The first section explored participant demographics and work-related environment information including age, gender, country of residence, type of work institution, expertise in neurosurgery and clinical areas of interest. The second section explored confidence with and knowledge of basic AI terms: Machine Learning, Deep Learning, Big Data (detailed definitions provided in Table 1). Moreover, it investigated the level of interest in AI research, measured in terms of number of papers read on AI topics and numbers of AI research projects with active involvement. The last section explored perspectives and attitude towards the application of AI technologies in neurosurgery in terms of potential impact and perceived barriers as well as concerns regarding the implementation of these technologies in the day-to-day practice.

The target population consisted of the global neurosurgical community inclusive of medical students with an interest in pursuing a career in neurosurgery. The survey was preceded by an introductory section where the aim of the study, the length of time for completing the survey, the developers and the principal investigator's email contact were provided. The survey was implemented on google forms and disseminated in the form of a link or a QR code by means of the EANS mailing list, the publication on EANS website, and social media. Participation to the survey was voluntary, and no incentives were offered to participants. The only piece of personal information collected was the email address in case the respondent wanted to be informed on the results of the study. Data were collected between June 2022 and February 2024.

Table 1
AI terms definitions and features.

Machine Learning	A branch of artificial intelligence (AI) and computer science which focuses on the use of data and algorithms to imitate the way that humans learn, gradually improving its accuracy
Deep Learning	A branch of artificial intelligence (AI), which attempts to simulate the behavior of the human brain allowing it to "learn" from large amounts of data
Artificial Intelligence	The science and engineering of making intelligent machines, especially intelligent computer programs.
Big Data features	Big Data represent extremely large data sets that may be analyzed computationally to reveal patterns, trends, and associations. The main Big Data features are high **Volume** of data, high **Velocity** of production, high **Variety** of types.

The results were stored in a Microsoft Excel sheet and analyzed with built-in functions to obtain descriptive statistics. We produced confusion matrices and calculated odds ratios (OR) (95% CI) to evaluate the potential influence of working in an academic environment, being of younger age (<40) or being in training on the responders' ability to correctly define basic AI terms. This survey was conducted in accordance with the Declaration of Helsinki and its subsequent revisions and approved by the EANS and the Emerging Technology and Innovation in Neurosurgery Task Force. Electronic informed consent was obtained from each participant online prior to survey commencement and information was stored in accordance with GDPR regulations.

3. Results

3.1. Population demographics and work-related features

Overall, the survey received a total of 250 responses and 248 were included in the analysis (two participants did not complete the survey). Participants from a total of 61 countries distributed in all continents completed the survey, with most of the respondents located in Europe (69%) (Table 2 and Fig. 1). Most participants already completed residency (62%) and were working in academic hospitals (68%). Areas of personal interest in neurosurgery varied widely, with oncology and spine as the most represented single topics (respectively 21% and 16%) (Table 2).

3.2. Knowledge of AI basic concepts and interest in AI research

The first part of this survey section consisted of six questions. The first three aimed to assess participants' confidence in their understanding of key Artificial Intelligence terms: 'Machine Learning', 'Deep Learning', and 'Big Data'. The last three questions were intended to test the actual comprehension of these concepts.

Regarding 'Machine Learning', 70% of respondents claimed to be familiar with the term's meaning. However, this confidence was not fully justified, as only 60% of this group of participants correctly identified the definition. As a result, just 42% of the entire survey population demonstrated a correct understanding of the concept.

The term 'Deep Learning' revealed an even more pronounced gap. While 46% of participants stated they knew the term, only 51% of this subgroup correctly identified its meaning. Consequently, a mere 23% of the total survey population chose the correct definition.

Finally, the concept of 'Big Data' obtained similar findings. Although 59% of subjects claimed to understand the term, only 23% successfully identified the three main characteristics traditionally associated with Big Data: Volume, Velocity, and Variety (Boaro et al., 2022a; Davenport and Kalakota, 2019) (Fig. 2).

Odds Ratios for defining properly the term 'Machine Learning' were slightly in favor of younger and in-training surgeons, and only in favor of in-training surgeons for the term 'Deep Learning'; nevertheless, no statistically significant difference between the subgroups was detected (Fig. 3).

In the second part of this survey section, we asked participants to provide examples of AI and Big Data applications in neurosurgery, and we assessed their exposure to AI research.

40% of respondents stated they had never encountered AI applications in their work environment, while 49% claimed to have

Table 2
Survey population's features.

	n of patients	% of patients
Age group		
20–29	46	18.5
30–39	108	43.5
40–49	54	21.8
50–59	24	9.7
60–70	15	6.0
>70	1	0.4
Gender		
M	201	81.0
F	46	18.5
Other	1	0.4
Region		
Africa	15	6.0
Asia	36	14.5
Australia-New Zealand	4	1.6
Central-South America	10	4.0
Europe	171	69.0
North America	11	4.4
Other	1	0.4
Working/studying environment		
Academic hospital	170	68.5
Community hospital	53	21.4
Private Practice	23	9.3
Industry	1	0.4
Research Network	1	0.4
Level of expertise in neurosurgery		
Student	15	6.0
Junior resident	34	13.7
Senior resident	45	18.1
Junior attending/fellow	52	21.0
Senior attending	102	41.1
Areas of interest in neurosurgery		
Epilepsy/Functional	64	8.3
Neurovascular	111	14.5
Trauma	108	14.1
Spine	126	16.4
Pediatric	56	7.3
Peripheral	28	3.6
Oncology	160	20.8
Skull base	115	15.0

encountered at least one. Not surprisingly, imaging was the main application area, suggested by 38% of subjects. This was followed by applications in navigation software (18%), intraoperative applications (13%), outcome predictions (7%), tissue analysis (4%), and training (2%) (Table 3).

Participants were also asked to provide examples of Big Data in neurosurgery. Imaging was the most suggested example (23%), followed by registries (21%), hospital records (18%), and others. Interestingly, 27% of the answers were not appropriate, ranging from suggestions of study methodologies (such as randomized controlled trials, meta-analysis) to specific technological devices (like robots), instead of actual data types (Table 3).

Regarding involvement in AI research, 68% of the sample claimed they had read at least one paper on AI/ML/DL/Big Data over the last year, while 28% claimed to be actively working on AI projects (Table 3).

3.3. Perspectives and attitude towards AI in neurosurgery

In the last part of the survey, we explored the opinion of neurosurgeons regarding impact, barriers and concerns about AI implementation in neurosurgery. 94% of the respondents considered the potential impact of AI applications on both patient outcome and on neurosurgical practice to be beneficial (Table 3). The most important barriers to the implementation of AI solutions in neurosurgery, with similar level of relevance, were considered the lack of funding, infrastructure, knowledge and multidisciplinary collaboration; on the other hand, lack of interest was not seen as a relevant barrier (Fig. 4).

With regard to perceived concerns to AI implementation, trustworthiness was the one with the highest scores, followed by liability, and with slightly lower scores for privacy, equality and sustainability (Fig. 4).

The survey results indicate that most participants see the greatest potential for AI solutions in the areas of prevention and diagnosis, with 60% of respondents holding this view. The remaining respondents were equally split between therapy and follow-up, each with 20% of the responses. There was a strong consensus among the participants regarding the need for specialized oversight of AI applications in neurosurgery. A significant majority, 79% of respondents, supported the need of a dedicated task force or expert panel within their neurosurgical association for the assessment of the clinical readiness of AI applications in the field. The survey also revealed a high level of interest in staying informed about future developments in AI applications for neurosurgery. This was evidenced by the fact that 70% of the participants voluntarily provided their email addresses, expressing their desire to receive updates on future studies in this area.

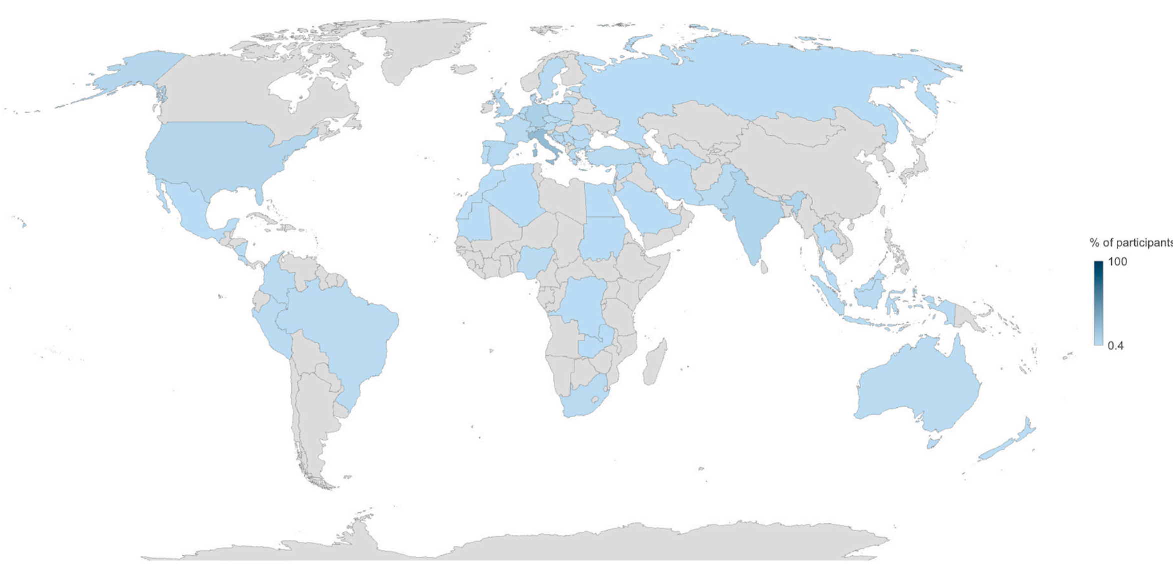

Fig. 1. Geographical distribution of the participants. Geographical representation on a global map of the participants' provenance with percentages reported at a country level.

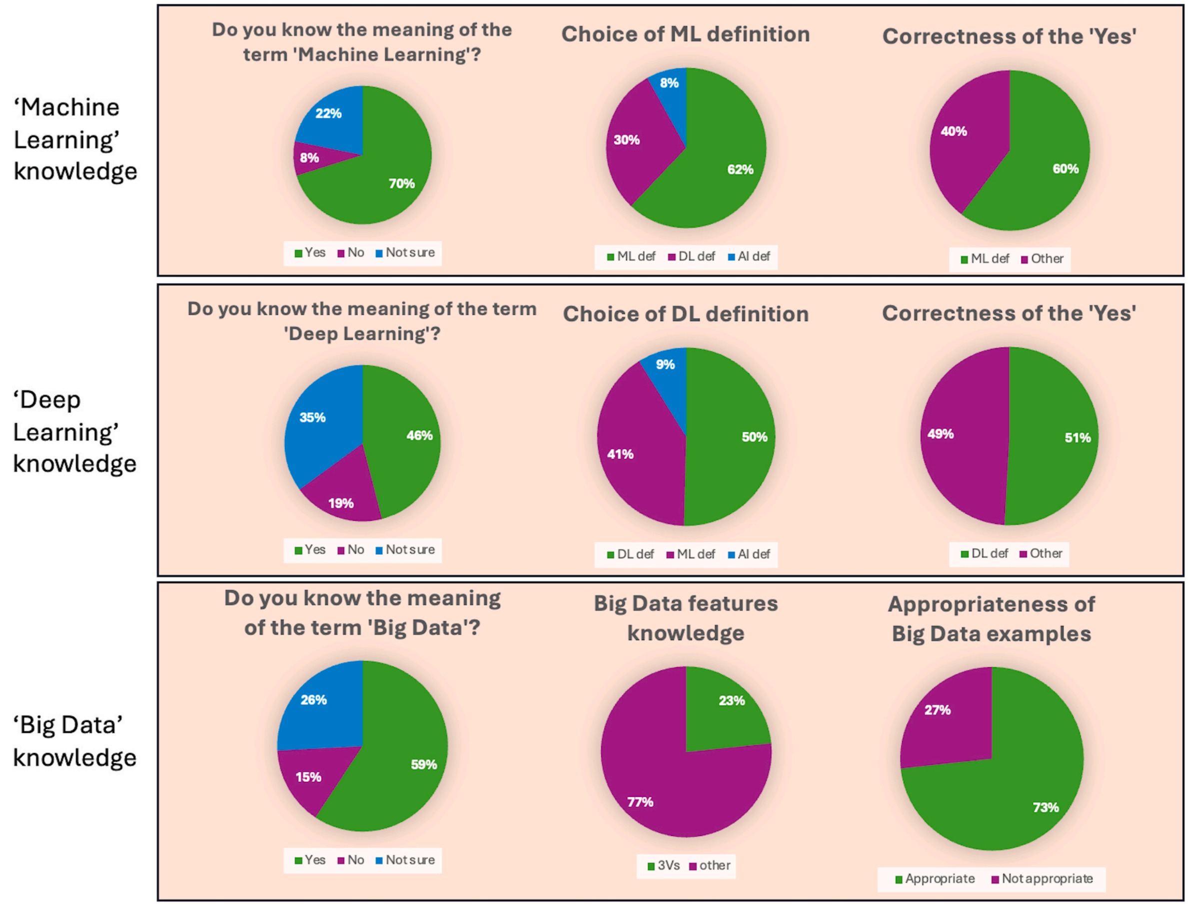

Fig. 2. Perceived and actual knowledge of AI concepts. *Upper section,* pie charts presenting the perceived knowledge of the term 'Machine Learning' (left), the proportions of definitions chosen by the participants (center) and the proportion of subjects who both believed and proved to know the definition of the term (right). *Central section,* pie charts presenting the perceived knowledge of the term 'Deep Learning' (left), the proportions of definitions chosen by the participants (center) and the proportion of subjects who both believed and proved to know the definition of the term (right). *Lower section,* pie charts presenting the perceived knowledge of the term 'Big Data' (left), the proportion of participants who correctly identified the three main Big Data features (center) and the appropriateness of the examples of Big Data provided (right).

4. Discussion

The results of our survey portray a situation of high interest in Artificial Intelligence and its clinical applications within the global neurosurgical community. Participants hold a certain level of perceived confidence in their understanding of AI basic terms, which didn't seem to be matched by a corresponding level of actual knowledge. In the most favorable scenario, fewer than half of the survey respondents could accurately define any of the basic AI terms presented, while in the least favorable scenario, this percentage dropped to less than 25%. In addition, when asked to provide examples of Big Data in neurosurgery, more than one quarter of the participants provided inappropriate responses.

Over the last decade, terms like Artificial Intelligence, Machine Learning, Deep Learning and Big Data have become more and more familiar and diffusely used in the general population. (Davenport and Kalakota, 2019; https://www.grandviewresearch.com/industry-analysis/artificial-intelligence-ai-market; Parliament - wwweuroparleuropaeu E) Such trend has been particularly strong in the healthcare professional community, in consideration of the potentialities that AI technology could bring for improvement of patient outcomes, hospital work environment and research (Manickam et al., 2022; Yu et al., 2018; Keskinbora, 2019; Aung et al., 2021; Davenport and Kalakota, 2019). Accordingly, the publication rate of AI-based scientific works has risen significantly, as there is a tremendous, generalized push towards developing, introducing and implementing AI technology in almost every field of medicine. Consequently, an increasing number of studies has been conducted in recent years to evaluate current level of knowledge of and attitude towards AI technologies in numerous medical disciplines in multiple countries (Maassen et al., 2021; Oh et al., 2019; Palmisciano et al., 2020; Tamori et al., 2022; Doraiswamy et al., 2020; Scheetz et al., 2021; Castagno and Khalifa, 2020; Allam et al., 2023; Laï et al., 2020; Fritsch et al., 2022). In their online survey, Scheetz et al. reported that half of 632 responders from ophthalmology, radiology/radiation oncology, dermatology training programs in Australia and New Zealand rated their knowledge of AI concepts as average with only 5.5% rating it as excellent. Only 13.8% felt that they were adequately prepared for the introduction of AI in clinical practice (Scheetz et al., 2021). Oh et al. explored the confidence of Korean medical doctors and students regarding AI concepts, reporting that only 40 out of 669 (6%) felt that they had good familiarity with AI (Oh et al., 2019). Similarly, Castagno et al. found that within their survey target population of 98 staff of the Royal Free London NHS Foundation Trust, 87% did not know the difference between machine learning and deep learning, although 50% knew at least one of the two terms (Castagno and Khalifa, 2020).

Consistent with these findings, our analysis indicates that the average knowledge of basic AI concepts within the neurosurgical community is low, although there is a relatively higher level of self-reported confidence in understanding these concepts. One potential explanation for these findings is that AI as a topic is currently discussed and presented across disciplines very often, providing information that can create a general understanding in the minds of the listener. This superficial understanding can indeed produce a sense of higher confidence

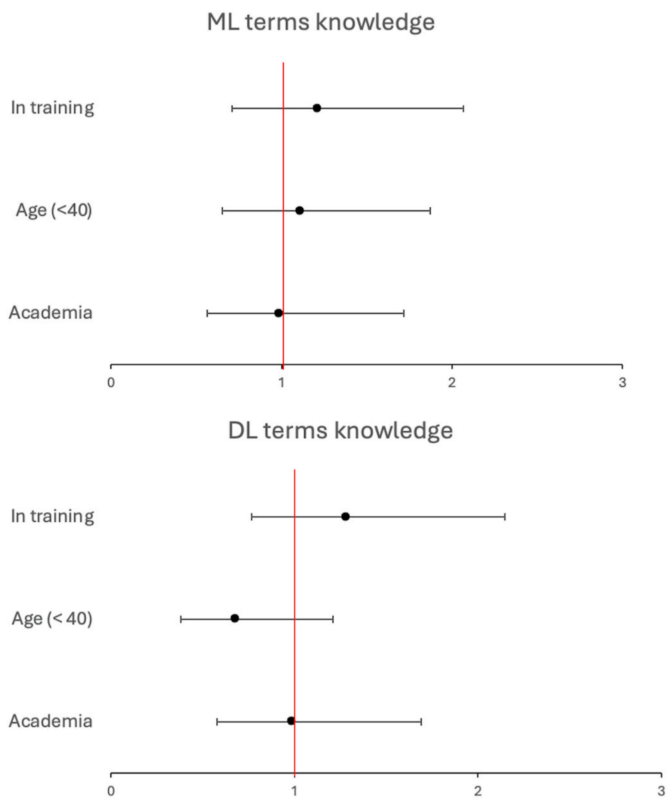

Fig. 3. Odds Ratio of specific factors influencing AI concepts knowledge. Forest plots presenting ORs and related confidence intervals representing the influence of being in training, being of a younger age and working in an academic environment on choosing the correct definition of 'Machine Learning' (Above) and Deep Learning (Below). The x-axis represents the odds ratio scale, with 1 being the reference (red vertical line) indicating no effect or association. The y-axis lists the different categories or groups being compared. The positioning and length of the horizontal lines represent confidence intervals of the odds ratio estimates (black dots).

in the topic compared to the actual competence, which is a common effect known to psychologists as Dunnig-Kruger effect (Kruger and Dunning, 1999). We therefore believe that this type of mismatch is more related to how the general population may address survey questions rather than to the features of a specific population of interest. On the other hand, we found an underlying strong interest in increasing the personal knowledge, as almost 70% of the responders reported to have read at least one AI-based scientific paper over the previous year, while an active role in AI research remains understandably confined to a minority of the participants.

The sentiment toward the implementation of these technologies is diffusely positive, and our findings are in line with the results of other surveys, as we found that there is a strongly positive attitude towards the possibilities that AI applications can open in the neurosurgical practice. To investigate whether sample characteristics explained the perceived positive AI impact, we employed an ordinal logistic regression model. We examined if exposure to AI tools at work, age group, and academic environment influenced perceptions of AI's benefits for patients and surgeons. The model showed significant fit only for patient impact ($p = 0.035$), with AI exposure in the workplace emerging as the sole factor increasing the likelihood of perceiving a more positive impact. Although the overall perception of AI's impact on patients and neurosurgical practice was predominantly positive, with over 93% of responses falling into 'moderate beneficial' or 'strongly beneficial' categories, our findings suggest an significant insight. The opportunity to use AI solutions firsthand appears to enhance appreciation of AI's usefulness and potentially mitigate fears surrounding its adoption.

Table 3
Familiarity, utilization and perception of AI technologies by the survey population.

	n of patients	% of patients
Number of AI applications used		
None	101	40.7
One	47	19.0
Two to four	48	19.4
More than four	27	10.9
Not sure	25	10.1
AI applications examples		
Imaging analysis	38	38
Navigation software	18	18
Intraoperative applications	13	13
Training	2	2
Tissue analysis	4	4
Outcome predictions	7	7
Other	18	18
Number of AI papers read		
None	79	31.9
One	35	14.1
Two to four	75	30.2
More than four	59	23.8
AI research involvement		
Yes	70	28.2
No	168	67.7
Not sure	10	4.0
AI impact on patient outcomes		
Definitely beneficial	144	58.1
Somewhat beneficial	90	36.3
Neither beneficial nor detrimental	12	4.8
Somewhat detrimental	2	0.8
Definitely detrimental	0	0.0
AI impact on neurosurgical practice		
Definitely beneficial	137	55.2
Somewhat beneficial	96	38.7
Neither beneficial nor detrimental	9	3.6
Somewhat detrimental	5	2.0
Definitely detrimental	1	0.4

Most of the respondents believe that AI will make the biggest difference on prevention and diagnosis, which is understandable considering the strong success that AI applications are already having in these areas, thanks to wide availability of structured, highly informative data, as imaging and electronic health records. Regarding the potential barriers to implementation, funding and infrastructure were considered of similar high importance. Both are key factors, as acquiring data of high quality and providing dedicated hardware structures upon which develop AI applications are needed and can be costly; over the years there has been increasing investments from both the private and public sectors, in the form of acquiring and making resources available and opening research grants dedicated to AI applications in medicine.

Lack of knowledge and multidisciplinary collaboration were also considered among the main barriers to AI solutions implementation. This result is not surprising, as currently we are not aware of programs for integrated teaching of AI topics in neurosurgery. Nevertheless, over the last years there have been increasing efforts all over the world to try to improve the training in computational and AI disciplines for healthcare professionals in general, with the introduction of mixed medical and engineering degrees as well as more advanced degrees and courses dedicated to specific AI areas, as for example medical imaging analysis (De La Higuera, 2019; Paranjape et al., 2019). The cross-contamination of medical and computational fields and the systematization of training will be fundamental to create a generation of prepared, accultured professionals, with the ability to go beyond the low hanging fruit of developing ML and DL algorithms by virtue of the current relative ease of their implementation. Finally, it was not surprising to find that lack of interest is not seen as a relevant barrier given the strong positive attitude AI technologies development and implementation depicted by the survey results (Castagno and Khalifa, 2020; Allam et al., 2023; Laï et al., 2020; Fritsch et al., 2022).

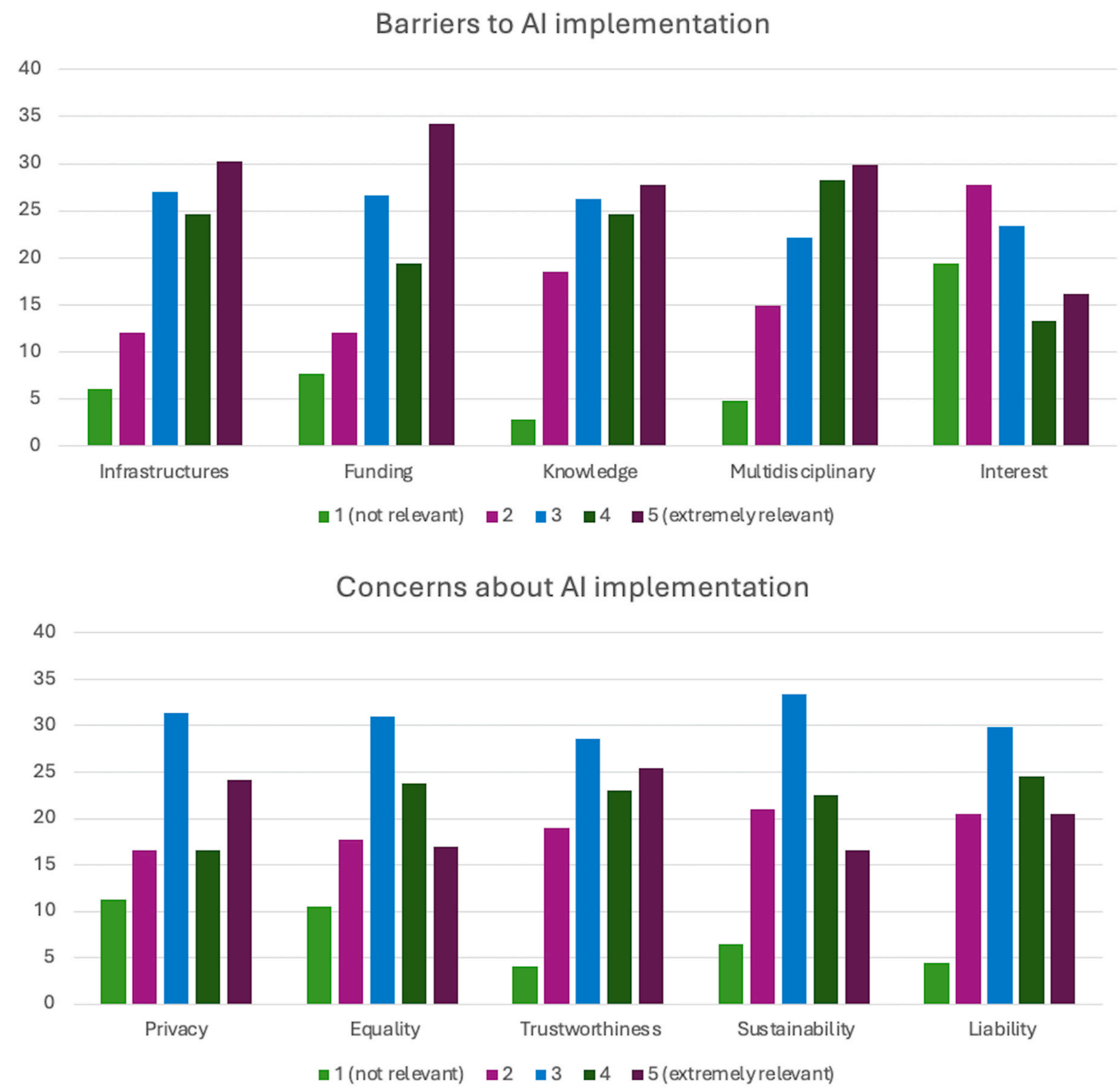

Fig. 4. Perceived barriers and concerns on AI implementation. *Above*, bar plots reporting the perceived relevance of lack of infrastructures, funding, knowledge, multidisciplinary collaboration, interest as barriers for the implementation of AI in neurosurgery; *Below*, bar plots reporting the perceived relevance of privacy, equality, trustworthiness, sustainability and liability as concerns about the implementation of AI in neurosurgery.

Indeed, given the rising interest and enthusiasm for AI healthcare applications, both the regulatory process and training programs in the use of such technologies for healthcare professionals are devoting significant resources to keep up (De La Higuera, 2019; Paranjape et al., 2019). The importance of having an adequate regulatory and educational framework within which to develop and exploit the potentialities of AI in a responsible and effective manner, cannot be underestimated. In fact, on one hand the development of effective AI applications results from the close collaboration between the final users, the healthcare professionals, and the data scientists, therefore a common language to allow effective communication must be developed and learned, with shared concepts and definitions. On the other hand, the power of AI applications expressed as the ability to automate processes, provide new information and partake in clinical decision-making, will compete in performance with human experts, raising fundamental questions regarding liability and trustworthiness. Indeed, our results showed that the main concerns regarding AI implementation resulted to be trustworthiness and liability of the use of such applications, followed by privacy, equality and sustainability (Reddy, 2022). Adequate answers will be needed by a corresponding, clear regulatory framework. At a general, higher level, policymakers and regulatory bodies are acutely aware of these necessities and of the need to close the gap between regulation and implementation, as demonstrated by the recent publication of the world's first comprehensive AI body of law in the form of the EU AI Act, in the second quarter of 2023 (European Parliament and Council, 2024).

In this regard, we did find an acute awareness of the need to have dedicated experts to inform and guide the community as almost 80% of the neurosurgeons considered useful the creation of a task force or expert board within their professional association. In fact, while it is true that almost 70% of the respondents work in an academic environment, we didn't find a significant difference in the ability to provide correct definitions of AI basic terms compared to non-academic participants. In our opinion, such finding could be one of the strongest points in the confirmation of the results of the survey and on the need of dedicated experts, because participants from academic environment should be more exposed to and aware of new ideas and new technologies, and therefore, if the survey population was to be balanced between academics and non-academics, we would expect an even lower level of knowledge. It was interesting to see that being in training tended to produce a positive effect, even if not significant, in correctly define ML and DL terms, while this effect was less evident for the condition of being less than 40 of age. This scenario could be partially explained by the fact that residents and students are more consistently exposed to learning materials, new ideas and concepts thanks to the training programs they are in, while young attendings may be more focused in building their surgical careers.

Indeed, as future generations of neurosurgeons may be exposed to AI concepts since medical school or even before, the challenge remains for those who have already completed their training as they will still work for many years and, with all probability, will be active users of AI applications on a daily basis.

Given the high workload of neurosurgeons and residents, which limits time for exploring new disciplines, one solution could be to offer dedicated workshops at national and international meetings. These workshops would cover AI fundamentals and showcase real applications, highlighting benefits, challenges, and pitfalls. Another option is to develop learning materials for association websites, enabling flexible, self-paced learning.

The importance of continuing education and professional updating, when it comes to a disruptive and game-changing topics as artificial intelligence in healthcare, cannot be overstated. With this survey, we wanted to create a tool for AI knowledge and attitude assessment which was compliant with established guidelines for online survey and whose potential applications could go beyond the neurosurgical field. The survey template in fact, can be easily applied to any other healthcare professional community. We therefore included the survey template in this work (Supplementary File 1), with the intent of promoting its widespread dissemination across various disciplines and research communities, to be used to establish the state of AI concepts knowledge and to use the results as foundation for future planning.

Some limitations must be considered in reading and interpreting the results presented in this work. First, the survey sample is numerically limited and therefore not necessarily representative of the global neurosurgical community. On this note, there could be a selection (geographical) bias, as most responders were located in Europe and, while we received responses from all the continents, not all the countries were equally represented or represented at all. Second, the survey design limits the range of response options, so the findings should not be viewed as a complete representation of respondents' perceptions. This limitation was addressed by incorporating open-ended questions. Finally, those participants interested in AI in general, might have been more interested in completing the survey, thus potentially skewing the results in a more positive direction.

While we couldn't conduct a comparative analysis of non-respondents given the open nature of our survey, our sample and results still provide meaningful insights considering that neurosurgical realities can be very different in terms of available technologies within the same continent or even the same country, mitigating the geographical bias; in addition, we saw that interest, compared to other factors, was considered the least relevant barrier towards the implementation of AI solutions, suggesting a consistent level of interest in the topic in the survey population itself, which was also confirmed by the survey completion rate, which was 99.2% (248 out of 250), partially mitigating a potential more favorable view. Finally, the observation that being of academic extraction didn't translate in higher knowledge, speaks in favor of a current, generalized low familiarity with AI concepts. Nonetheless, the results of our survey remain preliminary, and they should be considered a starting point for the conduction of future studies for a more robust validation of our findings. An interesting, potential opportunity could be that of focusing on a single country level, taking into consideration country-specific features in terms of healthcare system, education and policy. Such an approach would provide more granular data and would allow the development of tailored implementation programs.

In conclusion, there seems to be a low familiarity with basic AI concepts in the general neurosurgical population. At the same time, there is a strong interest in the topic and a positive attitude towards the possibilities that such technology could bring to the field. We believe that the systematization of training and the production of educational resources by national and international professional organizations, in collaboration with experts of adjacent fields as data science, law and policy making, will be key in guaranteeing a successful implementation of AI in the evolutive history of neurosurgery.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Aknowledgments

The publication costs have been covered by the 'Fondo Straordinario di Ateneo per la pubblicazione in Open Access' of the University of Verona.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bas.2024.104156.

References

Allam, A.H., Eltewacy, N.K., Alabdallat, Y.J., Owais, T.A., Salman, S., Ebada, M.A., 2023. Knowledge, attitude, and perception of Arab medical students towards artificial intelligence in medicine and radiology: a multi-national cross-sectional study. Eur. Radiol. https://doi.org/10.1007/s00330-023-10509-2. Published online July 1.
Aung, Y.Y.M., Wong, D.C.S., Ting, D.S.W., 2021. The promise of artificial intelligence: a review of the opportunities and challenges of artificial intelligence in healthcare. Br. Med. Bull. 139 (1), 4–15. https://doi.org/10.1093/bmb/ldab016.
Awuah, W.A., Adebusoye, F.T., Wellington, J., et al., 2024. Recent outcomes and challenges of artificial intelligence, machine learning, and deep learning in neurosurgery. World Neurosurg X 23, 100301. https://doi.org/10.1016/j.wnsx.2024.100301.
Boaro, A., Mammi, M., Arnaout, O., 2022a. Artificial intelligence and Big data in neurosurgery. In: Winn, R.H. (Ed.), Youmans and Winn Neurological Surgery, eighth ed. Elsevier, pp. e1–e12.
Boaro, A., Moscolo, F., Feletti, A., et al., 2022b. Visualization, navigation, augmentation. The ever-changing perspective of the neurosurgeon. Brain Spine 2, 100926. https://doi.org/10.1016/j.bas.2022.100926.
Castagno, S., Khalifa, M., 2020. Perceptions of artificial intelligence among healthcare staff: a qualitative survey study. Front Artif. Intell. 3. https://doi.org/10.3389/frai.2020.578983.
Chen, M., Decary, M., 2020. Artificial intelligence in healthcare: an essential guide for health leaders. Healthc. Manag. Forum 33 (1), 10–18. https://doi.org/10.1177/0840470419873123.
Davenport, T., Kalakota, R., 2019. DIGITAL TECHNOLOGY The Potential for Artificial Intelligence in Healthcare, 6.
De La Higuera, C., 2019. A report about education, training teachers and learning artificial intelligence: overview of key issues. Edu. Comput. Sci. 1–11. Published online.
Di Domenico, M., Viola, D., Izzo, A., et al., 2023. Methods and Principles of the Intraoperative Neurophysiologic Monitoring in Neurosurgery, pp. 45–49. https://doi.org/10.1007/978-3-031-36084-8_9.
Doraiswamy, P.M., Blease, C., Bodner, K., 2020. Artificial intelligence and the future of psychiatry: insights from a global physician survey. Artif. Intell. Med. 102. https://doi.org/10.1016/j.artmed.2019.101753.
European Parliament and Council, 2024. REGULATION (EU) 2024/1689 of the EUROPEAN PARLIAMENT and of the COUNCIL of 13 June 2024 Laying Down Harmonised Rules on Artificial Intelligence and Amending Regulations (EC) No 300/2008, (EU) No 167/2013, (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1139 and (EU) 2019/2144 and Directives 2014/90/EU, (EU) 2016/797 and (EU) 2020/1828 (Artificial Intelligence Act), pp. 1–144.
Eysenbach, G., 2004. Improving the quality of web surveys: the checklist for reporting results of Internet E-surveys (CHERRIES). J. Med. Internet Res. 6 (3). https://doi.org/10.2196/jmir.6.3.e34.
Fritsch, S.J., Blankenheim, A., Wahl, A., et al., 2022. Attitudes and perception of artificial intelligence in healthcare: a cross-sectional survey among patients. Digit Health 8. https://doi.org/10.1177/20552076221116772.
Haan, M., Ongena, Y.P., Hommes, S., Kwee, T.C., Yakar, D., 2019. A qualitative study to understand patient perspective on the use of artificial intelligence in radiology.

J. Am. Coll. Radiol. 16 (10), 1416–1419. https://doi.org/10.1016/j.jacr.2018.12.043.
Haug, C.J., Drazen, J.M., 2023. Artificial intelligence and machine learning in clinical medicine. N. Engl. J. Med. 388 (13), 1201–1208. https://doi.org/10.1056/NEJMra2302038, 2023.
Hengstler, M., Enkel, E., Duelli, S., 2016. Applied artificial intelligence and trust—the case of autonomous vehicles and medical assistance devices. Technol. Forecast. Soc. Change 105, 105–120. https://doi.org/10.1016/j.techfore.2015.12.014.
Home (/) » Next Generation Technologies (/Industry/Emerging-and-next-Generation-Technologies) » Artificial Intelligence Market Size. https://www.grandviewresearch.com/industry-analysis/artificial-intelligence-ai-market.
Keskinbora, K.H., 2019. Medical ethics considerations on artificial intelligence. J. Clin. Neurosci. 64, 277–282. https://doi.org/10.1016/j.jocn.2019.03.001.
Kruger, J., Dunning, D., 1999. Unskilled and unaware of it: how difficulties in recognizing one's own incompetence lead to inflated self-assessments. J. Pers. Soc. Psychol. 77 (6), 1121–1134. https://doi.org/10.1037//0022-3514.77.6.1121.
Laï, M.C., Brian, M., Mamzer, M.F., 2020. Perceptions of artificial intelligence in healthcare: findings from a qualitative survey study among actors in France. J. Transl. Med. 18 (1). https://doi.org/10.1186/s12967-019-02204-y.
Liyanage, H., Liaw, S.T., Jonnagaddala, J., et al., 2019. Artificial intelligence in primary health care: perceptions, issues, and challenges. Yearb Med. Inform. 28 (1), 41–46. https://doi.org/10.1055/s-0039-1677901.
Maassen, O., Fritsch, S., Palm, J., et al., 2021. Future medical artificial intelligence application requirements and expectations of physicians in German university hospitals: web-based survey. J. Med. Internet Res. 23 (3). https://doi.org/10.2196/26646.
Manickam, P., Mariappan, S.A., Murugesan, S.M., et al., 2022. Artificial intelligence (AI) and Internet of medical things (IoMT) assisted biomedical systems for intelligent healthcare. Biosensors 12 (8), 562. https://doi.org/10.3390/bios12080562.
Mishra, R., Narayanan, M.D.K., Umana, G.E., Montemurro, N., Chaurasia, B., Deora, H., 2022. Virtual reality in neurosurgery: beyond neurosurgical planning. Int. J. Environ. Res. Publ. Health 19 (3), 1719. https://doi.org/10.3390/ijerph19031719.
Oh, S., Kim, J.H., Choi, S.W., Lee, H.J., Hong, J., Kwon, S.H., 2019. Physician confidence in artificial intelligence: an online mobile survey. J. Med. Internet Res. 21 (3). https://doi.org/10.2196/12422.
Palmisciano, P., Jamjoom, A.A.B., Taylor, D., Stoyanov, D., Marcus, H.J., 2020. Attitudes of patients and their relatives toward artificial intelligence in neurosurgery. World Neurosurg. 138, e627–e633. https://doi.org/10.1016/j.wneu.2020.03.029.
Paranjape, K., Schinkel, M., Nannan Panday, R., Car, J., Nanayakkara, P., 2019. Introducing artificial intelligence training in medical education. JMIR Med. Educ. 5 (2), e16048. https://doi.org/10.2196/16048.
Parliament - wwweuroparleuropaeu E. What is artificial intelligence and how is it used? | News | European Parliament.
Pinto dos Santos, D., Giese, D., Brodehl, S., et al., 2019. Medical students' attitude towards artificial intelligence: a multicentre survey. Eur. Radiol. 29 (4), 1640–1646. https://doi.org/10.1007/s00330-018-5601-1.
Reddy, S., 2022. Explainability and artificial intelligence in medicine. Lancet Digit Health 4 (4), e214–e215. https://doi.org/10.1016/S2589-7500(22)00029-2.
Scheetz, J., Rothschild, P., McGuinness, M., et al., 2021. A survey of clinicians on the use of artificial intelligence in ophthalmology, dermatology, radiology and radiation oncology. Sci. Rep. 11 (1). https://doi.org/10.1038/s41598-021-84698-5.
Tamori, H., Yamashina, H., Mukai, M., Morii, Y., Suzuki, T., Ogasawara, K., 2022. Acceptance of the use of artificial intelligence in medicine among Japan's doctors and the public: a questionnaire survey. JMIR Hum. Factors. 9 (1). https://doi.org/10.2196/24680.
Walker, C.T., Kakarla, U.K., Chang, S.W., Sonntag, V.K.H., 2019. History and advances in spinal neurosurgery. J. Neurosurg. Spine 31 (6), 775–785. https://doi.org/10.3171/2019.9.SPINE181362.
Yu, K.H., Beam, A.L., Kohane, I.S., 2018. Artificial intelligence in healthcare. Nat. Biomed. Eng. 2 (10), 719–731. https://doi.org/10.1038/s41551-018-0305-z.
Zoli, M., Bongetta, D., Raffa, G., Somma, T., Zoia, C., Della Pepa, G.M., 2022. Young Neurosurgeons and Technology: Survey of Young Neurosurgeons Section of Italian Society of Neurosurgery (Società Italiana di Neurochirurgia, SINch). World Neurosurg. 162, e436–e456. https://doi.org/10.1016/j.wneu.2022.03.022.