Original Article

The most recommended neuroanatomy resources for neurosurgeons: an international survey

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ABSTRACT

Background: Neuroanatomy is the core basis for neurosurgical excellence. The quantity of accessible neuroanatomy resources has witnessed exponential growth in recent years. Accumulating a list of popular sources and getting them ranked by neurosurgeons was the motivation behind this investigation.

Methods: A list of neuroanatomy resources was compiled using Google search wherein multiple sets of variable combinations of keywords were used. A three-section, eleven-item questionnaire was designed by two neurosurgeons and revised by a third independent reviewer. Neurosurgeons from different parts of the world were invited to participate. The participants were asked to rank the neuroanatomy textbook and non-book online source that they would recommend to neurosurgeons and the features that make a textbook appealing to them.

Results: A total of 250 neurosurgeons at different levels of training responded to our questionnaire. Overall, "Rhoton's Cranial Anatomy and Surgical Approach: Albert L. Rhoton Jr., Doctor of Medicine" was the most commonly chosen textbook that the neurosurgeons would use to revise neuroanatomy (86.0%; $n = 215$), recommend for residents (80.8%; $n = 202$) and recommend for certified surgeons (Continuing Medical Education (59.8%; $n = 150$), where applicable. "Illustrations" was rated as the most important neuroanatomy textbook quality by 53% ($n = 134$). "Rhoton collection" was the most popular online source (65.7%; $n = 164.25$). Chi-square tests showed no association between years of experience and the textbooks neurosurgeons recommended.

Conclusion: Based on our study Rhoton's book and his online collection are the leading neuroanatomy resources, recommended by neurosurgeons for neurosurgeons worldwide. The other selected resources can be implemented as a complementary part of a comprehensive neuroanatomy teaching curriculum. Knowing the relevance of these assets from a neurosurgeon's perspective is valuable in directing future educational plan updates and recommendations.

Keywords: Neuroanatomy, Neurosurgery, Textbooks

INTRODUCTION

"We want perfect anatomical dissections, because we want perfect surgical operations," said Albert L. Rhoton Jr., Doctor of Medicine (MD); an influential neurosurgeon and a pioneer in micro-neuroanatomy. This sentence reflects not only his philosophy but also the value of intricate neuroanatomical knowledge in ensuring immaculate surgical technique and better patient outcomes.[6,8]

The primary depictions of human anatomy instructing in Europe go back to Greece, in the third century before christ, with the presentation of foundational human cadaveric analyzation.[3,4] In spite of the fact that the act of human dismemberment was prohibited during the Middle Ages because of strict and popular convictions, its practice was restored toward the start of the fourteenth century when it remained the center premise of clinical education and life structures instructing until the 20th century.[3,4]

The brain is the crown gem of creation. Neuroanatomy functions as the most key assemblage of information characterizing the excellence of this creation and driving the endeavors of each neurosurgeon in their journey to protect and recover the human brain.[2] The number of available neuroanatomy resources is vast, necessitating a critical analysis of their utility in neurosurgical clinical practice.[7]

The aim of this study is several fold (1) to accumulate a rundown of neuroanatomy assets accessible to neurosurgeons including reading material and non-course book online assets, (2) to evaluate the preferences of neurosurgeons as to these resources, (3) to associate the varieties in prescribed sources with the number of experience years of neurosurgeons, and (4) to feature the characteristics that make a neuroanatomy textbook reading alluring to neurosurgeons.

Ultimately, the aftereffects of the study will be setting the foundation for future research with regard to "neuroanatomy educational program update and institutionalization" activity. The outcomes are additionally of incentive to medicals school graduates embarking on neurosurgery as a career, as it spares them valuable time spent in seeking recommendations and searching resources.

MATERIALS AND METHODS

A three-section, 11-item questionnaire was designed by two neurosurgeons and revised by a third independent reviewer. The survey was open for a period of 90 days, with the target population being neurosurgeons at all levels of training. The questionnaire was distributed through social media platforms, including Facebook, WhatsApp, and Telegram. No incentives for participation were offered. The participants were guaranteed the anonymity of the data. The first section was designed to collect demographic information including gender, age, years in training or experience, and the country of study/practice. The second section included a list of neuroanatomy resources that was compiled using Google search wherein multiple sets of variable combinations of the following keywords were used: neuroanatomy, neurosurgery, anatomy, learning, teaching, textbooks, websites, online, resources, portals, forums, mobile applications, collections, databases, Atlas, YouTube channels, preferences, best-selling, recommended, popular, neurosurgeons, neurosurgical, training, trainees, and residency. The results from the first five pages of each search were included in the study. The available resources were categorized into either "books" or "online-non-book" subdivisions; the latter section included a combination of neuroanatomy websites, applications, portals, and forums. Participants were instructed to choose their preferred source of neuroanatomy. This option was further subdivided into three sections that allowed participants to name the book that they would (a) prefer to study, (b) recommend for neurosurgery residents, and (c) recommend for certified neurosurgeons continuous medical education (CME), where applicable. Multiple choices were allowed per participant. In addition, an "others" section was included so that participants could suggest any unlisted source. A similar set of choices was applied for the "online-non-book-" category. The third section asked the respondents to rank the qualities they found most useful in a textbook. Here again, an open-ended "others" choice allowed the participant to list any qualities not mentioned in the survey [Supplementary Material]. A Chi-square test was used to examine the association between the surgeon's year of experience and the recommended textbook and "online-non-book" resources. The significance level was set at $P < 0.05$ and all statistics were done using the Statistical Package for the Social Sciences, version 20 and 22 (International Business Machines Corporation., Armonk, New York).

RESULTS

The response rate to the survey was 19.2% ($n = 307/1600$). After excluding incomplete answers, only 250 responses were included for further analysis. Of those, 235 participants were males (94%) and 15 were females (6%). The age of the participants was 37.01 ± 7.944 (mean ±Standard Deviation) with a range of 24–66 years. The majority (78%; $n = 195$) of respondents were junior neurosurgeons – arbitrarily defined as those having <10 years of experience as a certified surgeon – and 22% ($n = 55$) were experienced neurosurgeons (>10 years of experience as a certified surgeon). Of the 250 respondents, 64% ($n = 160/250$) were practicing in academic institutions and 36% ($n = 90/250$) were in the private sector. Thirty-five ($n = 88/20$) percent of the respondents were from three countries, namely; India (15.2%; $n = 38$), Iraq (10.4%, $n = 26$), and Egypt (9.6%; $n = 24$). The remaining 65% ($n = 162$) of

the responses came from the United States, Canada, Australia, the United Kingdom, Ireland, Italy, Germany, Sweden, Spain, France, Peru, Mexico, Italy, Denmark, and Indonesia, Malaysia, Pakistan, Lebanon, Kuwait, and Algeria.

Ten textbooks were named in our questionnaire; six neuroanatomy books and four general anatomy books [Table 1]. Overall, "Rhoton's Cranial Anatomy and Surgical Approaches: Albert L. Rhoton Jr., MD" was the most commonly chosen book that the neurosurgeons would use to revise neuroanatomy (86.0%; *n* = 215), recommend for residents (80.8%; *n* = 202) and recommend for certified surgeons (CME (59.8%; *n* = 150), where applicable. This was followed by "Clinical Neuroanatomy: Richard S. Snell," and "Operative Neurosurgical Anatomy: Damirez T. Fossett, Anthony J. Caputy," respectively [Table 1]. Among the general anatomy textbooks "Atlas of Human Anatomy: Frank H. Netter" was the most frequently recommended and the fourth recommended book overall [Table 1].

As for the qualities that make a neuroanatomy textbook attractive to neurosurgeons, "illustrations" were the highest-rated option; chosen by 53% (*n* = 134) of the respondents. Other frequently-chosen qualities were "the presence of detailed discussion of structures and their relations;" selected by 34.3% (*n* = 86) and "the presence of summarized tables and schemes;" rated by 12% (*n* = 30).

In the "online-non-book" category "Rhoton collection" available world wide web (www).rhoton.ineurodb.org came first with 65.7% (*n* = 164) of the respondents rating it as the best online neuroanatomy learning resource. The second most popular choice was "The neurosurgical atlas

by Dr. Aaron Cohen-Gadol at (neurosurgicalatlas.com)," chosen by 18.9% (*n* = 47) of the participants [Table 2].

The Chi-square tests showed no association between years of experience and the textbooks neurosurgeons chose to study themselves (χ^2 = 9.170, *P* = 0.688), recommend for residents (χ^2 = 8.427, *P* = 0.751) or propose for certified neurosurgeons (CME) (χ^2 = 10.115, *P* = 0.484).

DISCUSSION

Neuroanatomy is the core basis for neurosurgical excellence. The quantity of accessible neuroanatomy resources has witnessed exponential growth in recent years. Accumulating a list of popular sources and getting them ranked by neurosurgeons was the motivation behind this investigation.

Our study demonstrated that "Rhoton's Cranial Anatomy and Surgical Approaches: Albert L. Rhoton Jr., MD" was the neuroanatomy textbook most highly rated by neurosurgeons across all sub-categories. Similarly, "Rhoton collection" (available at www.rhoton.ineurodb.org) was the most popular online source. Users considered "illustrations" as the most useful quality in a neuroanatomy book. The majority of our study subjects were males, reflecting the gender disparity in the field, although to an exaggerated extent; currently, neurosurgery is 82.5% male-dominated.[1] The recommendations did not vary significantly by the number of years of experience; while this can be attributed, in part, to our small sample size, it may also reflect the robustness of the recommended sources and/or the universal level of skilled-neuroanatomy knowledge a neurosurgeon needs throughout his/her career. No direct

Table 1: The most commonly recommended neuroanatomy textbooks by neurosurgeons to neurosurgeons.						
Textbooks names	Neurosurgeons preference		Recommendation for residents		Recommendation for certified surgeons continuous medical education	
	n	%	*n*	%	*n*	%
Rhoton's Cranial Anatomy and Surgical Approaches: Albert L. Rhoton Jr., Doctor of Medicine	215	86.0	202	80.8	150	59.8
Core Text of Neuroanatomy: Malcolm B. Carpenter	33	13.2	35	14.0	44	6.0
Clinical Neuroanatomy: Richard S. Snell	87	34.8	82	32.8	54	7.4
*Sobotta Atlas of Human Anatomy: Reinhard Putz	27	10.8	15	6.0	35	4.8
*Gray's Anatomy, The Anatomical Basis of Clinical Practice: Susan Standring, PhD, DSc	48	19.2	35	14.0	32	4.4
Head and Neuroanatomy: Michael Schuenke, Erik Schulte: Thieme	28	11.2	23	9.2	17	2.3
Operative Neurosurgical anatomy: Damirez T. Fossett, Anthony J. Caputy	59	23.6	35	14.0	58	8.0
Neuroanatomy through Clinical Cases: Hal Blumenfeld	30	12.0	27	10.8	20	2.7
*Atlas of Human Anatomy: Frank H. Nette	53	21.2	34	13.6	21	2.9
*Cunningham's Manual of Practical Anatomy: G. J. Romane	8	3.2	10	4.0	4	0.5
Other	18	7.2	14	5.6	8	1.1

Table 2: Frequency table showing the best neuroanatomy websites and YouTube channels according to the neurosurgeons' preference.

	n	%
Neuroanatomy websites		
The Rhoton collection (rhoton.ineurodb.org)	190	34.5
The neurosurgical atlas by Dr. Aaron Cohen-Gadol. (neurosurgicalatlas.com)	104	18.9
3D Neuroanatomy (3dneuroanatomy.com)	103	18.7
Neuroanatomy (neuroanatomy.org)	42	7.6
The whole brain atlas (med.harvard.edu/aanlib)	19	3.4
UpSurgeOn (upsurgeon.com)	19	3.4
Interactive Neuroanatomy Atlas – Columbia University	16	2.9
Atlas of Functional Neuroanatomy The Whole Brain Atlas – Harvard medical school	9	1.6
Neuroanatomy Video Tutorials – University of British Columbia	12	2.2
Hyper Brain – University of Utah	7	1.3
The Brain From Top to Bottom – McGill University	12	2.2
Salamon's Neuroanatomy and Neurovasculature Web-Atlas – UCLA	6	1.1
Neuroanatomy Online: An Open Access Electronic Laboratory	9	1.6
Neuroscience Resource Page	3	0.5
Neuroanatomy YouTube Channels		
AANSNeurosurgery The Rhoton Collection	196	31.2
3DNeuroanatomy	84	13.4
Seattle Science Foundation	70	11.1
Dr. Najeeb Lectures	67	10.7
The Neurosurgical Atlas by Aaron Cohen-Gadol, Doctor of Medicine	104	16.6
Human Anatomy Education	13	2.1
Draw it to Know it	16	2.5
The Noted Anatomist	9	1.4
Clinical Anatomy Explained!	10	1.6
Nets Aiims	20	3.2
Stanford Anatomy	6	1.0
Access Anatomy	4	0.6
Anatomy Tutorials	3	0.5
Anatomie 3D Lyon	4	0.6
Theanatomyroom	2	0.3
UBC Medicine - Educational Media	6	1.0
Handwritten Tutorials	4	0.6
Neuromatiq	4	0.6
Anatomy Videos	4	0.6
Cuneatos	2	0.3

comparison, in terms of popularity, was attempted between the two sets of resources, namely; "textbooks" and "non-book-online," due to the significant differences that exist between the two forms of educational materials and the fact that they are often used in parallel by must learners.

The polled results in our study represent the sum of the personal experience of a cohort of neurosurgeons at various levels of training from different countries. The results of this study are important as they will guide a series of future studies that will be performed by the authors as part of a neuroanatomy curriculum reform and standardization initiative. In addition, knowing the most recommended sources and the qualities that make these sources desirable to neurosurgeons will inform future book authors in the field. The results are also important for those embarking

on a carrier in neurosurgery, by sparing them the time and effort required to search the realm of available neuroanatomy resources. The value of these results lies in the fact that the recommendations were given by certified neurosurgeons who reported the sum of their personal experience not only with the study of neuroanatomy but also with the level of neuroanatomical knowledge more junior neurosurgeons would need to master. In addition, because the results came from neurosurgeons practicing in different parts of the world, they give a good indication of the applicability of the chosen resources in different educational and practical environments, supporting the concept of neuroanatomy curriculum standardization.

Several shortcomings of our study should be noted: first, the responses to the questionnaire reflect the subjective

opinions of the respondents. A more objective assessment of the utility of the proposed sources should be sought. For example, a form of standardized testing could be employed to reliably measure the neuroanatomical knowledge of the participants and correlate the scores to their respective recommended sources. Second, the small sample size and the limited number of the host countries of the participating neurosurgeons make our results less generalizable and mandate a larger-scale study to confirm our conclusions. Notably, a sub-optimal response rate was also reported by multiple other international, survey-based studies in neurosurgery.[5,9] Third, Google searches-derived results of the most popular anatomy and neuroanatomy textbooks are not the most comprehensive or reliable form of data collection. Alternatively, library-catalog-based searches could be used to retrieve the list of the textbooks at the question. In an attempt to indemnify for the aforementioned drawback, the survey was made open-ended by the addition of an "others" section, which allowed the participants to add any resource(s) they considered significant. The fact that the results in this "others" section were included in the final analysis should have, at least partially, compensated for any search-related deficits in resource listing.

One limitation of this study is that it did not measure the local availability of the resources in question, a factor that might have had an impact on the participants' choice.

CONCLUSION

Based on our study, Rhoton's book and his online collection are the leading neuroanatomy resources, recommended by neurosurgeons for neurosurgeons worldwide. The other selected resources can be implemented as a complementary part of a comprehensive neuroanatomy teaching curriculum. Knowing the relevance of these assets from a neurosurgeon's perspective is valuable in directing future educational plan updates and recommendations.

Declaration of patient consent

Patient's consent not required as patients identity is not disclosed or compromised.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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Supplementary Material

The Questionnaire

The most-recommended neuroanatomy sources for neurosurgeons: an international survey

Section 1: Demographic information

- Age
- Gender
- The country in which you did your neurosurgery residency
- The country your working in it now
- Current academic position:
    - Junior neurosurgeon (<10 years as a certified surgeon)
    - Experienced neurosurgeon (10 years or more as a certified surgeon)

Section 2: Neuroanatomy resources

A. Book resources
    - From the list below, please choose the best neuroanatomy text according to your preference? (you can choose one or more)
    - From the list below, please choose the best neuroanatomy text you suggest for residents?
    - From the list below, please choose the best neuroanatomy text you suggest for certified surgeons CME?
B. Non-Book online resources
    - From the list below, please choose the best neuroanatomy website according to your preference? (you can choose one or more)
    - From the list below, please choose the best neuroanatomy website you suggest for residents?
    - From the list below, please choose the best neuroanatomy website you suggest for certified surgeons CME?
    - From the list below, please choose the best neuroanatomy YouTube channel according to your preference? (you can choose one or more)
    - From the list below, please choose the best neuroanatomy YouTube channel you suggest for residents?
    - From the list below, please choose the best neuroanatomy YouTube channel you suggest for certified surgeons CME?

Section 3: Textbook qualities

- Which characteristic should be present in the neuroanatomy book that make you choose it and read it
    i. The presence of illustrations
    ii. The presence of detailed discussion of structures and their relations
    iii. The presence of summarized tables and schemes

The textbooks list

- Rhoton's Cranial Anatomy and Surgical Approaches: Albert L. Rhoton Jr., MD
- Core Text of Neuroanatomy: Malcolm B. Carpenter
- Clinical Neuroanatomy: Richard S. Snell
- Sobotta Atlas of Human Anatomy: Reinhard Putz
- Gray's Anatomy, The Anatomical Basis of Clinical Practice: Susan Standring, PhD, DSc
- Head and Neuroanatomy: Michael Schuenke, Erik Schulte: Thieme
- Operative Neurosurgical Anatomy: Damirez T. Fossett, Anthony J. Caputy
- Neuroanatomy through Clinical Cases: Hal Blumenfeld
- Atlas of Human Anatomy: Frank H. Netter
- Cunningham's Manual of Practical Anatomy: G. J. Romanes
- Others (please specify)

The websites list

- Interactive Neuroanatomy Atlas – Columbia University
- Atlas of Functional Neuroanatomy The Whole Brain Atlas – Harvard Medical School
- Neuroanatomy Video Tutorials – University of British Columbia
- Hyper Brain – University of Utah
- The Brain from Top to Bottom – McGill University
- Salamon's Neuroanatomy and Neurovasculature Web-Atlas – UCLA
- Neuroanatomy Online: An Open Access Electronic Laboratory
- Neuroscience Resource Page
- The Rhoton collection. (www.rhoton.ineurodb.org)
- The neurosurgical atlas by Dr. Aaron Cohen-Gadol. (www.neurosurgicalatlas.com)
- The whole brain atlas. (www.med.harvard.edu/aanlib)
- 3D Neuroanatomy (www.3dneuroanatomy.com)

- Neuroanatomy (www.neuroanatomy.org)
- UpSurgeOn (www.upsurgeon.com)
- Others (please specify)

The YouTube channel list

- AANS Neurosurgery the Rhoton Collection – 15,778 subscribers
- 3DNeuroanatomy – 890 subscribers
- Seattle Science Foundation – 11,140 subscribers
- Dr. Najeeb Lectures – 406,567 subscribers
- The Neurosurgical Atlas by Aaron Cohen – Gadol, M.D.- 8,158 subscribers
- Human Anatomy Education – 78,525 subscribers
- Draw it to Know it – 5,271 subscribers
- The Noted Anatomist – 29,214 subscribers

- Clinical Anatomy Explained – 31,410 subscribers
- Nets Aiims – 2162 subscribers
- Stanford Anatomy – 10,167 subscribers
- AnatomyZone – 351,752 subscribers
- Access Anatomy – 12,994 subscribers
- AnatomyTutorials – 22,379 subscribers
- Anatomie 3D Lyon – 57,129 subscribers
- Theanatomyroom – 9296 subscribers
- UBC Medicine - Educational Media – 27,535 subscribers
- Handwritten Tutorials – 177,462 subscribers
- Neuromatiq – 21,945 subscribers
- Anatomy Videos – 2906 subscribers
- Cuneatos – 83,163 subscribers
- Kenhub – 181,776 subscribers
- Others (please specify)