



# Role and contributions of women in revolutionizing neurosurgery

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## ABSTRACT

We owe it to the women neurosurgeons for paving the way to a more gender-inclusive world of medicine. Their dedication and sacrifices have led them and their followers to scale unimaginable heights in terms of administrative positions, leadership, and academics. In today's scenario, it is safe to say that society has progressed considerably. Past years have seen an uprise in the number of females enrolling in a medical degree programme however, this proportion is highly distorted when it comes to specialties such as Neurosurgery. This disparity seems to be evolving and leveling out in all specialties, as more and more women are stepping out of their comfort zone and challenging the established standards of the society. It is with the collective efforts of all stakeholders and women that we see more women not only choosing such specialties which were previously uncharted terrain, but also leading organizations globally and excelling on the administrative and academic fronts. Veteran female surgeons have revolutionized neurosurgery and its subspecialties in unimaginable ways and the present as well as the future generation neurosurgeons continue to take inspiration from them and follow their footsteps. This paper has put together the contributions of female neurosurgeons in various subspecialties of neurosurgery as well as giving an account of the leadership and administrative positions served by women. We also shed light on the role of women as an academician and a researcher.

## 1. Introduction

Over the years, neurosurgery has become an increasingly inclusive field with professionals from all races, genders, and nationalities contributing immensely to the advancement of science. The path taken by women neurosurgeons is worth-noting and has been a major theme of discussion as we have progressed.<sup>1</sup> The simplest explanation lies in the fact that women have had to prove their mettle time and again to be seen as equal stakeholders in the system of healthcare and education. Robert Speltzer discussed in his article about the inadequately counted contributions of female neurosurgeons that directs to their diminished importance in the field, which needs to be mended<sup>2</sup>

In as early as the fifteenth century, a Turkish book by Serefeddin Sabuncuoglu<sup>3</sup> portrayed illustrations of the first female surgeon, known as Tabibes, who was shown to practice a primitive form of pediatric neurosurgery. Even though neurosurgery as a field was largely male-dominated, the twentieth century saw a rise in the number of

women deciding to take up careers in this unexplored domain.<sup>4</sup>

## 2. First female neurosurgeons around the world

The World Federation of Neurosurgical Societies (WFNS) officially declared Dr. Sofia Ionescu, from Romania, to be the first female neurosurgeon in the world.<sup>5</sup> A British neurosurgeon, Dr. Diana Beck was a contemporary.<sup>6</sup> In the United States of America (USA), Dr. Ruth Kerr Jakob became the first female neurosurgeon in the year 1959.<sup>7</sup> Around the same time, Latin American women started adopting neurosurgery with María Cristina García-Sancho y Álvarez-Tostado, from Mexico graduating in 1951 from neurosurgery residency in Santiago, Chile.<sup>8</sup> Considering South America, Noya Silva Chavez became the first woman neurosurgery resident, in 1969 in Rio de Janeiro.<sup>8</sup>

Women in Asia and Australasia faced an additional challenge given the conservative social and religious contexts as compared to the Americas and Europe. Even in this dismal background, women powered

*Abbreviations:* American Association of Neurological Surgeons (AANS), American Society of Pediatric Neurosurgeons (ASPNS); Arteriovenous malformations (AVMs), Asian Congress of neurological surgeons (ACNS); Congress of Neurological Surgeons (CNS), Dural arteriovenous fistulas (DAVF); European Association of Neurological Surgeons (EANS), International Society for Pediatric Neurosurgery (ISPN); Lower middle income countries (LMICs), Thanjavur Santhanakrishna (T.S.); United States of America (USA), World Federation of Neurosurgical Societies (WFNS).

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through. Professor Thanjavur Santhanakrishna (T.S.) Kanaka became Asia's first, and the world's third female neurosurgeon in the year 1968.<sup>1</sup> She is a pioneer of stereotactic and functional neurosurgery and inspired many young minds to follow in her footsteps. In Australia, Dr. Elizabeth Lewis became the first woman neurosurgeon in 1970s.<sup>1</sup>

### 3. Academics, leadership and administration

In 2014, Khan et al observed no difference in the h-indices of male and female neurosurgeons of same academic rank, however when there was no stratification according to rank the h-index, g-index and hc-index had a significant variation by sex.<sup>9</sup> A recent study reported that 11% of all neurosurgeons (1494) were females in the United States of America (USA) of which majority of them were assistant professors (n = 105, 61%) followed by 31 (18%) associate professors, and 36 (21%) full professors (P < 0.001).<sup>10</sup> Of only 19 women with leadership positions, Six served as chairperson of the department, Eight were program directors and five served as assistant program directors. Only 24 (14%) women have received NIH funding for carrying out a research project. The relation of NIH funding with the number of publications and h-index was statistically very strong (P < 0.001). The study was conclusive that the productivity of women have increased since 2014 as observed in the h-index values but the gender wise trend still remains the same. Contrary to this, a study in Great Britain and Ireland reported that there was no significant difference in these indices as per sex of the neurosurgeon. However, of the 16 professors there was no female professor.<sup>11</sup> In Germany, women held only 6.3% (n = 9) of the head positions across 143 departments, 1 (2.4%) Vice Director position, 17 (14.5%) senior chief physicians and 4 (12.5%) managing senior physicians.<sup>12</sup>

Klimo Jr. et al found that the productivity of men in pediatric neurosurgery was higher than that of females as estimated through h-, g- and e-indices.<sup>13</sup> Aslan et al.<sup>14</sup> tried to estimate the contribution of female authors to research studies published in 'Neurosurgery' and 'Journal of Neurosurgery'. They reported an increase in the first authorship from 12% in 2003 to 16.5% in 2018. However, despite this fact the representation of women in the editorial board of neurosurgery journals was very low.<sup>15</sup>

Shaikh et al<sup>16</sup> found that on a global scale, 29% of the executive positions in various neurosurgical societies were held by female neurosurgeons. Similar to Melnick et al this study reported a positive correlation between the h-index and the academic rank of the neurosurgeons. They also assessed the m-indices of the two genders and found that there was no statistically significant difference negating the effect of time and career duration as pre dominant factors that play a role in the contribution of females to organizational and administrative work. The difference in the number of executive positions held by female neurosurgeons was statistically significant (p = 0.00) across the continents with Australia and Europe having a higher number (n = 3 each) than North America, Asia and South America (n = 1 each). They also compared the productivity of top 5 male and female neurosurgeons on the basis of their h-index and found that there was no statistically significant difference in terms of funding or executive positions held by them. All these top 5 neurosurgeons in either sex belonged to North America. The authors suggested the neurosurgeons in Asian and African countries 'to engage and involve themselves in the evolving process of organization and association.'

Feng et al<sup>17</sup> reported that women neurosurgeons had a higher number of postgraduate degrees than male neurosurgeons and the most common of these were Ph.D. and M.P.H./M.S.P.H. Women held only 1% of over 2000 neurosurgery organizational leadership positions in the USA over the past 89 years including 5 as presidents, 8 as vice-presidents and 4 as a secretary or treasurer. Till date Congress of Neurological Surgeons (CNS) have had no woman president. According to Feng's study in 2021, women served as a leader for 7% positions in American Association of Neurological Surgeons (AANS)/CNS subspecialty section committees, 10 women have served as chairs, 1 woman has been a Vice

president and 3 women have been a secretary/treasurer.<sup>17</sup> (Table 1) Until last year, the tumor joint section had no female chair, however, Isabelle M. Germano became the first woman chair of the tumor committee.<sup>18</sup> She has also been the past chair of the WFNS Education and Training. Recently, Moroccan female professor Najia El Abbadi was elected as the president of the WFNS for the period 2021–23.<sup>19</sup> Dr. Laura Lippa and Professor Meng-Fai Kuo serve as the chairs for Neuro-traumatology and Pediatric committees of WFNS respectively for the term 2021–23.<sup>19</sup> The women members of WFNS ad-hoc committees are listed in Table 2.

European Association of Neurological Surgeons (EANS) is far behind in the representation of women with only 1 woman (Dr. Marike Broekman) holding a position on the board out of 17 neurosurgeons, rest 16 of whom are men.<sup>20</sup>

After 45 years of establishment of International Society for Pediatric Neurosurgery (ISPN), Prof. Dr. Graciela Noemi Zuccaro, from Argentina, became the first female neurosurgeon to be elected as the president in 2015.<sup>21</sup> Another notable mention is of Professor Yoko Kato from Japan, who is the president for Asian Congress of neurological surgeons (ACNS). She is the first full female professor from Japan.<sup>22</sup> She has also served as the assistant secretary of the WFNS, as the Secretary of the WFNS Foundation Committee and chairperson of WFNS Fund-Raising Committee.<sup>22</sup> She has also been appointed as an associate editor for the renowned journal 'Neurosurgery' and is currently the Editor-in-Chief of 'Asian Journal of Neurosurgery'.<sup>22</sup> Dr. Julie Pilitsis became the first female neurosurgeon to be the dean of a medical school.<sup>23</sup> Her other academic achievements include serving as a section editor for the functional neurosurgery in Operative Neurosurgery, editorial board member of Neuromodulation and Journal of Neurosurgery and review panel on review panel for neurological devices.<sup>23</sup>

Table 3 summarizes the leadership positions served by women in the prestigious neurosurgical societies around the globe.

### 4. Representation of women in conferences and meetings

Johnson et al.<sup>24</sup> in a very recent study reported their findings on the representation of female neurosurgeons as abstract authors at neurosurgical conferences that included annual meetings of AANS and CNS as well the joint section meetings. The Pediatrics section had the maximum female members while Stereotactic and functional had the least percentage of members. In terms of representation of the first and last

**Table 1**  
Leadership positions Served by female neurosurgeons in the Joint Subspecialty committees of AANS and CNS.

Name of the neurosurgeon	Position Held and year
<b>Cerebrovascular</b>	
Sepideh Amin-Hanjani	President (2012–13)
Judy Huang	Vice President (2020–21)
Stavropoula Tjoumakaris	Secretary-Treasurer (2020–23)
<b>Functional/Stereotactic</b>	
Aviva Aboesch	President (2014–16)
Julie Pilitsis	Secretary (2022–22)
<b>Pain</b>	
Julie Pilitsis	President (2013–15)
<b>Pediatrics</b>	
Joan Venes	President (1983–84)
Ann-Christine Duhaime	President (2009–10)
Sarah Gaskill	President (2015–16)
<b>Spine</b>	
Carole Miller	President (1991–92)
Marjorie Wang	President (2017–18)
<b>Trauma</b>	
Shelly Timmons	President (2010–12)
Jamie Ullman	President (2014–16)
Patricia Raksin	Secretary-Treasurer (2018–20)
<b>Tumor</b>	
Isabelle M Germano	President (2022–24)
Isabelle M Germano	Secretary (2020–22)

**Table 2**  
Female neurosurgeon-members of ad-hoc committees in the WFNS.

Committee	Name
Cerebrovascular Education and Training	Mahjoubia Boutarbouch
	Carolina Benjamin
	Wenya Linda Bi
Global Neurosurgery Liaison Committee WFNS/WHO	Mojgan Hodaie
	Laura Lippa
	Gail Rosseau
	Mabel Banson
	Rezina Hamid
Neuro-oncology	Roxanne Garcia
	Shweta Kedia
	Claire Karekezi
	Emilie Le Rhun
Neurosurgical Anatomy	Rachel Grossman
	Abhidha Shah
Neurotraumatology	Maria Peris-Celda
	<b>Laura Lippa (Co-Chair)</b>
Pediatrics	Eve Tsai
	Faiqa Filza Khan
	<b>Meng-Fai Kuo (Chair)</b>
	Ji Yeoun Lee
	Kelly Mahaney
Peripheral Nerve Surgery Spine Young Neurosurgeons Award Young Neurosurgeons Forum	Nora Dengler
	Erica Bisson
	Alexandra Golby
	Faith Robertson
	Sarah Cain
	Nqobile Thango
	Marisa Gandia
	Laura Lippa
	Adriana Libório
	Elizabeth Ogando-Rivas
Christiane Silva	

**Table 3**  
Leadership positions Served by female neurosurgeons in the Prestigious Neurosurgical societies around the world.

Society/ Organization	Name and Country	Position and Year
AANS	Shelly Timmons (USA)	President (2019–20)
	Gail Rosseau (USA)	Vice President (2014–15)
	Deborah Benzil (USA)	Vice President (2015–16)
ACNS	Yoko Kato (Japan)	President
CAANS	Najia El Abbadi (Morocco)	Treasurer (2016–17)
CNS	Jamie Ullman (USA)	Vice President (2013–14)
ISPN	Graciela Noemi Zuccaro (Argentina)	President (2015–16)
WFNS	Najia El Abbadi (Morocco)	President Elect (2021–23)
WSSFN	Dr. Mojgan Hodaie (Canada)	Vice Secretary

AANS, American Association of Neurological Surgeons; ACNS, Asian Congress of Neurological Surgeons; CAANS, Continental Association of African Neurosurgical Societies; CNS, Congress of Neurological Surgeons; ISPN, International Society for Pediatric Neurosurgery, WFNS, World Federation of Neurosurgical Societies; WSSFN, World Society for Stereotactic and Functional Neurosurgery.

authors also, Pediatrics had the maximum representation of women while Spine had the minimum representation. Qualitative analysis was suggestive of a higher number of females than males to be first authors while the opposite was true in context of last authors. When stratifying the authorship with the membership with the societies, deviation was found in spine and cerebrovascular societies where females were having less authorship proportion as compared their memberships.

In another study by Johnson et al,<sup>25</sup> in the past 54 years from 1965 to 2019 only 9.4% of the awards were received by females at the various neurosurgical meetings including AANS, CNS and joint sections. 36.1% of the awards that were granted for a minimum of 5 times were never

received by women. They recorded a statistically significant increase in the number of awards bagged by women from 2000 to 09 and 2010–19 ( $p = 0.018$ ). The Pediatrics section had the most female awardees while spine and cerebrovascular had the least. Not even a single named award was behind a female.

A similar disproportion can be observed at the level of speakers at national and international meetings and conferences. The representation of females in sessions associated with a senior post such as plenary sessions and keynote presentations is scarce.<sup>26</sup>

Neurosurgical meetings and conferences provide a huge platform for the neurosurgeon to widen their academic careers, exchange ideas, build strong professional and interpersonal relationships and enhance their visibility. Number of presentations, talks delivered, papers published and awards won serve as a metric in job opportunities and hence are essential in career advancement. Lack of adequate representation can pose another barrier for female neurosurgeons apart from societal and institutional challenges. It has been suggested in the previous studies that having women on the selection/organizing committee, the representation of women is most likely to enhance with a threefold increase in the receiving awards.<sup>25</sup>

## 5. Representation of women in various subspecialties of neurosurgery

### 5.1. Cerebrovascular

Cerebrovascular neurosurgery has been immensely enriched by the contributions of the women holding leadership positions in various societies aforementioned including Professor Yoko Kato, Dr. Sepideh Amin-Hanjani, Dr. Judy Huang, Dr. Rose Du and Dr. Stavropoula Tjoumakaris.

Over her career, Professor Kato has performed more than 1800 brain aneurysm neurosurgical procedures and published over 100 peer reviewed journals which have made her well-renowned face in cerebrovascular neurosurgery. Furthermore, she has set an example for women worldwide to pursue their passion of neurosurgery, especially in Asia.<sup>27</sup>

Prof. Dr. Amin-Hanjani currently serves as the residency program director and Co-director for Neurovascular Surgery at the University of Illinois School of Medicine. Her premiere NIH funded project, the VERITAS study, aimed at the examination of cerebral blood flow and stroke risk. Another of her active projects include the NIH national StrokeNet consortium, a stroke trials network. She has over 20 years of experience in microsurgical treatment of brain aneurysms and other abnormalities affecting brain blood vessels. She has an international reputation in performing brain blood vessel bypass surgery. She also serves as a Co-Editor for the prestigious ‘Journal of Neurosurgery’.<sup>28</sup>

Dr. Huang has been named as America’s top 1% doctors in the previous years owing to her dedication towards her patients and her students as a researcher and an academician. She is well known for her surgical skills and research publications on the neurosurgical management of brain aneurysms, carotid artery stenosis, dural arteriovenous fistulas (DAVF), and arteriovenous malformations (AVMs).<sup>29</sup> She serves as the neurosurgery residency program director at Johns Hopkins University as well as an Associate Editor for cerebrovascular section of the journal ‘Neurosurgery’ along with a fellow woman neurosurgeon Dr Rose Du.

Dr. Du serves as the Director of Cerebrovascular Surgery at Brigham and Women’s Hospital. She has extensively worked in deciphering the genetics behind cerebrovascular diseases including aneurysms, vasospasm and stroke.<sup>30</sup>

Serving as the Director of Endovascular Surgery and Cerebrovascular Neurosurgery Fellowship, Dr. Tjoumakaris is not only a brilliant surgeon but also a gifted researcher with an h-index of 53. She is the first female dual-trained cerebrovascular neurosurgeon in the USA. Her areas of expertise include conventional microsurgery, minimally invasive

endovascular techniques and stereotactic radiosurgery for cerebrovascular diseases. She also specializes in performing intra-arterial chemotherapy treatment for infants with retinoblastoma.<sup>31</sup>

## 5.2. Neuro-oncology and skull base

Dr. Isabelle M Germano, Dr. Rachel Grossman, Dr. Lola Chambless, Dr. Claire Karekezi, Dr. Emilie Le Rhun, Dr. Analiz Rodriguez, Dr. Linda Liau and Professor Kate Drummond are some of the many female neurosurgeons who with their passion and interest in tumors of brain and spine have made extensive efforts in the field of neuro-oncology.

Dr. Germano broke the chain by being the first woman to be the chair for the AANS/CNS joint section on tumors for the term 2022–24. She is the director of Mount Sinai Comprehensive Brain tumor program and Co-director for the radiosurgery program. She is well known for her work in the first human trial on the implication of gene therapy in recurrent glioblastoma as well as first in human technology applications for computer assisted, image guided neurosurgery.<sup>32</sup>

Dr Grossman serves as the Vice Chairman for the department of neurosurgery Tel Aviv Medical center. She has led many innovative neurosurgical projects at Johns Hopkins Hospital, worth mentioning of those is gene therapy for brain tumors. She has been principal investigator in numerous multicenter international clinical studies on brain tumors conducted by pharmaceutical companies. One of her most cited works is titled '*Differentiation between glioma and radiation necrosis using molecular magnetic resonance imaging of endogenous proteins and peptides*'.<sup>33</sup> Gifted surgeon and an avid researcher, she is a role model for many aspiring neurosurgeons.

Having specialized in Neuro-oncology, Dr Chambless holds a reputation in the management of brain and skull base tumors with a clinical expertise in minimally invasive and endoscopic approaches. She initiated the Vanderbilt Brain Tumor Outcomes lab in 2010 which aims at Prediction of clinical outcomes using advanced data science in patients with brain tumors.<sup>34</sup>

Dr Le Rhun, a female neuro-onco surgeon from Switzerland has published over 150 studies and book chapters in the field of neuro-oncology. She has worked extensively on the therapeutic management of leptomeningeal metastasis and glioblastoma.<sup>35–37</sup>

Dr Rodriguez's work on the use of laser thermal ablation for brain tumors and understanding the immune microenvironment has brought her international repute. She serves as the Director of Neurosurgical Oncology at UAMS where she has set up a brain tumor biobank which facilitates direct study of the tumor samples from the resected specimens along with appropriate drug identification. She has established the 'Rodriguez Lab' where next generation sequencing and proteomics are utilized which assist in identifying novel targets and understand tumor progression.<sup>38</sup>

Professor Liau serves as the Chair of the Department of Neurosurgery as well as Director of the Brain Tumor Program at UCLA. She has served as former Editor-in-Chief of the prestigious '*Journal of Neuro-Oncology*'. Intra-operative functional brain mapping and intraoperative imaging for resection of brain tumors are her areas of clinical expertise. She has worked substantially in understanding the molecular biology of brain tumors, gene therapy, immunotherapy, and brain cancer vaccines.<sup>39</sup>

Serving as the Director of Neurosurgery at Royal Melbourne Hospital and Head of CNS Tumors at the VCCC Parkville Precinct, Dr Drummond is one of the leading ladies from Australia. Having published more than 140 articles, received more than \$15 million in research funding in her projects which focus on the biology and management of brain tumors have made her an internationally renowned neurosurgeon.<sup>40</sup>

## 5.3. Pediatrics

The discussion of pediatric neurosurgery is incomplete without mentioning Dr. Joan Venes, Dr. Alexa Irene Canady, Dr. Espérance, Dr. Marianne Juhler a. k.a M.J., Dr Martina Messing-Jünger, and Dr.

Benedetta Pettorini,

Legendary pediatric neurosurgeon Dr Joan Venes, served as the secretary and founding member of the American Society of Pediatric Neurosurgeons (ASPN) and Chairman of the Pediatric Section of the AANS. She was awarded the Van Wagenen Fellowship which facilitated her to travel to various setups in Europe and America and hence, became a pioneer in intracranial pressure monitoring and control. She has extensively worked on shunt infection, intracranial pressure and monitoring, Reyes' syndrome, tethered cord, craniofacial anomalies, and Chiari malformations.<sup>41</sup>

Dr. Alexa Irene Canady, first board-certified African-American female neurosurgeon has held office as the chief of neurosurgery at Children's Hospital of Michigan with a subspecialty degree in pediatric neurosurgery. She was immensely fond of children as evident from her own words, '*it never ceased to amaze me how happy the children were*'. She specialized clinically in treatment of children with trauma induced brain injuries, hydrocephalus, congenital spinal abnormalities and brain tumors. Her persistent efforts to revolutionize pediatric neurosurgery led to the development of an anti siphon shunt for hydrocephalus.<sup>42</sup>

Dr. Espérance Maman You Broalet became the first woman to become a neurosurgeon in West Africa where she founded "Espérance's Hope," a national organization aiming to combat hydrocephalus and neural tube defects in the region in 2013. In 2019, she set up the department of Neurosurgery in the St. Joseph Moscati Catholic Hospital in Yamoussoukro, where she is currently the HOD. She has served as treasurer of the Ivorian Society of Neurosurgery (SINC) in 2017 and 2019.<sup>43</sup>

Dr. Marianne Juhler a. k.a M.J. currently serves as chair of the EANS Pediatric Neurosurgery Section as well as the head of Copenhagen CSF Study Group that works towards clinical, experimental and technical research related to hydrocephalus. She is currently a professor at the University of Copenhagen.<sup>44</sup>

Dr. Martina Messing-Jünger, a pediatric neurosurgeon from Germany hold numerous leadership positions in pediatric neurosurgery including Chair of liaison committee in ISPN,<sup>45</sup> initiator and coordinator of German Pediatric Neurosurgery Course as well as head of Department of Pediatric Neurosurgery at Asklepios Children's Hospital.<sup>46</sup>

Dr. Benedetta Pettorini, an Italian female neurosurgeon from England specializes in pediatric neurosurgery and serves as a consultant at Alder Hey Children's Hospital. She introduced Selective Dorsal Rhizotomy (SDR) as a new treatment for spasticity in the region in 2012 for which she was awarded the "*Investing in Children's Service*" national award. Her research on craniopharyngiomas secured her a grant from Children with Cancer UK.<sup>47</sup>

## 5.4. Peripheral nerve

The contributions of Dr. Indira Devi, Dr. Susan E. Mackinnon and Dr. Yang in the field of peripheral nerve surgery are unprecedented.

Veteran Indian neurosurgeon, Dr. Indira Devi crafted the peripheral nerve specialty for the first time in India. She has a keen interest in studying cortical plasticity in peripheral nerve injuries.<sup>48,49</sup> Her research interests are focused on functional and connectivity MRIs particularly in peripheral nerve injuries and traumatic brain injuries. She was the president-elect of the Indian Society of Peripheral Nerve Surgery for term 2021–2022 and has served as the co-chair to the WFNS Committee on Peripheral Nerve Surgeries.<sup>50</sup>

Dr. Susan E. Mackinnon is a pioneer in the field of nerve transfer and regeneration. She performed the world's first ever nerve allotransplantation in 1988.<sup>51</sup> Dr. Mackinnon has developed a multitude of nerve transfer techniques to aid reinnervation of paralysed areas.<sup>51</sup> She holds a position on the editorial board of the journal '*Neurosurgery*' under the Peripheral nerve surgery section. She held this responsibility with Dr. Lyunda Jun San Yang, whom we lost in the year 2022.<sup>52</sup>

Dr Yang served as the program director of the Brachial Plexus and Peripheral Nerve Program at the University of Michigan. She was well

known for the management of brachial plexus palsies in children as well as peripheral nerve injuries.<sup>53</sup>

### 5.5. Spine

Dr. Carole A. Miller, Dr. Corinna Zygourakis, Dr. Marjorie Wang, Dr. Deborah Benzil, Dr. Eve Tsai, Dr. Ann Parr, Dr. Uzma Samadani and Dr. Jocelyne Bloch have successfully pursued their passion for the field spine surgery and paved the path for other determined women to take on challenging fields.

Dr. Carole A. Miller is fondly remembered as the matriarch of Ohio State University Neurosurgery.<sup>54</sup> Dr. Miller was the first to describe “impaction” thoracic and lumbar fractures caused by the increased axial load as well as the first researcher to stress upon the significance of recognizing ligamentous injury in the context of thoracolumbar fractures.<sup>50</sup> She published a paper chronicling her decade-long experience of treating pediatric cervical injuries.<sup>55</sup>

Dr. Corinna Zygourakis is well known for performing a surgery with the Globus Excelsius spinal robot, a first of its kind internationally.<sup>56</sup>

Dr. Marjorie Wang currently serves as the Director of complex spine fellowship program at the Medical College of Wisconsin.<sup>57</sup> She specializes in managing disc and nerve injuries and their neurosurgical management via microsurgery, spinal decompression, disk replacement, minimally invasive spinal surgery and robotic surgery.<sup>57</sup> Dr. Wang was elected to the board of Journal of Neurosurgery in the year 2019, and she also is the lead editor for the spine section in World Neurosurgery.<sup>50</sup>

Dr. Deborah Benzil has contributed immensely to the upliftment of women.<sup>58</sup> As a specialist, she is a leader in establishing guidelines for safe stereotactic radiosurgery of tumors in the spine.<sup>59</sup>

Dr. Eve Tsai from Ottawa Hospital Research Institute is well known for her achievements in the fields of spinal cord injury, myelopathy, translational research and applied radiology.<sup>50</sup> Working on repair after injuries in the spinal cord, axonal regeneration, post-operative outcomes, and MRIs of human and animal spinal cords using different experimental modalities made her the Suruchi Bhargava Chair in Spinal Cord and Brain Regeneration Research.<sup>60</sup>

Dr. Ann Parr serves as the director of the spinal surgery program at the University of Minnesota as well as the principal investigator in the Parr Laboratory and the Stem Cell Institute of the University of Minnesota. Dr. Parr bagged international repute for her 3D print device for spinal cord repair.<sup>61</sup>

Dr. Uzma Samadani is well known for performing complex spinal tumor resections as exemplified by a 15-year old patient in whom she removed 5 tumors in a 25 h surgery with no traces of residual or recurrent tumor at 4 months.<sup>62</sup> She is a successful surgeon in performing numerous epidural spinal cord stimulation surgeries in paralyzed patients.

Dr. Jocelyne Bloch, a swiss neuroscientist, has actively participated in the field of neuroprosthetics as a therapeutic for spinal cord injury.<sup>63</sup> In 2018, she developed an automated system for epidural lumbar stimulation.<sup>64</sup> She is currently adjunct professor of neuroscience at EPFL, since 2019.<sup>65</sup>

### 5.6. Stereotactic and functional neurosurgery

The field of Stereotactic and Functional Neurosurgery was greatly augmented by Professor T.S. Kanaka, Dr. Natalia Bechtereva, Dr. Hilda Molina, Dr. Gunvor Kullberg, Dr. Vandewalle, Dr. Zelma Kiss, Dr. Mojgan Hodaie, Dr. Jocelyne Bloch and Dr. Carine Karachi. These are some of the many women without whom it would be difficult to imagine advancements in the field.

Professor Thanjavur Santhanakrishna Kanaka, or T.S. Kanaka, completed her Ph.D. degree with her research on the management of cerebral palsy using stereotactic surgery. She worked on 1700 different cases over a period of 15 years covering disorders relating to psychiatry, behavior, spasticity and epilepsy.<sup>66</sup> She was the first neurosurgeon in

India to use chronic electrode implants for deep brain stimulation (DBS) at affordable costs.<sup>67</sup>

Dr. Natalia Petrovna Bechtereva was a Soviet and Russian neurophysiologist and neuroscientist at Polenov Institute of and her greatest contribution lies in the introduction of Therapeutic Electrical Stimulation (TES) for the management of chronic pain and movement disorders, using high frequency pulses.<sup>68</sup>

Dr. Hilda Molina in 1978, became the first ever woman neurosurgeon in Cuba where she established CIREN with an aim to work extensively on neuro-transplantation in patients with Parkinsonism.<sup>69</sup> She successfully implanted fetal mesencephalic tissue into the caudate nucleus applying open-surgery technique.<sup>70</sup> as well as performed pioneering stereotactic transplantation.<sup>71</sup>

Dr. Gunvor Kullberg began her journey in medicine as a psychiatrist, switching fields to functional neurosurgery. In 1960, she initiated a variety of research involving stereotactic psychosurgery and the role of corticosteroids in cerebral edema that manifests post-operatively.<sup>69</sup> Her highest commended work was on Parkinson’s patients, wherein she studied cerebral blood flow after stereotactic lesioning.

Dr. Vandewalle serves in the Department of Stereotactic and functional Neurosurgery at the University Hospital of Cologne, Germany. As a pioneer, she introduced DBS as a treatment modality for neuropsychiatric disorders, in Ghent, Belgium, in 1999.<sup>72</sup>

Dr. Zelma Kiss is currently holding office as the Head of Neuro-modulation program of South Alberta. Her areas of interest in research include the therapeutic importance of DBS in movement disorders which she has analyzed using mouse models.<sup>73</sup> Her work has helped in establishing a strong understanding about DBS and its applications in humans.<sup>74</sup> She leads the neurosurgery section in the high impact journal “Brain Stimulation”.<sup>69</sup>

Dr. Mojgan Hodaie has dedicated much of her career to understanding the management of functional neurological disorders such as trigeminal neuralgia and facial pain.<sup>75</sup> Mojgan Hodaie has greatly contributed to distance teaching of functional neurosurgery, more importantly in developing countries.<sup>69</sup> Presently, she serves as Professor of Surgery and surgical co-director of the Joey and Toby Tanenbaum Gamma Knife radiosurgery unit at the Toronto Western Hospital. She is also an associate member of the Institute of Medical Science.<sup>76</sup>

Dr. Jocelyne Bloch is currently serving in the capacity of the Vice-President of the European Society for Stereotactic and Functional Surgery as well as leading the Stereotactic and Functional Neurosurgery team at University Hospital in Lausanne, Switzerland.<sup>69</sup> She has worked in modeling Parkinson’s disease and studying the autologous transplantation of adult brain cells in primates.<sup>69</sup>

Dr. Carine Karachi, a French neurosurgeon and neuroscientist, has worked extensively in the pathophysiology of gait and balance disorders in patients with movement disorders. Her novel work has helped us gain an insight into the application of deep brain stimulation in managing disturbances at the level of pedunculo-pontine nucleus. Her dual expertise is exemplified by her appointment as neurosurgeon at the Pitié-Salpêtrière Hospital and as a lead researcher at the Institut du Cerveau et de la Moelle Épinrière (Brain and Spine Institute) in Paris.<sup>69</sup>

## 6. Conclusion

Most of the contributing women were from the western countries, the USA being a pioneer and Lower middle income countries (LMICs) of Asia and Africa were left behind. The biggest reason being the dearth of neurosurgeons and infrastructure to cater to high patient load that leads to deviation of all neurosurgeons towards exclusive clinical practice and care, hence missing out leadership and research opportunities. Additionally, there is a need for certified subspecialty courses in LMICs. Societal roles imposed on the women along with minimal assistance during pregnancy and child care are the other challenges for females to have a less opportunistic career. It is therefore imperative to uplift the future generation of female neurosurgeons, especially from LMICs right

from the beginning of medical school.

### CRedit authorship contribution statement

**Bhavya Pahwa:** Conceptualization, Data curation, Methodology, Project administration, Visualization, Writing – original draft. **Anushruti Shukla:** Data curation, Methodology, Writing – original draft, Supervision, Writing – review & editing.

### Declaration of competing interest

The authors declare no conflict of interest in the preparation of this manuscript.

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