Tracheostomy as a Risk Factor for Paroxysmal Sympathetic Hyperactivity in Severe Traumatic Brain Injury

Zhenxing Li, Jigang Chen, Danfeng Zhang, Liquan Lv, Lijun Hou

BACKGROUND: **Paroxysmal sympathetic hyperactivity (PSH) is an uncommon complication of severe traumatic brain injury (sTBI). The clinical risk factors for PSH have not been fully characterized, especially regarding tracheostomy, which has usually been recommended for patients with sTBI to facilitate treatment. We examined the effects of tracheostomy on PSH incidence in patients with sTBI.**

METHODS: **The present single-center, retrospective study included consecutive patients with sTBI who had been admitted to the Shanghai Changzheng Hospital from January 1, 2013 to March 31, 2018. The potential risk factors related to the occurrence of PSH was explored by univariate analysis. Multivariate logistic regression analysis was conducted to determine the independence of the factors associated with PSH development.**

RESULTS: **Of the 120 patients with sTBI, 17 with PSH were identified (14.16%). We found 3 risk factors were significantly associated with PSH on univariate and multivariate analyses: 1) tracheostomy (odds ratio [OR], 5.368; 95% confidence interval [CI], 1.102–26.151; $P = 0.038$); 2) age (OR, 0.916; 95% CI, 0.874–0.960; $P < 0.001$); and 3) hydrocephalus (OR, 6.715; 95% CI, 1.708–26.408; $P = 0.006$).**

CONCLUSIONS: **Our results suggest that tracheostomy is independently associated with an increased incidence of PSH.**

INTRODUCTION

Paroxysmal sympathetic hyperactivity (PSH) has been recognized as an uncommon complication of severe traumatic brain injury (sTBI), and its incidence has ranged from 8% to 33% in different case series.[1-3] The syndrome consists of a cluster of symptoms and abnormal vital signs, including elevated heart rate, blood pressure, respiratory rate, and temperature, sweating and muscle rigidity,[4] leading to prolonged hospitalization and increased morbidity and mortality.[5,6]

A consensus on the definition of PSH has been formally established to replace such phrases as "paroxysmal autonomic instability with dystonia" or "sympathetic storm" in 2014.[4] However, the pathogenesis of PSH remains largely unknown. Therefore, research on the pathophysiological mechanism of PSH is imperative. Multiple factors potentially correlating with the development of PSH have been analyzed previously, including diffuse axonal injury, young patient age, and focal and deep intraparenchymal lesions.[7-9] However, the relationship between the use of tracheostomy and PSH has not yet been clarified. Tracheostomy has been widely used and has been generally recommended to facilitate treatment and reduce the duration of mechanical ventilation in patients with sTBI. However, no conclusive evidence has shown that the use of early tracheostomy could reduce the incidence of PSH and improve patients' prognosis.[5,10,11] In the present study, we evaluated the risk factors, in particular, the independence of tracheostomy as a prognostic factor for PSH in patients with sTBI.

METHODS

Participants

The present retrospective study included consecutive patients with sTBI who had been admitted to the neurointensive care unit at the

Key words
- Paroxysmal sympathetic hyperactivity
- Severe traumatic brain injury
- Tracheostomy

Abbreviations and Acronyms
CI: Confidence interval
CT: Computed tomography
GCS: Glasgow coma scale
OR: Odds ratio
PSH: Paroxysmal sympathetic hyperactivity
sTBI: Severe traumatic brain injury

Department of Neurosurgery, Changzheng Hospital, Second Military Medical University, Shanghai, China

To whom correspondence should be addressed: Lijun Hou, M.D. [E-mail: shczsjwk11@126.com]

Zhenxing Li, Jigang Chen, and Danfeng Zhang contributed equally to the present study.

Citation: World Neurosurg. (2019) 123:e156-e161. https://doi.org/10.1016/j.wneu.2018.11.101

Journal homepage: www.journals.elsevier.com/world-neurosurgery

Available online: www.sciencedirect.com

Table 1. Clinical Feature Scale for Paroxysmal Sympathetic Hyperactivity Assessment

	Score			
Variable	**0**	**1**	**2**	**3**
Heart rate	<100	100–119	120–139	≥140
Respiratory rate	<18	18–23	24–29	≥30
Systolic blood pressure	<140	140–159	160–179	≥180
Temperature	<37	37–37.9	38–38.9	≥39.0
Sweating	None	Mild	Moderate	Severe
Posturing during episodes	None	Mild	Moderate	Severe

Possible total ranges from 0 to 18.

Shanghai Changzheng Hospital from January 1, 2013 to March 31, 2018. The inclusion criteria were as follows: 1) isolated head injury; 2) admission Glasgow coma scale (GCS) score of ≤8; and 3) age ≥10 years. Patients who died within 24 hours after admission were excluded. Patients with tumor, epilepsy, cardiovascular disease, or chronic respiratory disease were also excluded. The research ethics board of the Shanghai Changzheng Hospital fully approved the present study.

The diagnostic criteria of PSH included 1) body temperature ≥38.5°C, 2) heart rate ≥140 beats/min; 3) respiratory rate ≥20 breaths/min; 4) systolic pressure ≥140 mm Hg; 5) sweating; and 6) muscle rigidity. Patients were identified as having PSH if any 4 of 6 symptoms were present. The PSH assessment measure proposed by the consensus was also applied to confirm the diagnosis of PSH.[4] The PSH assessment measure consisted of the clinical feature scale and diagnosis likelihood tool. Patients with a combined score from the diagnosis likelihood tool and clinical feature scale of >8 were considered to possibly, and those with a combined score of >17 to likely, have PSH (Tables 1–3).

Outcome Variables

The patients were divided into the PSH group and non–PSH group according to the development of PSH. The collected clinical variables included sex, age, mode of injury, history of hypertension, admission GCS score, admission computed tomography (CT) findings, hydrocephalus, emergency neurosurgery, tracheostomy, mechanical ventilation, and duration of mechanical ventilation. The patients' medical history was identified from the medical records and unit care records. Emergency neurosurgery included removal of intracranial hematoma and decompressive craniectomy in the first 24 hours after admission. Tracheostomy was performed by trained surgeons in the neurointensive care unit using an open surgical procedure. The patient was positioned with neck moderately extended; 2% lidocaine (10 mL) was usually injected for local anesthesia. A 3–5-cm vertical skin incision initiated below the inferior cricoid cartilage was required. The strap muscles were retracted laterally, and the thyroid isthmus was retracted superiorly or inferiorly or divided. A sideways "H" incision at the level of the second tracheal ring was created.[12,13] Finally, the endotracheal tube was carefully placed.

Statistical Analysis

Statistical analysis was conducted with SPSS, version 24.0, software (IBM Corp., Armonk, New York, USA). We performed a univariate analysis to assess the relationships between the clinical variables and the development of PSH. We used the Mann-Whitney U test for the quantitative variables and the χ^2 test for qualitative variables. Multivariate analysis was also conducted using logistic regression model to determine the factors independently associated with the development of PSH. Odds ratios (ORs) with the corresponding 95% confidence intervals (CIs) were evaluated after adjustment for

Table 2. Diagnosis Likelihood Tool for Paroxysmal Sympathetic Hyperactivity Assessment

Diagnosis Likelihood Tool	Score If Finding Present
Clinical features occur simultaneously	1
Episodes are paroxysmal in nature	1
Sympathetic overreactivity to normally nonpainful stimuli	1
Features persist ≥3 consecutive days	1
Features persist ≥2 weeks after brain injury	1
Features persist despite treatment of alternative differential diagnoses	1
Medication administered to decrease sympathetic features	1
>2 Episodes daily	1
Absence of parasympathetic features during episodes	1
Absence of other presumed cause of features	1
Antecedent acquired brain injury	1
Possible total	11

Table 3. Diagnostic Likelihood of Paroxysmal Sympathetic Hyperactivity Stratified by Combined Score

PSH Diagnostic Likelihood	Combined Total Score
Unlikely	<8
Possible	8–16
Probable	>17

PSH, paroxysmal sympathetic hyperactivity.

confounding factors. $P < 0.05$ was considered to indicate statistical significance.

RESULTS

A total of 120 patients with sTBI were included in the present study, 17 (14.16%) of whom developed PSH. The median age in the PSH group was 31 years and was 59 years in the non–PSH group. The difference between the 2 groups was statistically significant ($P < 0.001$). Sex, hypertension history, and mode of injury proved not to be related to the development of PSH (Table 4). The median admission GCS score in the PSH group was lower than that in the non-PSH group. However, the difference was not statistically significant (5; range, 4–6; vs. 6, range, 4–7; $P = 0.328$). The PSH group tended to have more diffuse lesions compared with the non-PSH group according to the admission CT findings, although the results were not statistically significant ($P = 0.549$; Table 4). Similarly, we found no statistically significant differences in the requirement for emergency neurosurgery or mechanical ventilation or duration of mechanical ventilation between the 2 groups ($P = 0.100$; $P = 0.247$; and $P = 0.278$, respectively; Table 4).

The use of tracheostomy was more frequent in the PSH group than in the non-PSH group, with a statistically significant difference (82.4% vs. 45.6%; $P = 0.005$). In addition, the presence of hydrocephalus was greater in the PSH group than in the non-PSH group (64.7% vs. 15.5%; $P < 0.001$; Table 4).

Variables with significant results on univariate analysis (i.e., age, tracheostomy, hydrocephalus) were included in the multivariate analysis to determine the independent risk factors for PSH. Several insignificant variables (e.g., sex, emergency neurosurgery, admission GCS score, and admission CT findings) were also included in the logistic regression model. Although these variables were not statistically significant on univariate analysis, they were considered clinically to be related to the outcome. The results of the logistic regression analysis showed that tracheostomy (OR, 5.368; 95% CI, 1.102–26.151; $P = 0.038$), age (OR, 0.916; 95% CI, 0.874–0.960; $P < 0.001$), and hydrocephalus (OR, 6.715; 95% CI, 1.708–26.408; $P = 0.006$) were independently associated with the development of PSH after sTBI (Table 5).

DISCUSSION

Many studies have investigated the clinical and prognostic implications of PSH, which has been widely recognized as an uncommon complication of sTBI that can result in great damage.[6,14] However, the causes of PSH remain largely unknown, and relevant investigations have been rare. Some investigators have proposed that the development of PSH might be related to an abnormality in connectivity within the central autonomic network,[15] although more detailed neuroanatomical and pathophysiological evidence was absent. Therefore, studies focusing on the risk factors for PSH would contribute to improved clinical decisions and the reduction of mortality and morbidity of patients with sTBI.

Several factors have been reported to be associated with the development of PSH such as age, early fever, and GCS score.[8,9] However, the association between the use of tracheostomy and PSH has rarely been studied. Tracheostomy is an effective method to provide a relatively stable airway and has been recommended for patients with sTBI (level IIA evidence, version 2017).[10,16] The benefits of tracheostomy include improved comfort, reduced oropharyngeal stimulation, and a decreased risk of ventilator-associated pneumonia.[17] In contrast, the adverse complications of tracheostomy have included bleeding, posterior tracheal perforation, and other airway injuries.[18,19] However, little attention has been given to the development of PSH caused by tracheostomy. Ringrose et al.[20] analyzed the data from patients with TBI who had undergone tracheostomy and compared the duration of tracheostomy weaning and influential characteristics between those with and without PSH. They concluded that PSH might be associated with prolonged tracheostomy weaning. We analyzed the data from patients with sTBI who had or had not undergone tracheostomy and explored the role of tracheostomy on PSH development. According to the univariate analysis, tracheostomy was more frequent in the PSH group than in the non-PSH group, with a statistically significant difference. Multivariate analysis also identified tracheostomy as an independent risk factor of PSH.

The mechanism behind the significant relationship between the use of tracheostomy and the presence of PSH is unclear. Studies have suggested that hypoxia in those with sTBI was common[21] and that the occurrence of PSH mostly resulted from the presence of cerebral hypoxia.[22] Nevertheless, to the best of our knowledge, no clinical and animal studies have focused on the relationship between the presence of hypoxia and PSH. One study reported the therapeutic effects of hyperbaric oxygen therapy for patients with PSH and TBI.[23] Because hyperbaric oxygen therapy could increase oxygen availability and improve cerebral aerobic metabolism for injured brain tissue,[24] the potential relationship between PSH and hypoxia secondary to sTBI requires investigation. We speculated that patients with PSH who experienced tracheostomy usually already had cerebral hypoxia. Although the tracheostomy could effectively ameliorate cerebral hypoxia, the irreversible neurologic damage caused by the presence of previous hypoxia could still have affected the development of PSH. Therefore, the need for tracheostomy might be a reflection of sustained hypoxic brain injury, which correlated with PSH occurrence after sTBI.

According to the results of our univariate analysis, patients with PSH seemed to have a lower admission GCS score, suggesting that patients who require tracheostomy are more likely to have severe brain injury and severely depressed consciousness.[18,25] Suction is a routine clinical procedure for patients with a tracheostomy in place.[26,27] We have assumed that frequent suction could trigger pain or other stimulation, which might lead to activation of the sympathetic nervous system. Although we have proposed some assumptions, the independent role of tracheostomy in the development of PSH lacks proof of causation. Therefore, the molecular

Table 4. Patient Demographic Characteristics and Clinical Findings

Variable	Total (n = 120)	PSH Group (n = 17)	Non-PSH Group (n = 103)	P Value
Age (years)				<0.001
Median	56.5	31	59	
IQR	42–64	20–52	45–66	
Male sex	97 (80.8)	13 (76.5)	84 (81.6)	0.622
Hypertension history	31 (25.8)	2 (11.8)	29 (28.2)	0.153
Mode of injury				
Traffic accident	74 (61.7)	10 (58.8)	64 (62.1)	0.795
Fall	20 (16.7)	3 (17.6)	17 (16.5)	0.907
Other/unknown	26 (21.7)	4 (23.5)	22 (21.4)	0.841
Admission GCS score				0.328
Median	5.5	5	6	
IQR	4–7	4–6	4–7	
Admission CT findings				0.549
Focal lesion	85 (70.8)	11 (64.7)	74 (71.8)	
Diffuse lesion	35 (29.2)	6 (35.3)	29 (28.2)	
Hydrocephalus	27 (22.5)	11 (64.7)	16 (15.5)	<0.001
Emergency neurosurgery	106 (88.3)	13 (76.5)	93 (90.3)	0.100
Tracheostomy	61 (50.8)	14 (82.4)	47 (45.6)	0.005
Mechanical ventilation	23 (19.2)	5 (29.4)	18 (17.5)	0.247
Mechanical ventilation duration (days)				0.278
Median	0	0	0	
IQR	0–0	0–2	0–0	

PSH, paroxysmal sympathetic hyperactivity; IQR, interquartile range; GCS, Glasgow coma scale; CT, computed tomography.

biological mechanism and pathophysiological process requires further investigation. Also, more attention and special care should be given to patients with sTBI and tracheostomy to avoid adverse outcomes. In addition, our study has provided a certain reference value for tracheostomy weaning. Because no agreement has been reached regarding the optimal timing of tracheostomy decannulation,[28] we would recommend early tracheostomy weaning for patients with sTBI who develop PSH.

In the present study, other variables were also found to be independent risk factors for PSH development, including patient age and hydrocephalus. Young patients seemed to have a high risks of PSH, similar to the results from other studies.[14,20] However, we found no reasonable explanation for the age difference. Moreover, we detected that the presence of hydrocephalus was related to the development of PSH. This result was also in line with previous clinical findings.[8] It has been controversial regarding whether the admission GCS score is an independent risk factor for PSH.[4,6] Our results did not support the independent value of admission GCS score for PSH, which might have been related to the rapidly deteriorating course. Also, the admission GCS score was unable to respond to subsequent progress of the disease for patients with sTBI. Also, the admission CT findings had no significant relationship with the development of PSH in our study, although the PSH group did show a tendency to have more diffuse lesions than those in the non-PSH group, in accordance with previous reports.[29] In terms of the limited sensitivity to the diagnosis of diffuse axonal injury, future studies that include magnetic resonance imaging findings would be valuable.

Table 5. Multivariate Analysis Results of Variables Related to Paroxysmal Sympathetic Hyperactivity Development

Variable	OR	95% CI	P Value
Age	0.916	0.874–0.960	<0.001
Hydrocephalus	6.715	1.708–26.408	0.006
Tracheostomy	5.368	1.102–26.151	0.038

OR, odds ratio; CI, confidence interval.

The treatment of PSH has not yet been standardized.[30] For PSH-related tracheostomy, intravenous morphine (1–2 mg every 1–2 hours as needed) or labetalol (10–20 mg every 1–2 hours, as needed) in the acute phase, followed by intragastric propranolol (20–80 mg 3 times daily) or gabapentin (100–900 mg 3 times daily) in the stable phase, has been recommended. A recent study suggested the use of intrathecal baclofen to treat PSH, combined with other conventional oral drugs, such as oral baclofen and oral propranolol.[31] Intrathecal pharmacotherapy might be a novel strategy because of its rapid-onset mechanism. In addition, frequent suctioning of the tracheostomy might lead to undesirable consequences. Although a plastic cannula is more flexible for connecting to the ventilator, it seems more likely to become occluded by sputum compared with a metal cannula. Therefore, we believe a metal cannula should be used, if available.

The present study had several limitations that should be noted. First, ours was a retrospective study, which could have resulted in bias caused by patient selection and the clinical findings. Second, although we analyzed several factors that could affect the occurrence of PSH, other related factors such as the magnetic resonance imaging characteristics and the presence of infection were not explored owing to incomplete medical record data. Moreover, the sample size was relatively small and the representativeness of our findings limited. Therefore, to validate the value of tracheostomy in predicting the development of PSH after sTBI, more prospective, multicenter studies with a greater number of participants are needed.

CONCLUSIONS

Our findings have shown that the use of tracheostomy might be independently associated with an increased incidence of PSH. Patients with tracheostomy after sTBI should be carefully monitored to reduce the damage caused by PSH.

ACKNOWLEDGMENTS

We would like to express our sincere gratitude to Chengguang Huang, Minkun Yu, Kehua Sun, and Rulin Bai at Changzheng Hospital for their work in providing the clinical data.

REFERENCES

1. Sheriff FG, Hinson HE. Pathophysiology and clinical management of moderate and severe traumatic brain injury in the ICU. *Semin Neurol*. 2015;35:42-49.
2. Laxe S, Terré R, León D, Bernabeu M. How does dysautonomia influence the outcome of traumatic brain injured patients admitted in a neurorehabilitation unit? *Brain Inj*. 2013;27:1383-1387.
3. Dolce G, Quintieri M, Leto E, et al. Dysautonomia and clinical outcome in vegetative state. *J Neurotrauma*. 2008;25:1079-1082.
4. Baguley IJ, Perkes IE, Fernandez-Ortega JF, et al. Paroxysmal sympathetic hyperactivity after acquired brain injury: consensus on conceptual definition, nomenclature, and diagnostic criteria. *J Neurotrauma*. 2014;31:1515-1520.
5. Siddiqui UT, Tahir MZ, Shamim MS, Enam SA. Clinical outcome and cost effectiveness of early tracheostomy in isolated severe head injury patients. *Surg Neurol Int*. 2015;6:65.
6. Mathew MJ, Deepika A, Shukla D, Devi BI, Ramesh VJ. Paroxysmal sympathetic hyperactivity in severe traumatic brain injury. *Acta Neurochir*. 2016;158:2047-2052.
7. Fernandez-Ortega JF, Prieto-Palomino MA, Muñozlópez A, Lebron-Gallardo M, Cabrera-Ortiz H, Quesada-García G. Prognostic influence and computed tomography findings in dysautonomic crises after traumatic brain injury. *J Trauma*. 2006;61:1129-1133.
8. Lv LQ, Hou LJ, Yu MK, et al. Prognostic influence and magnetic resonance imaging findings in paroxysmal sympathetic hyperactivity after severe traumatic brain injury. *J Neurotrauma*. 2010;27:1945-1950.
9. Hinson HE, Schreiber MA, Laurie AL, Baguley IJ, Bourdette D, Ling GSF. Early fever as a predictor of paroxysmal sympathetic hyperactivity in traumatic brain injury. *J Head Trauma Rehab*. 2017;32:E50-E54.
10. Carney N, Totten AM, O'Reilly C, et al. Guidelines for the management of severe traumatic brain injury, fourth edition. *Neurosurgery*. 2017;80:6-15.
11. Khalili H, Paydar S, Safari R, Arasteh P, Niakan A, Foroughi AA. Experience with traumatic brain injury: is early tracheostomy associated with better prognosis? *World Neurosurg*. 2017;103:88-93.
12. Cheung NH, Napolitano LM. Tracheostomy: epidemiology, indications, timing, technique, and outcomes. *Respir Care*. 2014;59:895-919.
13. De Leyn P, Bedert L, Delcroix M, et al. Tracheotomy: clinical review and guidelines. *Eur J Cardiothorac Surg*. 2007;32:412-421.
14. Fernandez-Ortega JF, Prieto-Palomino MA, Garcia-Caballero M, Galeas-Lopez JL, Quesada-Garcia G, Baguley IJ. Paroxysmal sympathetic hyperactivity after traumatic brain injury: clinical and prognostic implications. *J Neurotrauma*. 2012;29:1364-1370.
15. Hinson HE, Puybasset L, Weiss N, et al. Neuroanatomical basis of paroxysmal sympathetic hyperactivity: a diffusion tensor imaging analysis. *Brain Inj*. 2015;29:455-461.
16. Bouderka MA, Fakhir B, Bouaggad A, Hmamouchi B, Hamoudi D, Harti A. Early tracheostomy versus prolonged endotracheal intubation in severe head injury. *J Trauma Acute Care Surg*. 2004;57:251-254.
17. Scales DC, Ferguson ND. Early vs late tracheotomy in ICU patients. *JAMA*. 2010;303:1537-1538.
18. Alali AS, Scales DC, Fowler RA, et al. Tracheostomy timing in traumatic brain injury: a propensity-matched cohort study. *J Trauma Acute Care Surg*. 2014;76:70-78.
19. Hsu C-L, Chen K-Y, Chang C-H, Jerng J-S, Yu C-J, Yang P-C. Timing of tracheostomy as a determinant of weaning success in critically ill patients: a retrospective study. *Crit Care*. 2004;9:R46-R52.
20. Ringrose H, Brown M, Walton K, Sivan M. Association between paroxysmal sympathetic hyperactivity and tracheostomy weaning in traumatic brain injury. *NeuroRehabilitation*. 2018;42:207-212.
21. Vieira RDCA, Paiva WS, Oliveira DVD, Teixeira MJ, Andrade AFD, Sousa RMCD. Diffuse axonal injury: epidemiology, outcome and associated risk factors. *Front Neurol*. 2016;7:178.
22. Perkes I, Baguley IJ, Nott MT, Menon DK. A review of paroxysmal sympathetic hyperactivity after acquired brain injury. *Ann Neurol*. 2010;68:126-135.
23. Lv LQ, Hou LJ, Yu MK, Ding XH, Qi XQ, Lu YC. Hyperbaric oxygen therapy in the management of paroxysmal sympathetic hyperactivity after severe traumatic brain injury: a report of 6 cases. *Arch Phys Med Rehabil*. 2011;92:1515-1518.
24. Zhou Z, Daugherty WP, Sun D, et al. Protection of mitochondrial function and improvement in cognitive recovery in rats treated with hyperbaric oxygen following lateral fluid-percussion injury. *J Neurosurg*. 2007;106:687-694.
25. Boynton JH, Hawkins K, Eastridge BJ, O'Keefe GE. Tracheostomy timing and the duration of weaning in patients with acute respiratory failure. *Crit Care*. 2004;8:R261-R267.
26. Lewarski JS. Long-term care of the patient with a tracheostomy. *Respir Care*. 2005;50:534-537.
27. Ireton J. Tracheostomy suction: a protocol for practice. *Paediatr Nurs*. 2007;19:14-18.

28. Heffner JE. Tracheostomy decannulation: marathons and finish lines. *Crit Care*. 2008;12:128.

29. Baguley IJ. The excitatory:inhibitory ratio model (EIR model): an integrative explanation of acute autonomic overactivity syndromes. *Med Hypotheses*. 2008;70:26-35.

30. Meyfroidt G, Baguley IJ, Menon DK. Paroxysmal sympathetic hyperactivity: the storm after acute brain injury. *Lancet Neurol*. 2017;16:721-729.

31. Pucks-Faes E, Hitzenberger G, Matzak H, Verrienti G, Schauer R, Saltuari L. Intrathecal baclofen in paroxysmal sympathetic hyperactivity: impact on oral treatment. *Brain Behav*. 2018;8:e01124.

Conflict of interest statement: The present study was funded by the Natural Science Foundation of China (grant 81271350) to Liquan Lv and the Natural Science Foundation of China (grant 81671206) to Lijun Hou.

Received 13 September 2018; accepted 12 November 2018

Citation: World Neurosurg. (2019) 123:e156-e161.
https://doi.org/10.1016/j.wneu.2018.11.101

Journal homepage: ***www.journals.elsevier.com/world-neurosurgery***

Available online: ***www.sciencedirect.com***