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Cervical artery dissection after sports – An analytical evaluation of 190 published cases

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Abstract

Introduction: Cervical artery dissections may be preceded by mechanical trigger events, often related to sports.
Methods: Using the MEDLINE database, we identified case reports and case series of sports-related cervical artery dissections. Information of the type of sport, age and gender of the patient, affected vessels, associated infarction, time delay, and neurological sequelae were extracted. Demographic and clinical characteristics were compared between sport groups using analysis of variance and Chi square tests. Differences were further assessed with adjusted post hoc tests and homogenous subsets.
Results: A total of 115 reports describing 190 patients with cervical artery dissections related to 45 different sports were identified. The mean age of all patients was 35 years; 26% of all patients were women. Anterior and posterior circulation, as well as left and right side were affected with similar frequency. Patients belonging to different sport categories differed significantly with regard to age ($p < 0.001$), gender ($p < 0.001$), and affected circulation (anterior vs. posterior, $p = 0.02$). The posterior circulation was most often affected in golf players (88%) and least often in individuals engaging in exercise (23%) and scuba divers (29%). Laterality (left vs. right) and mortality were similar between sport groups.
Discussion: We performed a comprehensive review and analytical evaluation of case reports describing patients with cervical artery dissections after sport. Confirmation of our findings in prospective studies is needed.
Conclusion: Cervical artery dissection has been described in relation to a wide variety of sports. The risk of injury to particular neurovascular structures may depend on the type sport involved. Discipline-specific incidence rates are not known.

Keywords
Stroke, brain infarction, vertebral artery dissection, carotid artery dissection, sports, athletic injuries

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Introduction

Cervical artery dissection (CAD) is a rare cause of ischemic stroke in the general population. It occurs with an annual incidence of 2.5–3/100.000 [1,2] and affects predominantly younger individuals.[3] In patients

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between 15 and 45 years, it accounts for approximately 20% of all causes of ischemic stroke.[4] CAD can be associated with non-trivial neck trauma such as is seen in motor vehicle accidents, or occur spontaneously.[3] Patients with CAD were found to have sustained neck trauma within one month prior to first symptoms of dissection in 41% of cases. This included sports-related trauma in 6% of cases.[5] Most of those were mild and it is unclear whether or how often the association between mild trauma and CAD is coincidental rather than causal. Thus, in the context of CAD, mild trauma should more precisely be referred to as potential mechanical trigger events.[5] Over the last decades, a growing number of case reports describing patients with CAD that have occurred in relation to sport have been published. Among sports-related CAD, it is unclear whether characteristics of sports matter with regard to site of CAD, or age and gender of affected patients. The degree of, and motivations for, regular participation in sports differs between men and women[6–8] and changes with age.[9] Additionally, different sports vary widely in their dynamic and static components and in their risk of impact.[10] We therefore hypothesised that demographic characteristics (age, gender) and clinical manifestations (affected vessels, outcome) of CAD in relation to sport depend on the type of sport involved.

Methods

Study design

Our study consists of two parts. For the first part, we conducted a comprehensive review of the literature. In December 2016, we performed a literature search using the Medline database to identify case reports and case series of patients with CAD that were considered by the authors of the original publication to have occurred in relation to sport. No restriction with regard to publication date was applied. All reports for which at least an English abstract was available online were included in the analysis. Search parameters included the MESH-terms ‘cervical artery dissection’, ‘vertebral artery dissection’ and ‘athletic injuries’ as well as ‘sport’, ‘sports’, and the names of specific sport disciplines (‘soccer, ‘volleyball’, etc.) represented by *sportaccord*, the umbrella organisation for all Olympic and non-Olympic sport federations.[11] Following the Council of Europe’s definition laid out in the European Sports Charta,[12] we did not include sports primarily involving the mind (such as chess or go), motorised sports, and electronic sports. Bibliographies of identified articles were used to identify further publications. For identified cases, the following parameters were extracted from the reports: age; gender; type of sport preceding CAD; symptoms; location of vascular pathology; presence and anatomic location, or absence, of associated ischemic infarction; time of onset of stroke symptoms; and neurological sequelae.

For the second part, we combined patients described in the identified case reports that had engaged in the same or similar activities into groups of at least 10 patients each and compared demographic and clinical variables between groups.

Statistical analysis

Nominal data are presented as proportion and continuous data as mean with 95% confidence interval (calculated using Wilsons’s method for proportions[13]). Proportions were compared to the hypothesised proportion of 0.5 using an asymptotic one-sample binomial test. If multiple one-sample tests were performed, the significance level was adjusted using the Bonferroni method. Between-group differences of continuous variables were assessed using univariable analysis of variance with Tukey’s Honestly Significant Difference (HSD) post hoc test and analysis of covariance, as appropriate. The normality assumption was confirmed by one sample Shapiro-Wilk test. Equality of variances was assessed using Levene’s test. Nominal data were compared using Fisher’s exact Chi square test with Bonferroni-corrected post hoc pairwise comparisons. A two-sided p value of less than 0.05 was considered statistically significant. Data were analysed with IBM SPSS Statistics version 21 (IBM Corp.; Armonk, NY, USA) and MATLAB (Mathworks, Inc.).

Results

A total of 115 case reports and case series describing 190 different patients in which a CAD occurred in temporal relationship to engaging in a sportive activity were identified through our search. An overview over all cases is presented in Table S1 in the Online Supplement. The range of activities associated with the occurrence was diverse and included 44 different types of sport (Table 1). An overview of demographic and clinical characteristics of all 190 cases is presented in Table 2. The mean age of all patients described in published case reports was 35 years. The youngest patient described was a four-year-old boy who suffered a CAD-related stroke while playing on a trampoline (grouped under gymnastics in Table S1) resulting in a left vertebral artery dissection.[14] The oldest patient was a 70-year-old man who suffered a left vertebral artery dissection as a consequence of playing golf and subsequently died.[15] Reported patients were significantly more often men than women (74% vs. 26%, $p < 0.001$). Age distributions between men and women

Table 1. Types of sport described to have preceded CAD ($n = 190$).

Type of sport	n	Further analysis[a]
Water sport	26	/
Scuba diving[17,18–30]	14	Yes
Swimming[22,31–35]	7	–
Sailing[36]	1	–
Springboard diving[37]	1	–
Wakeboarding[38]	1	–
Waterskiing[39]	1	–
Surfing[40]	1	–
Kitesurfing[41]	1	–
Running/jogging[22,32,40,42–44]	23	Yes
Combat sport	17	Yes
Jujitsu[22]	4	(+)
Kendo[45,46]	2	(+)
Judo[47,48]	2	(+)
Kickboxing[49,50]	2	(+)
Taekwondo[51]	1	(+)
Mixed martial arts[52]	1	(+)
Kung Fu[53]	1	(+)
Karate[54]	1	(+)
Boxing[55]	1	(+)
Wrestling[41]	1	(+)
Capoeira[56]	1	Yes
Golf[15,57,58–63]	16	Yes
Exercise/weight lifting	14	(+)
Exercise[22,56,64–68]	10	(+)
Weight lifting[22,69,70]	4	Yes
Basketball[16,40,71–76]	12	Yes
Football[33,56,77–82]	10	Yes
Tennis[22,80,83–89]	10	Yes
Soccer[22,85,90–94]	9	–
Softball/baseball	7	–
Softball[95–97]	5	–
Baseball[31,98]	2	–
Winter sport	7	–
Skiing[99–102]	4	–
Snowboarding[56,103,104]	3	–
Gymnastics[14,22,40,105–107]	6	–
Cycling[16,56,108–111]	6	–
Rugby[80,112–114]	4	–
Extreme sport	4	–
Bungee jumping[22,115]	2	–
Skydiving[116]	1	–
Triathlon[117]	1	–
Yoga[86,118–120]	4	–
Horse riding[121–124]	4	–
Skating[125–127]	3	–
Volleyball[40,128,129]	3	–
Handball[74]	1	–
Hockey[78]	1	–
Paddle bal[40]	1	–
Bowling[84]	1	–

[a]Indicates which types of sports are included in between-group analyses (all groups with at least 10 cases). 'Yes': forming a main group, '(+)': part of main group, '–': not included in further analysis, '/': some of its constituents are included in between-group analyses.
CAD: cervical artery dissections.

were similar (34.8 [32.4–37.3] years vs. 34.0 [31.0–37.0] years, $p = 0.67$). Vessels on the left and on the right side (left: 49%, right: 40%, bilateral: 11%; $p = 0.32$) as well as in the anterior circulation (internal, external, and common carotid arteries; middle and anterior cerebral arteries) and the posterior circulation (vertebral arteries; posterior inferior cerebellar arteries; posterior cerebral arteries) were dissected with similar frequency (anterior: 51%, posterior: 48%, both: 1%; $p = 1.00$). In 58 of 120 cases (48%) for which the time of symptom onset could be ascertained, neurological symptoms attributable to cerebral ischemia occurred during the activity or immediately thereafter. In cases where symptoms occurred on the following day or later, the mean delay was 4.8 [2.2–7.4] days. The longest delay between sportive activity and onset of stroke symptoms was reported for a five-year-old girl who developed a left temporal ischemic infarction with right hemiparesis and dysarthria due to dissection of the left internal carotid artery that was believed to have occurred six months earlier during a bicycle accident.[16] Information of neurological sequelae was available for 170 patients of whom 12 patients (7%) died.

We identified eight categories of sports with at least 10 cases reported. Thereby, a total of 116 patients were included in further analyses (Table 1). Mean age was significantly different between sport categories ($p < 0.001$). Age was lowest in the group of patients that suffered a dissection while playing football (21.4 years [13.1–29.7 years]) and highest in the group of golfers (48.3 years [41.4–55.2 years]). Post hoc tests identified four homogenous subsets with regard to age: golf players were significantly older than participants of football, basketball, and combat sports; football players were also significantly younger than runners, tennis players, and people engaging in exercise/weight lifting and scuba diving (Figure 1(a)). The proportion of female patients also differed significantly

Table 2. Demographic and clinical characteristics of all sport-related CAD cases ($n = 190$).

Parameter	*n*	Value	*P*
Total number of references	–	115	
Total number of cases	–	190	–
Age (years)	183	34.6 (32.6–36.5)	–
Women	185	48, 26% (20%–33%)	<0.001[a]
Dissected vessel			
anterior circulation		94, 51% (43%–58%)	
posterior circulation	186	90, 48% (41%–56%)	1.00[b]
anterior and posterior circulation		2, 1% (0%–4%)	
Dissected vessel			
left side		87, 49% (42%–57%)	
right side	177	71, 40% (33%–48%)	0.23[c]
left and right side		19, 11% (7% – 16%)	
Onset of symptoms[d]			
immediately/within minutes		58, 48% (39%–57%)	
same day/within hours	120	30, 25% (17% –33%)	
following day or later		32, 26.7% (19%–35%)	
Outcome (mortality)			
Survival	170	158, 93% (88%–96%)	–
Death		12, 7% (4%–12%)	

Note: Continuous data are displayed as mean (95% confidence interval). Categorical data are displayed as absolute number and proportion (95% confidence interval).
[a]Null hypothesis: category 'woman' occurs with probability of 0.5.
[b]Null hypothesis: equal probability for 'anterior circulation' and 'posterior circulation'.
[c]Null hypothesis: equal probability for 'left side' and 'right side'.
[d]Onset of symptoms attributable to cerebral ischemia relative to sportive activity.
CAD: cervical artery dissections.

between groups ($p < 0.001$). It was higher than 50% in only two groups (exercise/weight lifting and running); no female patients suffering a CAD were reported for football, golf, and combat sports. Post hoc analysis of homogenous subsets yielded two subsets that showed no overlap for, and thereby separated, exercise/weight lifting/running on one hand and golf/combat sports on the other hand (Figure 1(b)). The distribution of anterior circulation vs. posterior circulation CAD was significantly different between groups ($p = 0.02$). This difference remained significant after adjustment for age ($p = 0.02$). Bonferroni corrected post hoc analyses indicated a significant higher proportion of posterior circulation dissections in golf players (88% [64%–97%]) than in exercisers (23% [8%–50%]) and scuba divers (29% [12%–55%], Figure 1(c)). The left and the right side of the cervicocephalic vasculature was affected similarly in different sports ($p = 0.29$). The outcome after CAD in relation to sport across the categories 'death', 'residual symptoms', and 'full recovery' did not depend on the type of sport preceding the injury ($p = 0.51$). No differences between groups were observed with regard to the time interval between the sportive activity and the onset of stroke symptoms ($p = 0.71$). Detailed results of group specific analyses are presented in Figure 2.

Discussion

Main findings

We provide the most comprehensive collection so far and a systematic analysis of case reports describing patients with CAD in relation to sport. Our main finding was significantly different distributions of posterior vs. anterior circulation CAD in different sports with the highest proportion of posterior circulation CAD in golf and the lowest in exercise/weight lifting and scuba diving. The number of patients being described in the scientific literature varies widely for different types of sport from only 1 (e.g. paddle ball, wrestling) to 23 (running/jogging).

Gender

In agreement with previous findings,[130,131] almost 75% of patients in our sample were male. Additionally, our results indicate that gender of CAD patients is

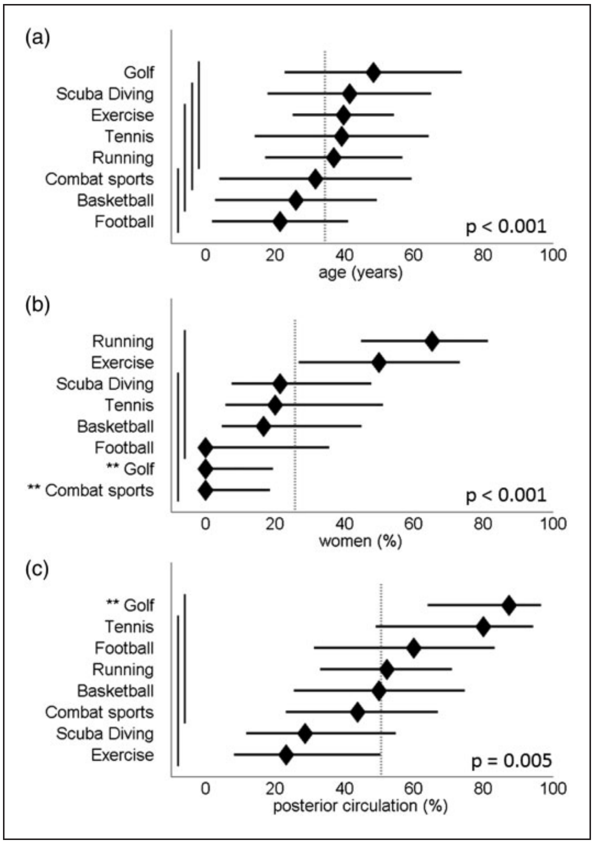

Figure 1. Demographic and clinical characteristics of patients with cervical artery dissection according to type of sport. Displayed are means (age) and proportions (gender, affected circulation) with 95% confidence intervals. The dotted vertical lines represent the average values from all 190 patients. The solid vertical lines next to the vertical axis represent results of post-hoc analysis derived classification into homogenous subsets. *P*-values are derived from univariable analysis of variance (Panel A) and Chi-squared test for categorical data (Panel B and Panel C). Values belonging to sports marked with two stars (**) are significantly different from 0.5 in one-sample analyses at a Bonferroni corrected significance level of 0.05/8 = 0.00625.

distributed unevenly between different types of sports. Questionnaire-based surveys have shown that women and men prefer different types of sport.[6,132] Thus, gender differences in the type of sports among patients with sport-related CAD are likely to reflect different degrees of participation in particular types of sports rather than gender-specific vulnerabilities to suffer sport-related dissections of the cervical arteries, although we cannot exclude this possibility.

Age

The mean age of patients analysed in our study was 35 years which is approximately 10 years younger than the mean age reported previously for CAD patients.[2,3,133] Higher percentages of younger people as compared to the elderly[132] participating in sport or exercise may be responsible for this difference. Similarly to gender, age of CAD patients was significantly different between types of sport. Participants of basketball and football were approximately half the age of golf players and also significantly younger than scuba divers. In our opinion, these imbalances most likely reflect different age structures associated with different types of sport. Indeed, golf and scuba diving require substantial financial resources for training, certification, purchase of equipment, green fees (for golfing), and associated travel. As financial means tend to accumulate with age,[134] these types of sport may be less popular among younger people and may be preferentially performed by older people.[135] Younger individuals, on the other hand, may more often engage in sports like basketball, football, and exercise which are often taught in school, are associated with less costs, and form an integral part of college life in many countries.

Site of vascular injury

The site of vascular injury may vary according to the type of sport. For example, as noted previously by Choi et al,[57] golfers tend to have CAD in the posterior rather than in the anterior circulation and predominantly on the right side. The authors suggest that rotational forces on the vertebral arteries that occur during the swing may be responsible for this observation. Our analysis adds further evidence to the presumption that sport-specific mechanisms of injury translate into an unbalanced distribution of damage to cervical vessels. Data by Metso et al.[136] suggest that the proportion of vertebral artery dissection as opposed to internal carotid artery dissection may increase with age. In our study, however, there was no association between CAD location and age, and adjustment for age did not account for the variation of CAD location (anterior vs. posterior) between types of sport. If it is true that participation in specific sports is associated with an increased risk of injury of particular neurovascular structures, this could serve as guidance for the development of better protective gear, the introduction of safer techniques, and adaptions to the rules of the sport with the ultimate goal to minimise long-term morbidity and mortality. From a clinical point of view, it may also be relevant to include this information when counseling patients diagnosed with spontaneous CAD about possible trigger factors.

Parameters not included in the analytical evaluation

We included the presence and location of ischemic infarctions associated with sport-related CAD in our individual case descriptions. However, because of

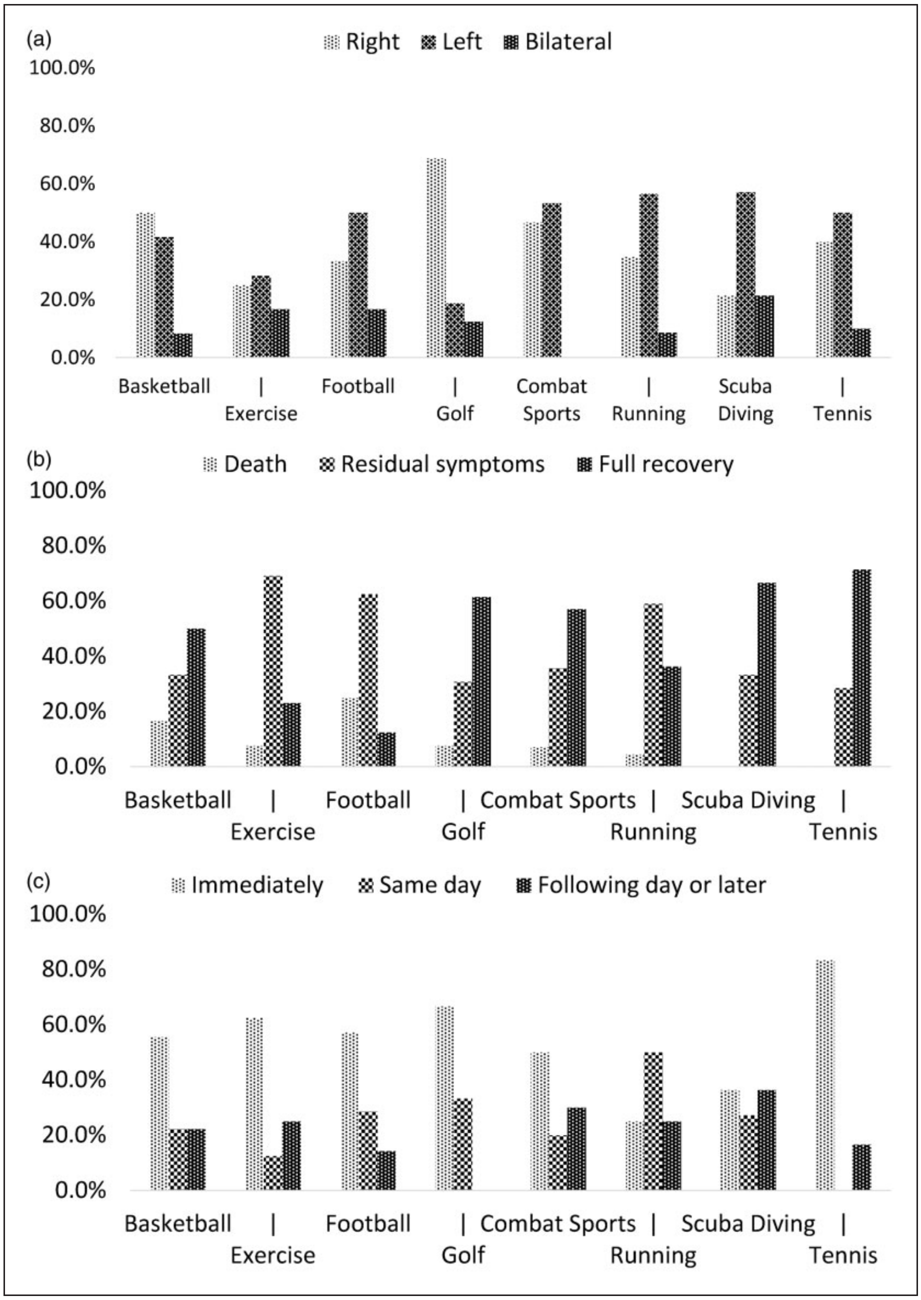

Figure 2. Side of affected vessels, outcome, and time delay before stroke symptoms of CAD patients according to type of sport. The distributions of the side of affected vessels (Panel A), of outcome (Panel B), and of the time interval between sportive activity and onset of stroke symptoms (Panel C) were not significantly different between groups ($p > 0.05$). CAD stands for cervical artery dissection.

large heterogeneity in the methodological ascertainment of ischemic infarction (clinical, CT, MRI, craniotomy, autopsy) no descriptive analyses and between-group comparisons were possible. Similarly, we found that the occurrence of cardiovascular risk factors such as arterial hypertension, atherosclerosis, dyslipidemia, atrial fibrillation, and diabetes mellitus as well as the results of investigations for rarer connective tissue disorders such as Ehlers-Danlos syndrome, Marfan syndrome, or Osteogenesis imperfecta were reported inconsistently in the literature. Only one case report described a patient with a proven connective tissue disorder: a 35-year-old women who suffered bilateral vertebral artery dissections in relation to scuba diving and was diagnosed with a mild phenotypic variant of osteogenesis imperfecta.[17] Recent studies have shown that patients with CAD often have clinical features of connective tissue abnormalities[137] but rarely meet criteria for established hereditary connective tissue diseases.[137,138] Furthermore, most publications included in our study did not contain specific information about the presence or absence of migraine, which was recently suggested to be a synergistic factor in the pathogenesis of CAD in young stroke patients.[139]

With regard to anatomical parameters, it has been noted that arterial tortuosity is more prevalent among CAD patients than among matched controls.[140–142] Whether the degree of arterial tortuosity reflects underlying risk factors such as (undiagnosed) connective tissue disease or represents an additional independent risk factor, e.g. by negatively affecting blood flow hemodynamics and wall shear stress, is uncertain. Similar to the clinical parameters mentioned earlier, case reports used for this study did not systematically report the degree of vascular tortuosity of their patients. None withstanding, it can be hypothesised that this risk factor also increases the likelihood of suffering a CAD after sport-related mechanical trigger events.

Limitations

We are aware of the following limitations: First, the design of our study does not allow to make inferences about incidence rates. Indeed, such a calculation would require detailed information about the number of individuals participating in each sport, stratified by country (popularity of each sport may differ from region to region) and time period. There may have been additional sources of distortion stemming from publication bias, recall bias, and geographic variation in the availability of diagnostic modalities needed to identify CAD. Second, we do not have data on the risk of recurrent dissection after a sports-related CAD. Third, the comparative analysis with regard to the site of vascular injury has limited topographical resolution with regard to the segments of the vertebral and internal carotid arteries involved (V1–V4 and C1–C7, respectively). Last, the case reports we included in our analytical evaluation described patients who suffered a CAD in temporal association with engagement in sports; inherent to the methodology of case reports, a causal relationship could not be established.

Conclusion

We used an analytical approach to systematically evaluate the currently existing evidence regarding sports-related CAD in the form of case reports. We found that age, gender, and the site of vascular injury differ between types of sports. Well-designed prospective studies are needed to gain a better understanding of the incidence and the clinical characteristics of CAD that occur in relation to individual sports.

Declaration of Conflicting Interests

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Ethical approval

Not applicable.

Informed consent

Not applicable.

Guarantor

LS.

Contributorship

LS conceived the study, researched the literature, performed the data analysis, interpreted the data, and wrote the first draft of the manuscript. MEn and MEb were involved in conceiving the study, searching the literature, and interpretation of the data. CHN and STE were involved in searching the literature. Additionally, all authors critically reviewed and edited the manuscript and approved the final version of the manuscript.

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References

1. Bejot Y, Daubail B, Debette S, et al. Incidence and outcome of cerebrovascular events related to cervical artery dissection: the Dijon Stroke Registry. *Int J Stroke* 2014; 9: 879–882.
2. Lee VH, Brown RD Jr., Mandrekar JN, et al. Incidence and outcome of cervical artery dissection: a population-based study. *Neurology* 2006; 67: 1809–1812.
3. Debette S and Leys D. Cervical-artery dissections: predisposing factors, diagnosis, and outcome. *Lancet Neurol* 2009; 8: 668–678.
4. Leys D, Bandu L, Henon H, et al. Clinical outcome in 287 consecutive young adults (15 to 45 years) with ischemic stroke. *Neurology* 2002; 59: 26–33.
5. Engelter ST, Grond-Ginsbach C, Metso TM, et al. Cervical artery dissection: trauma and other potential mechanical trigger events. *Neurology* 2013; 80: 1950–1957.

6. Azevedo MR, Araujo CL, Reichert FF, et al. Gender differences in leisure-time physical activity. *Int J Public Health* 2007; 52: 8–15.
7. Van Tuyckom C, Scheerder J and Bracke P. Gender and age inequalities in regular sports participation: a cross-national study of 25 European countries. *J Sports Sci* 2010; 28: 1077–1084.
8. Molanorouzi K, Khoo S and Morris T. Motives for adult participation in physical activity: type of activity, age, and gender. *BMC Public Health* 2015; 15: 66.
9. Belanger M, Townsend N and Foster C. Age-related differences in physical activity profiles of English adults. *Prev Med* 2011; 52: 247–249.
10. Levine BD, Baggish AL, Kovacs RJ, et al. Eligibility and disqualification recommendations for competitive athletes with cardiovascular abnormalities: task force 1: classification of sports: dynamic, static, and impact: a scientific statement from the American Heart Association and American College of Cardiology. *J Am Coll Cardiol* 2015; 66: 2350–2355.
11. SportAccord. SportAccord – members, www.sportaccord.com (2016, accessed 29 June 2017).
12. EUROPE CO and MINISTERS CO. EUROPEAN SPORTS CHARTER, www.coe.int: Council of Europe (2001, accessed 29 June 2017).
13. Brown LD, Cai TT and DasGupta A. Interval estimation for a binomial proportion. *Stat Sci* 2001; 16: 128–133.
14. Casserly CS, Lim RK and Prasad AN. Vertebral artery dissection causing stroke after trampoline use. *Pediatr Emerg Care* 2015; 31: 771–773.
15. Maroon JC, Gardner P, Abla AA, et al. "Golfer's stroke": golf-induced stroke from vertebral artery dissection. *Surg Neurol* 2007; 67: 163–168; discussion 8.
16. Pozzati E, Giuliani G, Poppi M, et al. Blunt traumatic carotid dissection with delayed symptoms. *Stroke* 1989; 20: 412–416.
17. Mayer SA, Rubin BS, Starman BJ, et al. Spontaneous multivessel cervical artery dissection in a patient with a substitution of alanine for glycine (G13A) in the alpha 1 (I) chain of type I collagen. *Neurology* 1996; 47: 552–556.
18. Alonso Formento JE, Fernandez Reyes JL, Envid Lazaro BM, et al. Horner's syndrome due to a spontaneous internal carotid artery dissection after deep sea scuba diving. *Case Rep Neurol Med* 2016; 2016: 5162869.
19. Bartsch T, Palaschewski M, Thilo B, et al. Internal carotid artery dissection and stroke after SCUBA diving: a case report and review of the literature. *J Neurol* 2009; 256: 1916–1919.
20. Brajkovic S, Riboldi G, Govoni A, et al. Growing evidence about the relationship between vessel dissection and scuba diving. *Case Rep Neurol* 2013; 5: 155–161.
21. Chojdak-Lukasiewicz J, Dziadkowiak E, Bladowska J, et al. Vertebral artery dissection and stroke after scuba diving. *Neurol India* 2014; 62: 711.
22. Fragoso YD, Adoni T, do Amaral LL, et al. Cerebrum-cervical arterial dissection in adults during sports and recreation. *Arq Neuropsiquiatr* 2016; 74: 275–279.
23. Fukuoka T, Kato Y, Ohe Y, et al. A case of anterior cerebral artery dissection caused by scuba diving. *J Stroke Cerebrovasc Dis* 2014; 23: 1982–1984.
24. Gibbs JW 3rd, Piantadosi CA and Massey EW. Internal carotid artery dissection in stroke from SCUBA diving: a case report. *Undersea Hyperb Med* 2002; 29: 167–171.
25. Hafner F, Gary T, Harald F, et al. Dissection of the internal carotid artery after SCUBA-diving: a case report and review of the literature. *Neurologist* 2011; 17: 79–82.
26. Kasravi N, Leung A, Silver I, et al. Dissection of the internal carotid artery causing Horner syndrome and palsy of cranial nerve XII. *CMAJ* 2010; 182: E373–E377.
27. Kocyigit A, Cinar C, Kitis O, et al. Isolated PICA dissection: an unusual complication of scuba diving: case report and review of the literature. *Clin Neuroradiol* 2010; 20: 171–173.
28. Konno K, Kurita H, Ito N, et al. Extracranial vertebral artery dissection caused by scuba diving. *J Neurol* 2001; 248: 816–817.
29. Nelson EE. Internal carotid artery dissection associated with scuba diving. *Ann Emerg Med* 1995; 25: 103–106.
30. Skurnik YD and Sthoeger Z. Carotid artery dissection after scuba diving. *Isr Med Assoc J* 2005; 7: 406–407.
31. Dharmasaroja P and Dharmasaroja P. Sports-related internal carotid artery dissection: pathogenesis and therapeutic point of view. *Neurologist* 2008; 14: 307–311.
32. Hayashi K, Kitagawa N, Hiu T, et al. [Three cases of internal carotid artery dissection due to trivial trauma]. *No Shinkei Geka* 2007; 35: 1175–1181.
33. Luken MG 3rd, Ascherl GF Jr. Correll JW, et al. Spontaneous dissecting aneurysms of the extracranial internal carotid artery. *Clin Neurosurg* 1979; 26: 353–375.
34. Mohaghegh S and Hajian M. Stroke in a young swimmer. *Asian J Sports Med* 2015; 6: e23812.
35. Tramo MJ, Hainline B, Petito F, et al. Vertebral artery injury and cerebellar stroke while swimming: case report. *Stroke* 1985; 16: 1039–1042.
36. Caplan LR, Estol CJ and Massaro AR. Dissection of the posterior cerebral arteries. *Arch Neurol* 2005; 62: 1138–1143.
37. Furtner M, Werner P, Felber S, et al. Bilateral carotid artery dissection caused by springboard diving. *Clin J Sport Med* 2006; 16: 76–78.
38. Fridley J, Mackey J, Hampton C, et al. Internal carotid artery dissection and stroke associated with wakeboarding. *J Clin Neurosci* 2011; 18: 1258–1260.
39. Willett GM and Wachholtz NA. A patient with internal carotid artery dissection. *Phys Ther* 2011; 91: 1266–1274.
40. Provenzale JM, Barboriak DP and Taveras JM. Exercise-related dissection of craniocervical arteries: CT, MR, and angiographic findings. *J Comput Assist Tomogr* 1995; 19: 268–276.
41. Driessen A, Probst C, Sakka SG, et al. [Bilateral carotid artery dissection in a kite surfer by strangulation with the kite lines]. *Unfallchirurg* 2015; 118: 567–570.
42. Berkowitz AL, Voinescu PE and Feske SK. Clinical reasoning: a 42-year-old man who developed blurred vision and dropped his iPod while jogging. *Neurology* 2014; 83: e89–e94.

43. Borgman C. Horner syndrome secondary to internal carotid artery dissection after a short-distance endurance run: A case study and review. *J Optom* 2012; 5: 209–216.
44. Macdonald DJ and McKillop EC. Carotid artery dissection after treadmill running. *Br J Sports Med* 2006; 40: e10.
45. Sakai H, Kaneko D, Yuki K, et al. [Carotid dissecting aneurysm due to blunt (rubbing) injury of the Kendo protector]. *No Shinkei Geka* 1986; 14: 91–94.
46. Suzuki R, Osaki M, Endo K, et al. Common carotid artery dissection caused by a frontal thrust in Kendo (Japanese swordsmanship). *Circulation* 2012; 125: e617–e619.
47. Freilinger T, Heuck A, Strupp M, et al. Images in vascular medicine: hypoglossal nerve palsy due to internal carotid artery dissection. *Vasc Med* 2010; 15: 435–436.
48. Lannuzel A, Moulin T, Amsallem D, et al. Vertebral-artery dissection following a judo session: a case report. *Neuropediatrics* 1994; 25: 106–108.
49. Echaniz-Laguna A, Fleury MC, Petrow P, et al. [Internal carotid artery dissection caused by a kick during French boxing]. *Presse Med* 2001; 30: 683.
50. Malek AM, Halbach VV, Phatouros CC, et al. Endovascular treatment of a ruptured intracranial dissecting vertebral aneurysm in a kickboxer. *J Trauma* 2000; 48: 143–145.
51. Pary LF and Rodnitzky RL. Traumatic internal carotid artery dissection associated with taekwondo. *Neurology* 2003; 60: 1392–1393.
52. Slowey M, Maw G and Furyk J. Case report on vertebral artery dissection in mixed martial arts. *Emerg Med Australas* 2012; 24: 203–206.
53. Pacei F, Valvassori L and Bet L. Vertebral artery dissection during Kung-Fu training. *Neurol Sci* 2014; 35: 331–332.
54. Sepelyak K, Gailloud P and Jordan LC. Athletics, minor trauma, and pediatric arterial ischemic stroke. *Eur J Pediatr* 2010; 169: 557–562.
55. Beck KD and Hernandez L. Central retinal artery occlusion in a 21-year-old boxer. *Ophthalmology* 2015; 122: 1568.
56. Alexandrino GM, Damasio J, Canhao P, et al. Stroke in sports: a case series. *J Neurol* 2014; 261: 1570–1574.
57. Choi MH, Hong JM, Lee JS, et al. Preferential location for arterial dissection presenting as golf-related stroke. *Am J Neuroradiol* 2014; 35: 323–326.
58. Choi KD, Oh SJ, Yang TI, et al. Golfer's stroke from internal carotid artery dissection. *Arch Neurol* 2008; 65: 1122–1123.
59. Guptha SH, Promnitz AD, Warner A, et al. A 'collapsing' golfer. *Cerebrovasc Dis* 2005; 19: 281–282.
60. Hong JM, Kim TJ, Lee JS, et al. Neurological picture Repetitive internal carotid artery compression of the hyoid: a new mechanism of golfer's stroke? *J Neurol Neurosurg Psychiatry* 2011; 82: 233–234.
61. Taniguchi A, Wako K, Naito Y, et al. [Wallenberg syndrome and vertebral artery dissection probably due to trivial trauma during golf exercise]. *Rinsho Shinkeigaku* 1993; 33: 338–340.
62. Tokumoto K and Ueda N. [Cervical cord infarction associated with unilateral vertebral artery dissection due to golf swing]. *Rinsho Shinkeigaku* 2014; 54: 151–157.
63. Yamada SM, Goto Y, Murakami M, et al. Vertebral artery dissection caused by swinging a golf club: case report and literature review. *Clin J Sport Med* 2014; 24: 155–157.
64. DeCarli C, Kurlan R and Green R. Exercise-related middle cerebral artery territory stroke. *Arch Neurol* 1987; 44: 11–12.
65. Oomura M, Terai T, Yamawaki T, et al. [A case of anterior cerebral artery dissection causing enlargement of infarction]. *Rinsho Shinkeigaku* 2005; 45: 762–765.
66. Pryse-Phillips W. Infarction of the medulla and cervical cord after fitness exercises. *Stroke* 1989; 20: 292–294.
67. Woll MM, Goff JM Jr. Gillespie DL and Minken SL. Bilateral spontaneous dissection of the internal carotid arteries – a case report. *Vasc Surg* 2001; 35: 221–224.
68. Lu A, Shen P, Lee P, et al. CrossFit-related cervical internal carotid artery dissection. *Emerg Radiol* 2015; 22: 449–452.
69. Berrouschot J, Bormann A, Routsi D, et al. [Sports-related carotid artery dissection]. *Fortschr Neurol Psychiatr* 2009; 77: 528–531.
70. Newton KI, Mallon WK and Henderson SO. Nontraumatic intracranial internal carotid artery dissection: a case report. *J Emerg Med* 1997; 15: 19–22.
71. Barrea C, Vigouroux T, Karam J, et al. Horner syndrome in children: a clinical condition with serious underlying disease. *Neuropediatrics* 2016; 47: 268–272.
72. De Giorgio F, Vetrugno G, De Mercurio D, et al. 1. Dissection of the vertebral artery during a basketball game: a case report. *Med Sci Law* 2004; 44: 80–86.
73. Fukunaga N, Hanaoka M and Sato K. Asymptomatic common carotid artery dissection caused by blunt injury. *Emerg Med J* 2011; 28: 50.
74. Kageyama H, Yoshimura S, Iida T, et al. Juvenile cerebral infarction caused by bow hunter's syndrome during sport: two case reports. *Neurol Med Chir* 2016; 56: 580–583.
75. Mas Rodriguez MF, Berrios RA and Ramos E. Spontaneous bilateral vertebral artery dissection during a basketball game: a case report. *Sports Health* 2016; 8: 53–56.
76. Ushida M, Fukuda K, Endo S, et al. [Cerebellar infarction due to vertebral artery dissection in a girl]. *No To Hattatsu* 1998; 30: 535–541.
77. Brosch JR and Golomb MR. American childhood football as a possible risk factor for cerebral infarction. *J Child Neurol* 2011; 26: 1493–1498.
78. Carr S, Troop B, Hurley J, et al. Blunt-trauma carotid artery injury: mild symptoms may disguise serious trouble. *Phys Sportsmed* 1996; 24: 48–54.
79. Garg BP, Ottinger CJ, Smith RR, et al. Strokes in children due to vertebral artery trauma. *Neurology* 1993; 43: 2555–2558.
80. McCrory P. Vertebral artery dissection causing stroke in sport. *J Clin Neurosci* 2000; 7: 298–300.
81. Schneider RC. Serious and fatal neurosurgical football injuries. *Clin Neurosurg* 1964; 12: 226–236.

82. Schneider RC, Gosch HH, Norrell H, et al. Vascular insufficiency and differential distortion of brain and cord caused by cervicomedullary football injuries. *J Neurosurg* 1970; 33: 363–375.
83. Abe A, Nishiyama Y, Kamiyama H, et al. Symptomatic middle cerebral artery dissection in a young tennis player. *J Nippon Med Sch* 2009; 76: 209–211.
84. Gabriel M, Gozdz T, Zielonka D, et al. [Vertebral arteries dissection as a rare cause of central nervous system ischemia]. *Przegl Lek* 2008; 65: 157–159.
85. Giroud M, Chague F, Guard O, et al. [Ischemic cerebrovascular accident and sport activity. 6 cases]. *Rev Med Intern* 1987; 8: 373–378.
86. Hilton-Jones D and Warlow CP. Non-penetrating arterial trauma and cerebral infarction in the young. *Lancet* 1985; 1: 1435–1438.
87. Josien E. Extracranial vertebral artery dissection: nine cases. *J Neurol* 1992; 239: 327–330.
88. Leys D, Lesoin F, Pruvo JP, et al. Bilateral spontaneous dissection of extracranial vertebral arteries. *J Neurol* 1987; 234: 237–240.
89. Roualdes G, Lartigue C, Boudigue MD, et al. [Dissection of the extracranial vertebral artery after a tennis match]. *Presse Med* 1985; 14: 2108.
90. Jorger G and Thielemann F. [Traumatic vertebral artery dissection in an 8 year old boy]. *Unfallchirurg* 2004; 107: 803–806.
91. Motohashi O, Kameyama M, Kon H, et al. [A case of vertebral artery occlusion following heading play in soccer]. *No Shinkei Geka* 2003; 31: 431–434.
92. Reess J, Pfandl S, Pfeifer T, et al. [Traumatic occlusion of the internal carotid artery as an injury sequela of soccer]. *Sportverletz Sportschaden* 1993; 7: 88–89.
93. Tascilar N, Ozen B, Acikgoz M, Ekem S, Aciman E and Gul S. Traumatic internal carotid artery dissection associated with playing soccer: a case report. *Ulus Travma Acil Cerrahi Derg* 2011; 17: 371–373.
94. Tekin S, Aykut-Bingol C and Aktan S. Case of intracranial vertebral artery dissection in young age. *Pediatr Neurol* 1997; 16: 67–70.
95. Goldstein SJ. Dissecting hematoma of the cervical vertebral artery. Case report. *J Neurosurg* 1982; 56: 451–454.
96. Katirji MB, Reinmuth OM and Latchaw RE. Stroke due to vertebral artery injury. *Arch Neurol* 1985; 42: 242–248.
97. Schievink WI, Atkinson JL, Bartleson JD, et al. Traumatic internal carotid artery dissections caused by blunt softball injuries. *Am J Emerg Med* 1998; 16: 179–182.
98. Benedict WJ, Prabhu V, Viola M, et al. Carotid artery pseudoaneurysm resulting from an injury to the neck by a fouled baseball. *J Neurol Sci* 2007; 256: 94–99.
99. Bremerich J, Kirsch E and Muller-Brand J. Cerebral infarction due to traumatic internal carotid artery dissection. *Clin Nucl Med* 1997; 22: 782–784.
100. Hinse P, Thie A and Lachenmayer L. Dissection of the extracranial vertebral artery: report of four cases and review of the literature. *J Neurol Neurosurg Psychiatry* 1991; 54: 863–869.
101. Li MS, Smith BM, Espinosa J, et al. Nonpenetrating trauma to the carotid artery: seven cases and a literature review. *J Trauma* 1994; 36: 265–272.
102. Stampfel G. [Winter sport injuries to the carotid artery]. *Radiologe* 1983; 23: 426–430.
103. Kalantzis G, Georgalas I, Chang BY, et al. An unusual case of traumatic internal carotid artery dissection during snowboarding. *J Sports Sci Med* 2014; 13: 451–453.
104. Yamakawa H, Niikawa S, Sakai H, et al. Vertebrobasilar occlusion following snowboarding: a case report and review. *Injury* 2002; 33: 182–185.
105. Wechsler B, Kim H and Hunter J. Trampolines, children, and strokes. *Am J Phys Med Rehabil* 2001; 80: 608–613.
106. De Broucker T, Amazan C, Forys E, et al. [Dissection of a vertebral artery during gymnastics]. *Presse Med* 1990; 19: 176.
107. Hsu KC, Kao HW and Chen SJ. Backward somersault as a cause of childhood stroke: a case report of isolated middle cerebral artery dissection in an adolescent boy. *Am J Emerg Med* 2008; 26: 519 e3–e5.
108. Cawood TJ, Dyker AG and Adams FG. Vertebral artery dissection diagnosed by non-invasive magnetic resonance imaging. *Scott Med J* 2000; 45: 119–120.
109. Lanczik O, Szabo K, Gass A, et al. Tinnitus after cycling. *Lancet* 2003; 362: 292.
110. Lee WW and Jensen ER. Bilateral internal carotid artery dissection due to trivial trauma. *J Emerg Med* 2000; 19: 35–41.
111. Singhi P, Khandelwal NK, Mahajan V, et al. Stroke following a bicycle injury. *Indian J Pediatr* 2007; 74: 856–858.
112. Davies SR. A rare complication of a unilateral vertebral artery occlusion, which resulted in a basilar emboli after a C5-C6 bifacet dislocation in a professional rugby player: case study. *Spine J* 2011; 11: e1–e4.
113. Miyata M, Yamasaki S, Hirayama A, et al. [Traumatic middle cerebral artery occlusion]. *No Shinkei Geka* 1994; 22: 253–257.
114. Palmer SH, Emery D and Paterson M. Stroke following neck injury in a rugby player. *Injury* 1995; 26: 555–556.
115. Zhou W, Huynh TT, Kougias P, et al. Traumatic carotid artery dissection caused by bungee jumping. *J Vasc Surg* 2007; 46: 1044–1046.
116. Abbo M, Hussain K and Ali MB. Blunt traumatic internal carotid artery dissection with delayed stroke in a young skydiver. *BMJ Case Rep* 2013; 2013: pii: bcr2012008412.
117. Sparing R, Hesse MD and Schiefer J. [Traumatic internal carotid artery dissection associated with triathlon: a rare differential diagnosis]. *Sportverletz Sportschaden* 2005; 19: 211–213.
118. Hanus SH, Homer TD and Harter DH. Vertebral artery occlusion complicating yoga exercises. *Arch Neurol* 1977; 34: 574–575.
119. Nagler W. Vertebral artery obstruction by hyperextension of the neck: report of three cases. *Arch Phys Med Rehabil* 1973; 54: 237–240.

120. Valle-Alonso J, Rudski-Ricondo L, Fonseca J, et al. [Thalamic stroke secondary to vertebral dissection after doing yoga]. *Rev Neurol* 2016; 62: 286–287.
121. Fletcher J, Davies PT, Lewis T, et al. Traumatic carotid and vertebral artery dissection in a professional jockey: a cautionary tale. *Br J Sports Med* 1995; 29: 143–144.
122. Keilani ZM, Berne JD and Agko M. Bilateral internal carotid and vertebral artery dissection after a horse-riding injury. *J Vasc Surg* 2010; 52: 1052–1057.
123. Traer EJ, Loganathan T, Sinha DM, et al. Fell off of a horse – journey from emergency department to stroke clinic. *BMJ Case Rep* 2010; 2010. doi:10.1136/bcr.03.2010.2819.
124. Proscholdt F, Heining S, Powerski M, et al. Traumatic dissection of four brain-supplying arteries without neurologic deficit. *Global Spine J* 2014; 4: 187–190.
125. Ganesan V and Kirkham FJ. Carotid dissection causing stroke in a child with migraine. *BMJ* 1997; 314: 291–292.
126. Gass A, Szabo K, Lanczik O, et al. Magnetic resonance imaging assessment of carotid artery dissection. *Cerebrovasc Dis* 2002; 13: 70–73.
127. Karnik R, Rothmund T, Bonner G, et al. Inline skating as a possible cause of consecutive bilateral vertebral artery dissection. *Acta Neurol Scand* 2000; 101: 70–71.
128. DeBehnke DJ and Brady W. Vertebral artery dissection due to minor neck trauma. *J Emerg Med* 1994; 12: 27–31.
129. Slankamenac P, Jesic A, Avramov P, et al. Multiple cervical artery dissection in a volleyball player. *Arch Neurol* 2010; 67: 1024.
130. Arnold M, Kappeler L, Georgiadis D, et al. Gender differences in spontaneous cervical artery dissection. *Neurology* 2006; 67: 1050–1052.
131. Metso AJ, Metso TM, Debette S, et al. Gender and cervical artery dissection. *Eur J Neurol* 2012; 19: 594–602.
132. The Scottish Health Survey 2014. In: The Scottish Government (ed) The Scottish Government, 2015. http://www.gov.scot/Publications/2015/09/6648/318786.
133. Touze E, Gauvrit JY, Moulin T, et al. Risk of stroke and recurrent dissection after a cervical artery dissection: a multicenter study. *Neurology* 2003; 61: 1347–1351.
134. Changes in U.S. Family Finances from 2010 to 2013: Evidence from the Survey of Consumer Finances, Federal Reserve Bulletin, Board of Governors of the Federal Reserve System, September 2014, Vol 100, No 4. https://www.federalreserve.gov/pubs/bulletin/2014/pdf/scf14.pdf Table 2.
135. Kolt GS, Driver RP and Giles LC. Why older Australians participate in exercise and sport. *J Aging Phys Act* 2004; 12: 185–198.
136. Metso TM, Debette S, Grond-Ginsbach C, et al. Age-dependent differences in cervical artery dissection. *J Neurol* 2012; 259: 2202–2210.
137. Giossi A, Ritelli M, Costa P, et al. Connective tissue anomalies in patients with spontaneous cervical artery dissection. *Neurology* 2014; 83: 2032–2037.
138. Debette S, Goeggel Simonetti B, Schilling S, et al. Familial occurrence and heritable connective tissue disorders in cervical artery dissection. *Neurology* 2014; 83: 2023–2031.
139. De Giuli V, Grassi M, Lodigiani C, et al. Association between migraine and cervical artery dissection: the Italian project on stroke in young adults. *JAMA Neurol* 2017; 74: 512–518.
140. Giossi A, Mardighian D, Caria F, et al. Arterial tortuosity in patients with spontaneous cervical artery dissection. *Neuroradiology* 2017; 59: 571–575.
141. Kim BJ, Yang E, Kim NY, et al. Vascular tortuosity may be associated with cervical artery dissection. *Stroke* 2016; 47: 2548–2552.
142. Saba L, Argiolas GM, Sumer S, et al. Association between internal carotid artery dissection and arterial tortuosity. *Neuroradiology* 2015; 57: 149–153.