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ORIGINAL ARTICLE

Sternal foramina: incidence in Greek population, anatomy and clinical considerations

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Abstract

Purpose Sternal foramina represent developmental defects in the sternum, which occur due to incomplete fusion of the sternal ossification centers. Sternal foramina have been correlated with several clinical implications and constitute a subject of interest for the forensic practice. The aim of this study is to define their incidence in Greek population.

Methods The presence of midline foramen was studied in 60 dried, adult sterna derived from the Anatomy Department of Medical School of Aristotle University of Thessaloniki. Measurements were made with a 0.01-mm accuracy caliber and photographic documentation was obtained. Additionally, computed tomography scanning of the sterna was performed.

Results Sternal foramina were found in 11 subjects, resulting in an incidence of 18.3 % over the total population. In 27.3 % of the subjects with sternal foramen, a single sternal foramen was observed in the body of the sternum, while in 45.5 % of the sterna presenting sternal foramina, multiple xiphoidal foramina were noticed. In two specimens, association of xiphoidal foramina with sternal cleft was documented.

Conclusion Sternal foramina are variant quite common in the population, with distinct imaging pattern and awareness of their existence is important for the physician.

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Introduction

Sternal foramina (SF) constitute congenital midline defects in sternum, caused by incomplete fusion of the multiple sternal ossification centers. Presence of SF was firstly documented in the 17th century. Riolanus (1649) reported that the first description of SF located at the sternal body was made by Massa, while Eustachius (1707) also noted the existence of the anomaly [3].

SF have been observed in the manubrium, body and xiphoid process, however, they appear mainly in the inferior part of the sternum. SF incidence in the literature ranges from 3.1 to 27.4 %, while the presence of xiphoidal SF has been reported up to 47.7 % [1–3, 5, 7, 9, 12, 15, 16, 18, 23, 24, 26, 28, 29]. Their presence varies among different populations, while no study has been documented describing SF incidence in Greek population. SF appearance is correlated with clinical and forensic implications, jeopardizing the radiologic evaluation of sternal pathology, sternal puncture and investigation of skeletal remains. The aim of this study is to evaluate the incidence of SF appearance in Greek population, compare results with other populations and discuss the importance of awareness concerning their existence and topography.

Material and methods

The study was conducted on 60 adult human dried sterna, collected from the Laboratory of Anatomy, Faculty of Health Sciences, School of Medicine, Aristotle University of Thessaloniki. 33 sterna belonged to male adults, while 27 to female. Age of donors ranged between 69 and 85 years old, with a mean age of 76 years. The bones were examined for the presence of SF and photographic documentation was obtained. Measurements of the SF were also obtained using a metric electronic digital caliper (Mitutoyo Co., Japan) with an accuracy of 0.01 mm.

Additionally, radiologic evaluation of the sterna was performed, including computed tomography (CT) scan, with a multislice spiral CT scanner and axial slice thickness of 3 mm, along with coronal and sagittal reconstruction to study the bone's anatomy and imaging.

Results

SF were encountered in 11 subjects studied, resulting in an incidence of 18.3 % over the total population. Six sterna with SF belonged to male subjects; thus, 18.2 % of males and 18.5 % of females presented SF. The age of donors ranged between 70 and 84 years old (mean age: 77 years old). The topography and measurements of the 11 sterna are summarized in Table 1. None of the subjects presented SF in the manubrium, while three showed one SF in the sternal body (Fig. 1a). Thus, in 27.3 % of the SF subjects and 5 % of total cases studied that one single SF was noted in the sternal body. The rest of the subjects presented one or more xiphoidal SF. One xiphoidal SF was present in three (27.3 %) of the SF cases (Fig. 1b). Two, three or four xiphoidal SF were present in 18.2, 18.2 and 9.1 % of the total SF cases, respectively (Fig. 2a–c). In two cases, the xiphoidal SF were associated with sternal cleft (Fig. 3). In one case, a xiphoidal SF continued inferiorly with a cleft, giving the impression of a keyhole-shaped defect (Fig. 3a), while in another case, three distinct SF co-existed with a xiphoidal cleft (Fig. 3b).

CT evaluation showed a "bow-tie" defect at the level of SF in axial sections (Fig. 4a), while in sagittal reconstruction SF presented as defect in the continuity of sternum (Fig. 4b). In coronal reconstruction, SF were shown as oval or circular defects, presenting mild to severe surrounding sclerosis; however, due to the anterior bowing of the bones, the whole sternum was not visualized in one single section (Fig. 4b). SF smaller in diameter that 1.1 mm (specimens 7, 9, 11) were not visualized, as the slice thickness used was 3 mm. It is interesting that in case of SF smaller than 1.1 mm in diameter, a more hyperdense area of sclerotic bone was observed at the known SF position in coronal reconstruction.

Table 1 Topography and measurements of the sternal foramina (SF) documented in the present study

No.	Gender	Age	Number of SF	Location		Measurements (transverse × vertical) in mm
1	M	70	One	Sternal body (3rd intercostal segment)		2.1 × 4.5
2	F	80	One	Xiphoid process		3.2 × 2.3
3	M	73	Three	Xiphoid process	Right	5.3 × 5.3
					midline fissure	2.9 × 16.7
					Left	3.7 × 3.5
4	M	78	One	Sternal body (5th intercostal segment)		3.7 × 3.3
5	F	81	One	Xiphoid process		5.6 × 4.8
6	F	84	Four	Xiphoid process (midline)	1st	8.6 × 12.3
					2nd	2.8 × 2.7
					3rd	2.8 × 3.9
					4th	2.6 × 3.8
7	F	79	Two	Xiphoid process	Upper	2.7 × 2.1
					Lower	0.9 × 1.1
8	M	83	One	Sternal body (4th intercostal segment)		6.1 × 5.5
9	M	77	Two	Xiphoid process	Right	0.9 × 1
					Left	2.1 × 2
10	M	71	One	Xiphoid process - with associated sternal cleft		4.7 × 6.5
11	F	73	Three	Xiphoid process	Right upper	1 × 1.1
				- with associated sternal cleft	Right lower	4.2 × 3.3
					Left	1.9 × 2.8

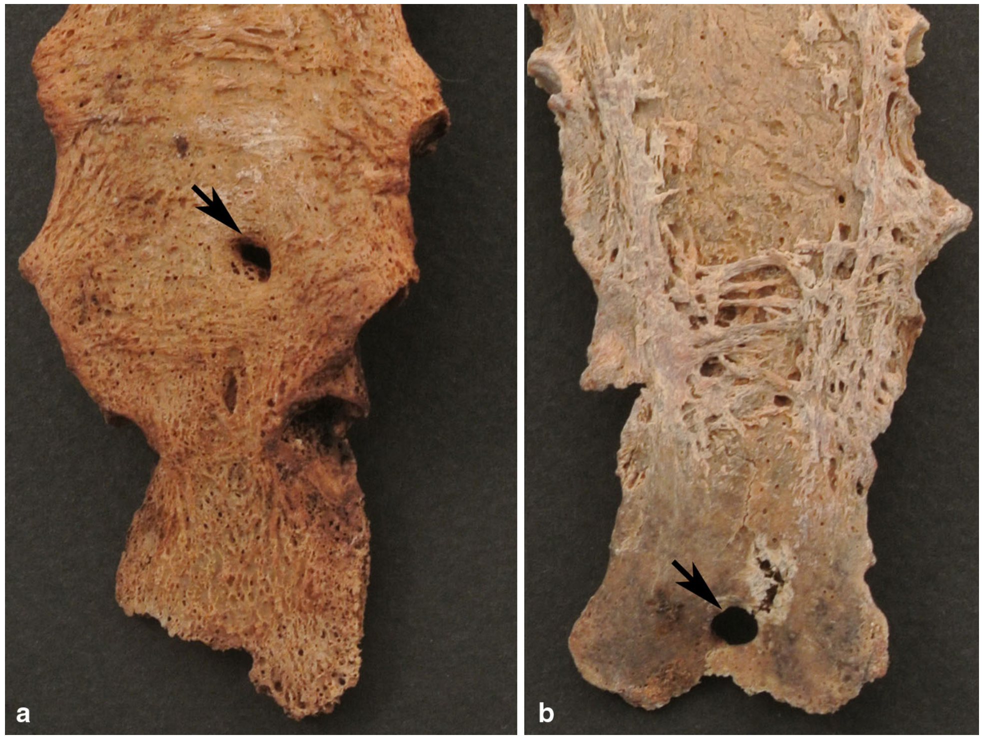

Fig. 1 **a** Sternal body foramina, located at the 5th intercostal segment. **b** Presence of a single xiphoidal foramen

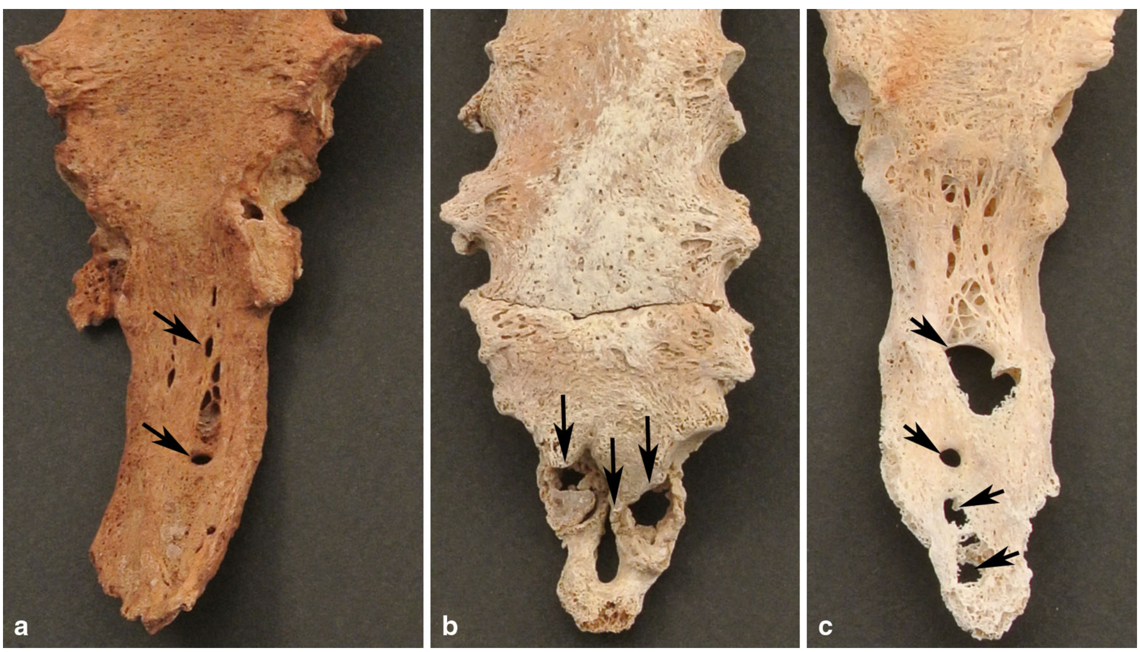

Fig. 2 Multiple xiphoidal foramina. **a** Two, **b** three and **c** four xiphoidal foramina

Discussion

Embryology, anatomy and epidemiology

Sternal foramina represent oval or circular developmental defects in sternum and constitute unrare anatomical variants. Sternum is formed by the fusion of two sternal bars, which constitute longitudinal mesenchymal tissue bands located originally, laterally to the anterior chest wall. The sternal bars migrate to the midline and fuse, after the instant attachment of the ribs to form the sternal plate. After chondrification, the manubrium, several body segments (sternebrae) and the xiphoid process appear. The manubrium ossification center is formed between the 3rd and 6th intrauterine months, while the usually paired ossification centers of the sternal body appear in a craniocaudal sequence within the first year of life and fuse during the first two or three decades. One or two ossification centers appear in the xiphoid process during the first decade of life [18, 20].

SF incidence presents great variability in different studies and populations, while literature data of SF incidence are documented in Table 2. In the literature, SF incidence ranges between 3.2 and 13.8 % in studies using dried sterna [2, 3, 9, 24], whereas in the current study, the SF's presence of in Greek population was found 18.3 %. Moreover, in approximately half of the cases studied, the SF was single, while in the rest, more than one SF was present. The existence of multiple xiphoidal SF has been noted in 1.2–9 % of the total population [1, 9, 29] by various authors and in 8.3 % in the present study. Multiple SF located at the sternal body have been documented in the literature [7, 13, 17], while presence of SF in the manubrium has also been noted [5, 7]. However, in our study, such cases were not observed.

Location of the SF may vary (Table 2). In 77.8 % of the SF present at the sternal body, the defects were encountered at the 5th intercostal segment [9], while in the present study, the SF of the sternal body were located between the 3rd and 5th intercostal segments (Table 1). Most studies indicate a higher prevalence of SF in the xiphoid process; a finding that is in accordance to the current study, in which one or more SF were noted in the xiphoid process in 72.7 % of the subjects with SF. However, some authors reported a greater incidence of SF in the sternal body [5, 9, 24]. The size of SF is also variable, ranging from 2 to 18 mm in the literature [12, 16, 29] and 0.9 to 16.7 mm in the present research. The largest SF detected in our study was 8.6 × 12.3 and situated at the xiphoid process, along with other three smaller foramina (Fig. 2b).

Although SF are usually solitary malformations, association with accessory fissures and supernumerary left lung lobules has been noted during high resolution CT evaluation [2]. Coexistence with sternal cleft is also reported [5, 22, 29] and seen in two of the presented cases too (Fig. 3). One specimen displayed a keyhole-shaped xiphoid sternal defect, presenting similarities with the case reported by Saccheri et al. [22]. Moreover, coexistence of SF and vertical sclerotic bands localized superiorly or inferiorly to the foramen was noted in 73 % of the multidetector computed tomography scans which revealed the presence of SF [29]. In the present study, CT scans showed mild to severe surrounding sclerosis at the SF location (Fig. 4c).

The morphology of the xiphoid process constitutes a subject of interest in anatomical research. In the literature, the presence of xiphoidal SF varies between 2.5 and 57.7 % (Table 2). Xie et al. [28] have suggested a classification of different types of xiphoidal morphology in relation to the SF existence. The authors, recommended four patterns: pattern L and pattern S include the presence of a single SF with diameter more than 5 mm and less than 5 mm, respectively, while pattern LS includes specimens which present a large and a small SF and pattern SS two or more small SF. They report an incidence of 55.5, 28.5, 9.2 and 6.8 % for L, S, LS and SS pattern, respectively. Thus, the aforementioned researchers detected a single xiphoidal SF in 84 % of the subjects studied. In the present study, one sternum may be included in L pattern, one in pattern S, two in pattern LS and two in pattern SS. However, there is no pattern for the cases in which the foramen co-existed with a cleft that is seen in our study (Fig. 3) and in the literature too [5, 22, 29]. We propose that an additional SF pattern could be added to Xie et al. classification, where the SF's presence is associated with a xiphoid process cleft.

Clinical and forensic impact

Presence of SF can lead to complications during sternal puncture, due to risk of injury to vital structures of the chest. After studying CT scans of 15 patients presenting SF of the sternal body, Gossner concluded that the directly adjacent structure to the SF was the lung in 53.3 % of the cases and the pericardium in 20 % [10]. Thus, accidental insertion of a needle through the SF may cause pneumothorax or pericardial tamponade in over 80 % of the cases. Moreover, if the needle is inserted deep enough, the pericardium, right ventricle or large thoracic vessels may be perforated [4, 10]. Indeed, injury to the pericardium has been mentioned during bone marrow aspiration and acupuncture, leading to fatal cardiac tamponade [6, 11]. Thus, in cases of sterna puncture, radiographic evaluation should be performed before intervening, while avoidance of the lower third of the sternal body is recommended [9, 14, 19]. In axial CT sections, SF is presented as a bow-tie [29] (Fig. 4a). At this point, however, it should be noted that SF smaller than the slice thickness used, may be overlooked. Ultrasonography may appear helpful in the visualization of sternal anomalies, whereas sternal bone marrow aspiration could be safely guided by CT [10].

During radiologic examination, SF could be misdiagnosed as osteolytic lesions or metastases. In scintigraphy and single photon emission tomography, SF may be shown as a distinct area of hypocaptation, resembling sternal pathology; furthermore, in case that a congenital defect is not suspected, the decision of diagnostic sternal biopsy could be proved hazardous [19]. Indeed, in Ishii et al. study, the existence of SF was proved with multidetector CT in 43.1 % of the patients presenting photopenic sternal

Table 2 Incidence of sternal foramina (SF) presence in literature

Authors	Year	Population	Specimen	Number of sterna studied	Presence of sternal foramina			
					Number of sterna presenting SF	Location	Incidence of SF over total population	
El-Busaid et al. [9]	2012	Kenyans	Dried sterna	80	9	Sternal body	11.3 %	13.8 %
					2	1 Xiphoidal	2.5 %	
						2 Xiphoidal		
Yekeler et al. [29]	2006	Turkish	MDCT	1000	45	Sternal body	4.5 %	
					246	1 Xiphoidal	24.6 %	27.4 %
					25	2 Xiphoidal	2.5 %	
					3	3 Xiphoidal	0. 3 %	
Aktan and Savaş [2]	1998	Turkish	HRCT	350	19	–	5.4 %	5.1 %
			Dried sterna	62	2	Sternal body	3.2 %	
Stark [26]	1985	USA	CT	140	6	Sternal body (lower third)	4.3 %	
Schratter et al. [23]	1997	Germans	CT	100	6	Sternal body	6 %	
Ashley [3]	1956	East Africans	Dried sterna	98	13	–	13.3 %	
		Europeans	Dried sterna	573	23	–	4 %	
Ishii et al. [12]	2012	Japanese	MDCT	1053	33	Lower sternum	3.1 %	
Bayaroğulları et al. [5]	2013	Turkish	MDCT	250	14	Sternal body	5.6 %	6 %
					1	Manubrium	0.4 %	
Moore et al. [18]	1988	Total	X-rays (cadavers)	2016	135	–	6.7 %	
Cooperet al [7]		White[a]		1286	75		5.8 %	
		Black[a]		507	47		9.3 %	
		Hispanic[a]		216	13		6 %	
		Oriental[a]		6	0		0 %	
		Amerind[a]		1	0		0 %	
		[a]As reported in their study						
McCormick [16]	1981	USA	X-rays (cadavers)	324	25	Sternal body (lower third)	7.7 %	
Shivakumar et al. [24]	2013	Indian	dried sterna	86	6	Body	7 %	
					3	Xiphoidal	3.5 %	
Macaluso et al. [15]	2014	Spanish	X-rays (cadavers)	122	4	Sternal body (lower third)	3.3 %	
						In one specimen, two SF were observed.		
Akin et al. [1] [a]	2011	Turkish	MDCT	500	171	1 Xiphoidal	34.2 %	43.2 %
					31	2 Xiphoidal	6.2 %	
					7	3 Xiphoidal	1.4 %	
					7	4+ Xiphoidal	1.4 %	
Xie et al. [28] [a]	2014	Korean	Cadaveric	41	23	Xiphoidal	56.1 %	57.7 %
			MDCT	902	521		57.8 %	
Present Study	2015	Greek	Dried sterna	60	3	Sternal body	5 %	18.3 %
					3	1 Xiphoidal	5 %	
					2	2 Xiphoidal	3.3 %	
					2	3 Xiphoidal	3.3 %	
					1	4 Xiphoidal	1.7 %	

MDCT multi-detector computed tomography, *HRCT* high resolution computed tomography

[a] In these studies, only the xiphoid process was studied

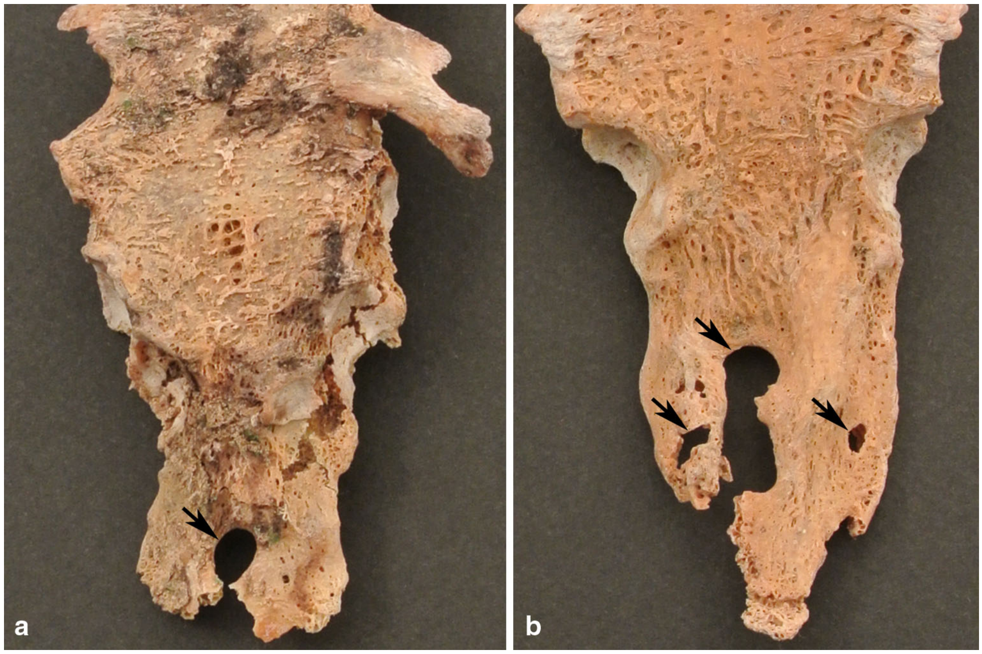

Fig. 3 **a** Keyhole-shaped xiphoidal foramen associated with sternal cleft. **b** A dried sacrum presenting a midline cleft and three smaller foramina

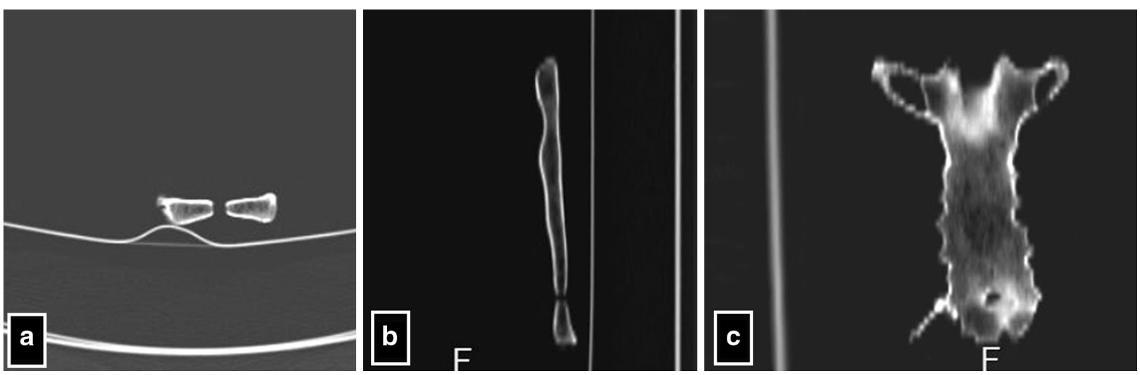

Fig. 4 Computed tomography scanning of the sterna presenting SF at the SF level. **a** Axial section showing "bow-tie" formation, **b** sagittal and **c** coronal reconstruction showing the SF as a defect

defect during bone scintigraphy [12]. It is interesting, however, that 24 % of the patients with SF had normal sternal scintigraphic results. The authors noted that all cases of SF larger than 5 mm presented with photopenic area, while photopenia could also exist in cases of thin middle portion of sternal bone marrow [12].

Presence of SF is also essential in forensic medicine and anthropology. A sternal defect may erroneously suggest the existence of traumatic or osteolytic lesion. During analysis of skeletal remains, SF may be misinterpreted as a bullet entry point or a traumatic penetrating lesion misleading the investigation of cause of death [7, 26]. Round or oval-shaped defects with smooth edges could indicate SF [15]. On the other hand, a known sternal variant may assist in the individualization of the skeletal remains. Antemortem radiographic data included in the victim's medical records may constitute a clue for directed investigation and identification of the victim [16, 25]. Confusing similarities, however, have been documented among the same family's members [8].

Conclusions

SF constitute unrare variants of the human bones and awareness of their existence is important for the radiologist, clinician and anthropologist. In the present study, the incidence of SF was found 18.3 % in Greek population, leading to the conclusion that their presence should be taken under consideration in everyday practice. CT scanning could be useful, even though small SF may not be visualized. Furthermore, it should be noted that if found incidentally, SF should be noted in patient's records, to avoid potential clinical and forensic malpractice.

Conflict of interest The authors declare that they have no conflict of interest.

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