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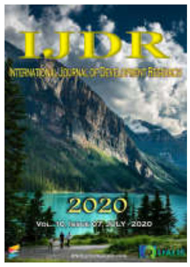

RESEARCH ARTICLE **OPEN ACCESS**

PARAMETERS OF SAGITTAL AND SPINOPELVIC ALIGNMENT IN YOUNG ADULT, ADULT AND ELDERLY ASYMPTOMATIC: A RADIOGRAPHIC ANALYSIS

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ABSTRACT

Background: Adult spinal deformity (ASD) has been reported to be as high as 60% in the elderly population, however, few studies have evaluated these normality parameters and pathologic alignment and the findings have not yet been established, especially among Brazilians. **Objective:** Verify the sagittal and spinopelvic balance parameters between young adults, adults and the elderly of the Brazilian and their influence on gender. **Methods**: This study investigated 167 asymptomatic individuals from Brazilians sample. Eight radiographic parameters were measured: sagittal vertical axis (SVA), sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI), spinopelvic inclination - T1 (SPI-T1), thoracic kyphosis (TK), lumbar lordosis (LL), and the PI minus the LL (PI - LL). **Results:** The mean of the radiographic parameters were: SVA (-11.77mm); SS (33.05°); PT (13.77°); PI (46.93°); LL (54.53°); TK (40.54°) and T1 (SPi-T1) was -5.74°. We observed that women presented a lower SVA, higher SS and LL and larger negative SPi-T1. We also observed that individuals older than 60 years had higher mean SVA, PT and SPi-T1. **Conclusion**: Full length, free-standing spine radiographs were obtained in 167 asymptomatic individuals in a sample of Brazilians. Standard values and deviations of spino-pelvic sagittal alignment were established according to gender and age from 18 'to 60'. The remarkable change of spino-pelvic sagittal alignment was verified, such as the decrease of SVA, higher SS and LL and larger negative T1-SPiSPi-T1 in young adult and adult women, while that the elderly than 60 years have had higher values of the SVA, PT, and T1-SPiSPi-T1.

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INTRODUCTION

The symmetrical posture results in harmony and balance in the forces distribution between the segments of the spine and pelvis during static and dynamic position (Arima, 2017). For this, the spine exhibits lordosis in the cervical and lumbar regions and kyphosis in the thoracic region, in which the muscles contribute to the stability, balance and joint motion between upper body segments and lower limbs (Shah, 2019). When this pattern is changed the spine deformities appear, especially in children, adolescents (Mac-Thiong, 2004; Vedantam, 1998), adults (Yukawa, 2018) and the elderly (Yukawa, 2018 and Hammerberg, 2003), in the latter with a high prevalence, reaching up to 60% of the population (Yukawa, 2018). Spinal deformities range from adolescent idiopathic scoliosis to vertebral fracture, intervertebral disc degeneration, and spinal muscle dysfunction with advancing age, which may result in pain symptoms, functional disorders of the lower limbs, and gait changes (Bartynski, 2005; Mardare, 2016; Haimoto, 2018 and Yagi, 2017). Spine deformities can occur in both the sagittal and coronal planes. The coronal deformities, providing surgeons with a common language for discussing pathology, treatment, and clinical results (Mac-Thiong, 2004; Duval-Beaupere, 1992 and Legaye, 1998). In contrast, the sagittal alignment of the spine is not as well understood, especially with regard to normal and pathologic curvatures (Van Royen, 1998). This is unfortunate, since the majority of degenerative disease occurs in spines that are well aligned in the coronal plane but exhibit highly variable morphology in the sagittal plane. The comprehensive of variations in the sagittal morphology of the spine, such as orientation of the pelvis has not well understood. Recent research reveals that spino-pelvic alignment of spinal deformities plays an important role in pain symptoms, physical disabilities, poor qualityoflife(Mac-Thiong2004; Berthonnaud, 2005 and Legaye, 1998), and is a determining factor for surgical correction treatment, being the main outcome clinical parameter after surgical procedure (Berthonnaud, 2005). A stable spine with minimal energy expenditure is the result of the alignment between its segments and the pelvis along the sagittal plane. In addition, studies of radiographic and clinical parameters have reported that the orientation and shape of the pelvis play significant roles in the balance of this plane.

The spinopelvic radiographic parameters, which include the sacral slope (SS), pelvic tilt (PT), and pelvic incidence (PI), were introduced by Legaye *et al.,* (1998) to help describe pelvic morphology and orientation. That same study emphasized the importance of the PI in the sagittal alignment of the spine because it ensures an economic equilibrium in terms of energy. Abnormal sagittal alignment negatively affects patients' clinical conditions because it leads to increases in biomechanical and energy demand to compensate for the imbalance generated. The major causes for a loss of sagittal balance are degenerative diseases, inadequate lumbar spine fixation, post-traumatic deformity and ankylosing spondylitis. With the progression of degenerative changes, the compensatory capacity of the trunk is exceeded, causing pain, fatigue, and even functional disability (Vedantam, 1998 and Van Royen, 1998). Recent study (Yukawa, 2018), conducted in 2018, with 626 asymptomatic volunteers from Japanese population showed that the advancing age can cause increase: cervical lordosis (C3–C7), pelvic tiltand sagittal vertical axis and decrease: lumbar lordosis (T12–S1) and sacral slope (Yukawa, 2018). Second authors, the 7th decade to 8th decade, promoted the decrease of thoracic kyphosis (T12–S1) and lumbar lordosis (T12–S1), as well as the increase of pelvic tilt (Yukawa, 2018). Other study, (Vialle, 2005) showed moderate to high correlations between the angular radiographic parameters, such as sacral slope versus pelvic incidence, maximum lumbar lordosis versus sacral slope, pelvic incidence versus pelvic tilt, maximum lumbar lordosis versus pelvic incidence, among others. For the authors, theses correlations may also be useful in calculating the corrections to be obtained during treatment.[15]According to Lee *et al.,*[16] evaluating 86 Korean volunteers, they concluded that the sagittal alignment could be classified into three types, with base on spinal balance (more negative), increase of thelumbar inclination and thoracolumbar angle and decrease of the sacral slope and pelvic incidence, this can be considered in young adults, as a reference for surgeons in degenerative lumbar fusion surgery. According to Kim *et al.,* (2003) the sagittal spinal balance is maintained by spinopelvic compensations over the hip axis with aging.
Based on the studies explained on normative parameters directed to samples and / or populations of Korean, Chinese and Argentine (Lee, 2011 and Kim, 2003) and new analyses are also being conducted in other populations, such as those from Argentina and China (Guiroy, 2018; Zhu, 2014) and none directed to samples of Brazilian individuals using a large cohort with an even age (young adult, adult and elderly) and gender distribution. Thus, the objective of study was to evaluate and describe the sagittal and spinopelvic balance parameters between young adults, adults and the elderly of the asymptomatic and healthy sample of Brazilians individuals. In addition, this study also has as purpose establishes a relationship between these parameters with the age and gender, as well as compares these results with those of other studies of other population groups.

MATERIALS AND METHODS

Study Design and Participants: This study wascross-sectional and observational. A total of 167 adult asymptomatic volunteers (with an average of 4.8 years of both sexes and aged 18 to 82 years, participated in this study. The recruitment was conducted through of the Public Hospital in the State of Sao Paulo/SP, Brazil, between January 2014 and June 2017. The experimental procedure was reviewed and approved by the Departmental Research Committee of the Institute of Medical Assistance to the State Public Hospital Servant – IMASPS (registration number: 533.756),in accordance with relevant guidelines and regulations. All participants provided their informed consent underwent radiographic assessment. The eligibility criteria of the adult asymptomatic volunteers were as follows: the participant's four grandparents must have been born in Brazil[20], no history of deformity or pathology of the spine, hip, pelvis, or lower limbs and no other musculoskeletal disorders, such as neuropathies, obesity and rheumatoid arthritis, such as absence back pain for more than 3 consecutive months. In addition, they could not have prostheses and/or orthoses in the lower limbs, i.e., they must maintaina good general health status), so as not to generate bias in the interpretation of pace evaluations.

Spine Measurements: Panoramic X-ray examinations: Full length, free-standing spine radiographs with fists on clavicles were obtained in all subjects and measured by experienced radiation technologists (Yukawa, 2018). The radiograph were centered on T12 during inspiration, with a 2-meter distance between the film and the focus (Yukawa, 2018 and Lafage, 2015). All images were transferred to a computer as digital image and evaluated using image software - Surgimap Spine (Nemaris Inc., New York, USA) (Lafage, 2015). Eight sagittal alignment and spinopelvic alignment parameters were analyzed on the radiographs of the 167 participants: sagittal vertical axis (SVA), sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI), spinopelvic inclination - T1 (SPI - T1), thoracic kyphosis (TK), lumbar lordosis (LL), and the PI minus the LL (PI - LL). The SVA was measured in millimeters as the distance from a line perpendicular to the C7 plumb line to the posterior edge of the upper endplate of S1. SS was defined as the angle formed by the upper endplate of S1 and the horizontal plane. PT was defined as the angle between the vertical plane and the straight line of the union between the femoral heads and the midpoint of the upper endplate of S1. PI was defined as the angle between a line extending from the midpoint of the hip to the center of the S1 endplate and a line perpendicular to it. TK was measured as the angle between the upper endplate of T5 and the lower endplate of T12. LL was measured using the angle formed between the upper endplate of L1 and S1, and SPI - T1 was measured as shown in Figs. 1 and 2. A total of 80 randomly selected radiographs of both men and women across different age groups were analyzed by a second evaluator to calculate the interclass correlation coefficient of the method.

Figure 1. The sagittal vertical axis, which corresponds to the plumb line in the sagittal plane, is measured as the distance between the line originating at the midpoint of the C7 body and the posterosuperior corner of the sacrum

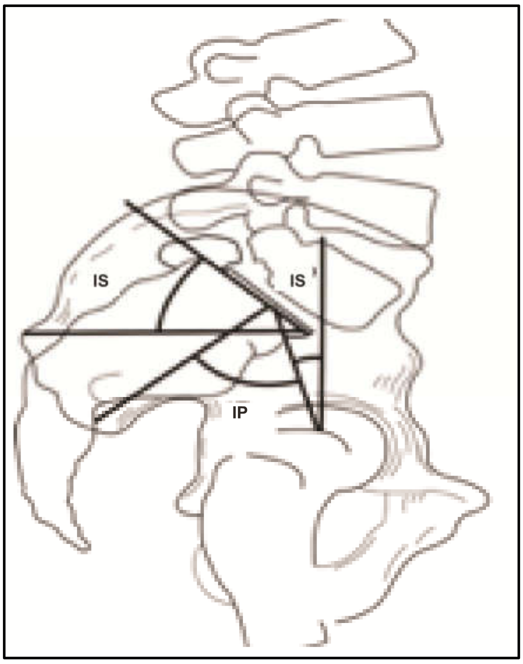

Figure 2. Illustration of the measurement of the pelvic incidence (PI), pelvic tilt (PT), and sacral slope (SS) angles

Statistical Analysis

The data were analyzed using SPSS version 20.0 (SPSS Inc., Chicago, IL). Calculations for the samples size of 167 runners was conducted based on the spinopelvic inclination variable using the Bioinstat software. A moderate effect size (F=0.25), an 80% power, and a 5% significance level were used in the calculation. The baseline characteristics of participants were described as means and standard deviations. The means of the radiographic measurements were compared between the genders using Student's t-test. An analysis of variance (ANOVA) was used to compare the interaction effect of the different age groups. Pairwise comparisons were conducted if necessary. The results were compared with the means and standard deviations described in other populations using Student's t-tests. A significance level of 5% for two-tailed tests was considered as significant.

RESULTS

Of the 167 volunteers analyzed, 62 were men, and 105 were women. The mean age of the volunteers was 42.8 years (range 18 – 82). The mean age of the men was 42.3 years old, and the mean age of the women was 43.1 years old. The inter-observer reliability was high for seven parameters: 0.901, 0.899, 0.909, 0.933, 0.951, 0.956, and 0.958 for SS, PT, PI, TK, LL, SPI - T1, and PI-LL, respectively. The measurements were considered as acceptable.

Table 1. Description of the radiographic measurements for all evaluated individuals

Variable	Mean ± SD
SVA	-11.7 mm ± 31.4 mm
PT	13.77° ± 9.04°
PI	46.93° ± 11.90°
SS	33.05° ± 7.35°
LL	54.53° ± 10.20°
PI - LL	-6.98° ± 12.27°
TK	40.54° ± 10.16°
T1-SPi	-5.47° ± 3.64°

Table 1 shows the means and standard deviations found for the eight radiographic measurements for all participants, and Table 2 shows the same values separated by sex. The mean SVA was -11.77 mm ±31.36 mm, the mean SS was 33.05±7.35°, the mean PT was 13.77±9.04°, the mean PI was 46.93±11.90°, the mean LL was 54.53±10.20°, the mean TK was 40.54±10.16°, and the mean SPi-T1 was -5.74±3.64°. Table 1 shows the measurement of the eight radiographic parameters in all evaluated individuals.

Table 2. Radiographic measurements: mean, standard deviation and inter-group comparison (female and male) in health and asymptomatic individuals

Variable	Gender	Mean ± SD	P (95%)
SVA	Female	-17.3 mm ± 28.5 mm	0.003
	Male	-2.38 mm ± 34.0 mm	
PT	Female	13.64° ± 10.04°	0.812
	Male	13.98° ± 7.09°	
PI	Female	48.14° ± 13.19°	0.088
	Male	44.89° ± 9.03°	
SS	Female	34.11° ± 7.65°	0.014
	Male	31.24° ± 6.50°	
LL	Female	56.52° ± 10.24°	0.001
	Male	51.16° ± 9.27°	
PI - LL	Female	-6.79° ± 12.93°	0.794
	Male	-7.31° ± 11.15°	
TK	Female	40.38° ± 10.24°	0.787
	Male	40.82° ± 10.09°	
T1-SPi	Female	-6.07° ± 3.44°	0.007
	Male	-4.45° ± 3.78°	

** Student's t test, considering statistical differences p <0.05.* Legend: sagittal vertical axis (SVA), sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI), spinopelvic inclination - T1 (SPI - T1), thoracic kyphosis (TK), lumbar lordosis (LL), and the PI minus the LL (PI - LL).

Table 2 shows the radiographic measurements according to sex and the results of the comparative tests. The results show that females have, on average, a significantly larger negative SVA value (p = 0.003), larger SS and LL values (p=0.014 and p=0.001, respectively), and a larger negative SPi - T1 value (p = 0.007). The values obtained for PT, PI, PI - LL, and TK were not significantly different.

Table 3. Radiographic measurements: mean, standard deviation and inter-group comparison by age: young adult (18-39 years), adult (40-59 years) and elderly (> 60 years)in health and asymptomatic

Variable	Age group (years)	Mean ± SD	P
SVA	18 - 39	-19.52 mm ± 26.13 mm	<0.00*1
	40 - 59	-18.39 mm ± 27.56 mm	
	>60	15.93 mm ± 33.07 mm	
PT	18 - 39	13.24° ± 7.29°	<0.00*1
	40 - 59	11.41° ± 7.94°	
	>60	20.09° ± 11.03°	
PI	18 - 39	46.09° ± 12.78°	0.014*
	40 - 60	45.27° ± 10.56°	
	>60	52.15° ± 12.25°	
SS	18 - 39	32.63° ± 8.29°	0.829
	40 - 60	33.41° ± 7.28°	
	>60	32.88° ± 5.97°	
LL	18 - 39	54.59° ± 10.84°	0.507
	40 - 60	55.24° ± 10.10°	
	>60	52.79° ± 9.45°	
PI – LL	18 - 39	-5.78° ± 11.76°	0.004*
	40 - 60	-9.97° ± 9.97°	
	>60	-1.94° ± 15.81°	
TK	18 - 39	39.61° ± 8.05°	0.662
	40 - 60	41.24° ± 10.99°	
	>60	40.41° ± 11.26°	
T1-SPi	18 - 39	-6.06° ± 3.69°	0.001*
	40 - 60	-5.94° ± 3.22°	
	>60	-3.44° ± 3.86°	

**ANOVA, post hoc Tukey test, considering differences of p<0.05 significant. Legend: sagittal vertical axis (SVA), sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI), spinopelvic inclination - T1 (SPI - T1), thoracic kyphosis (TK), lumbar lordosis (LL), and the PI minus the LL (PI - LL).*

Another important finding was that the mean radiographic values of SVA, PT, PI, PI – LL, and SPI - T1 were significantly different according to age group ($p < 0.05$). However, the SS, LL, and TK values showed no significant difference.

The results also showed that individuals aged 60 or older had significantly higher mean SVA, PT, and SPI - T1 values than did individuals in the other age groups ($p < 0.05$), and that the mean SVA value was positive for individuals in this age group, whereas the mean SPI - T1 value was negative but less negative than that in the other age groups. The mean PI and PI - LL values were significantly higher in individuals aged 60 or older than in individuals aged 40 to 59 years ($p = 0.014$ and $p = 0.004$, respectively). Additionally, the mean PI value was positive and higher in older individuals, and the mean PI - LL value was less negative in these individuals (Table 3 and 4). In the current study, the parameters of the LL, SS and PI were significantly different between the current studies cohort performed by Lafage *et al*., (2001), Roussouly *et al*., (2008); Vialle *et al*. (2005), Zhu *et al*., (2014) and showed a gradual decrease with aging observed in this study, as can be seen in Table 5.

DISCUSSION

In accordance with our hypotheses, the age and sex influence the spinopelvic parameters in the healthy and asymptomatic Brazilian sample. The women presented with a lower SVA, higher SS and LL and larger negative T1-SPiSPi-T1. In addition, individuals older than 60 years have had higher mean values of the SVA, PT, and T1-SPiSPi -T1. Several studies have determined that the sagittal profile of the spine and pelvis largely influences the standing balance of healthy adult[22-25]and adolescent populations, especially by regulating the LL and PI[3].Glassman *et al.,* (2005) showed the direct relationship between the loss of sagittal balance and quality of life indicators in adults previously subjected to spinal arthrodesis, as well as in individuals without prior surgery and report the

Table 4. Multiple comparison results of radiographic measurements that presented significant differences by age group

Variable	Comparison (years)	Difference Mean/SD	p
SVA	18 - 39 VS 40 - 60	-1.14 mm ± 5.00 mm	>0.999
	18 - 39 VS >60	-35.45 mm ± 6.20 mm	>0.001
	40 - 60 VS >60	-34.32 mm ± 5.81 mm	>0.001
PT	18 - 39 VS 40 - 60	1.84° ± 1.50°	0.663
	18 - 39 VS >60	-6.85° ± 1.85°	0.001
	40- 60 VS >60	-8.68° ± 1.74°	<0.001
PI	18 - 39 VS 40 - 60	0.83° ± 2.06°	>0.999
	18 – 39 VS >60	-6.05° ± 2.55°	0.057
	40 - 60 VS >60	-6.88° ± 2.39°	0.014
PI - LL	18 - 39 VS 40 - 60	4.20° ± 2.11°	0.144
	18 - 39 VS >60	-3.84° ± 2.61°	0.431
	40- 60 VS >60	-8.03° ± 2.45°	0.004
T1-SPi	18 - 39 VS 40 - 60	-0.12° ± 0.62°	>0.999
	18 - 39 VS >60	-2.61° ± 0.77°	0.003
	40- 60 VS >60	-2.50° ± 2.72°	0.002

**ANOVA, post hoc Tukey test, considering differences of p<0.05 significant. Legend: sagittal vertical axis (SVA), sacral slope (SS), pelvic tilt (PT), pelvic incidence (PI), spinopelvic inclination - T1 (SPI - T1), thoracic kyphosis (TK), lumbar lordosis (LL), and the PI minus the LL (PI - LL).*

Table 5. Comparison of sagittal alignment parameters in the current study with historical data ofpatients evaluated in the literature

Studies	N	Mean LL	SD	p	Mean SS	SD	p	Mean PI	SD	p
Barsotti[19]	167	54.53	10.2	-	33.05	7.35	-	46.93	11.9	-
Lee et al.[9]	86	49.6	9.6	0.0003	36.3	7.8	0.0013	47.8	9.3	0.5549
Gangnet et al.[20]	34	50.7	7.9	0.0402	37.9	5.9	0.0004	50.2	9	0.1313
Kenji[21]	86	43.4	14.6	0.0001	34.6	7.8	0.121	46.7	8.9	0.8747
Lafage et al.[22]	131	57	11	0.0459	36	10	0.0036	52	9	0.0001
Roussouly et al.[23]	160	61.43	9.7	0.000	39.92	8.17	0.0001	51.91	10.71	0.0001
Vialle et al.[7]	300	43	11.2	0.0001	41.2	8.4	0.0001	54.7	10.6	0.0001
Zhu et al.[12]	260	48.2	9.6	0.0001	32.5	6.5	0.4182	44.6	11.2	0.0413
Singh[24]	50	58.78	9.51	0.0093	39.14	7.05	0.0001	48.52	8.99	0.3838
Guiroy et al.[11]	100	59.1	9.87	0.0004				48.04	11.71	0.4587

pain complaints and functional limitations during the preoperative period as well as in the importance of the analysis of the results after surgical treatment (Lafage, 2008 and Roussouly, 2005). The differential of this study was to show that the sagittal profile of the spine parameters of the asymptomatic and healthy individuals and observe differences between young adults, adults and the elderly, showing higher SVA and T1-SPi values in young adults (18-39 years) when compared to adults (40-59 years) and elderly (> 60 years). Another important finding was to verify an increase in PT and PI in the elderly compared to young adults and adults, showing that these parameters are of great clinical importance to improve the balance strategy in this population. In adults, only PI-LL were higher than in young and elderly adults, which may reveal important clinical information to improve spinal stability and postural adjustment and, consequently, prevent the development of spinal dysfunction and pathologies. According to Berthonnaud *et al.,* (2005), proposed the concept of a linear chain linking the head to the pelvis in which the shape and the orientation of each anatomic segment are closely related with and influence the adjacent segment to maintain a stable posture with minimum energy expenditure. Another important finding in the study was regarding women presented a significantly higher mean negative SVA value ($p<0.05$) and higher mean SS and LL values, findings similar to studies on other populations. There is still debate regarding the influence of sex on spinopelvic parameters. A study by Vialle *et al*., (2005) showed a significant difference in SS and PI between 110 women and 190 men. However, Janssen *et al.,* (2009) did not find a significant difference between the sexes in their sample. Mac-Thiong *et al.* (2004) also found no relationship between pelvic parameters and the sexes. When comparing the mean and standard deviation values obtained in the present study with values published in the literature from samples of European, Asian, and American populations, a significant difference ($p<0.005$) was found in some pelvic parameters between the Brazilian population and the other populations. The PI values of the French, Korean, Argentine, and Indian populations were higher than those of the Brazilian population sample, and those of the Japanese population were lower. The SS values of the Japanese and Chinese populations were higher than that of the Brazilian sample. Lastly, the LL values differed among all populations described in the studies and were higher in the American, French, Indian, and Argentine population samples and lower in the Korean and Japanese samples. It is suggested, therefore, that different types of sagittal alignment may be prevalent in Asian populations compared to groups from other continents. Standardization of normal values has become increasingly important, from diagnosis to surgical planning, when indicated. Achieving the necessary correction in each individual based on specific sagittal alignment parameters is desired and goes beyond determining the numerically correlated global parameters (Qiu Yong, 2012). The study's limitations should be considered when interpreting its findings. In this study, sagittal and spinopelvic balance parameters was conducted on young adults, adults and the elderly of a sample of Brazilians composed of asymptomatic volunteers, which may limit the generalizability of the findings.

Conclusion

Free-standing spine radiographs were obtained in 167 asymptomatic and healthy individuals in a sample of Brazilians. Standard values and deviations of spino-pelvic sagittal alignment were established according to gender and age from 18 'to 60'. The remarkable change of spino-pelvic sagittal alignment was verified, such as the decrease of SVA, higher SS and LL and larger negative T1-SPiSPi-T1 in young adult and adult women, while that the elderly than 60 years have had higher mean values of the SVA, PT, and T1-SPiSPi-T1.

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Author contributions: The authors: CEGB, APR, CMMR, BPSNB, RRP, FEP, CEAO and MPN planned, interpreted the results and prepared the tables of the experiments, as well as contributed to the writing and reviewing of the manuscript.

Competing interests: The authors declare no competing interests.

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