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Changes in needle maneuver space and optimal insertion site for midline neuraxial puncture with progressive age: an analysis in computed tomography scans

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ABSTRACT

Introduction We systematically describe the morphology and accessibility of interspinous spaces across age groups of patients. Our primary goal was to objectively estimate if the maneuver space for a virtual spinal needle changes with age. Our secondary goal was to estimate if the optimal site and angle for midline neuraxial puncture change with age.

Methods Measurements were performed in mid-sagittal CT images. The CT images were retrospectively collected from the database of the Department of Radiology of our hospital. Three age groups were studied: 21–30 years (n=36, abbreviated Y(oung)), 51–60 years (n=43, abbreviated M(iddle-aged)) and older than 80 years (n=46, abbreviated Old).

A needle trajectory is defined by the chosen puncture point and by the angle at which the needle is directed to its target. We define a Spinal Accessibility Index (SAI) by numerically integrating for an interspace *all possible combinations* of puncture *points* and *angles* that lead to a successful virtual puncture. Successful in this context means that the needle tip reaches the spinal or epidural space without bone contact. Reproducible calculation of the SAI was performed with the help of custom-made software. The larger the value of the SAI, the more possible successful needle trajectories exist that the practitioner may choose from.

The optimal puncture point and optimal angle in an age group at a certain level of the spine are defined by the combination of these two, which generates the highest success rate of the entire sample of this age group.

Results At all levels of the spine, the median SAI differed significantly between age groups (independent-samples Kruskal-Wallis test, p<0.001–0.047). The SAI consistently decreased with increasing age. Post-hoc analyses using pairwise comparisons showed a significantly higher SAI in group Y versus Old at all levels (p<0.001—0.006) except at level thoracic (Th)1–Th2 (p=0.138). The SAI was significantly higher in group M versus Old at all levels (p<0.001–0.028) except at level Th1–Th2 (p=0.061), Th4–Th5 (p=0.083), Th9–Th10 (p=1.00) and Th10–Th11 (p=1.00).

Conclusions Needle maneuver space in midline neuraxial puncture significantly decreases with progressive age at all levels of the spine. Optimal puncture points and angles are similar between age groups.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Previous clinical studies suggest a more difficult midline neuraxial puncture with aging. An accurate morphological description of the interspinous space in different age groups in the context of a midline neuraxial puncture does not exist.

WHAT THIS STUDY ADDS

⇒ Accurate, reproducible measurements in CT scans of the spines of patients demonstrate that maneuver space for a virtual needle significantly diminishes with progressive age at all levels of the spine.
⇒ Optimal puncture points and angle are similar between age groups.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Detailed knowledge of the anatomy of the interspinous space and its changes during aging is useful for the clinician performing a puncture, especially for novices. It may guide in choosing an optimal puncture point and angle for midline neuraxial puncture for the different levels of the spine and for the different age groups. It might also guide in choosing an alternative—for example, a paramedian—approach for a puncture at certain levels of the spine, especially in the aged.

INTRODUCTION

During aging, the length, height, and width of the spinous processes increase,[1 2] whereas the intervertebral disks shrink.[3] Together, these changes result in a smaller distance between the spinous processes.

Degeneration and inflammation of bone and ligaments due to mechanical strain, damage or systemic disease may lead to additional changes like cartilage formation, calcification of ligaments, formation of osseous appositions and spurs[2 4] and even synovial membranes resembling articulation.[4]

Due to these changes, with progressive age, the spinal canal is possibly more difficult to approach for neuraxial puncture. Clinical studies have suggested that the performance of neuraxial puncture in elderly patients is indeed more difficult than in younger patients in terms of more time needed

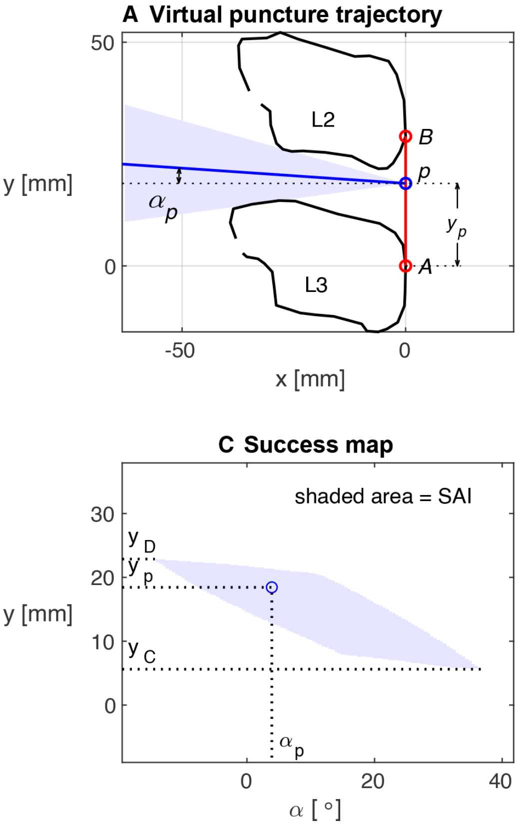

Figure 1 Calculation of the SAI. Two delineated spinous processes (L2 and L3) derived from a mid-sagittal CT scan are shown (A). The blue line represents a virtual needle that passes between the spinous processes with puncture point p on AB (part of a tangential reference line) and angle α (degrees, relative to the horizontal). (B) The two extreme needle trajectories are depicted with starting points C and D. CD is assigned the useful interspace expressed in millimeters. (C) All possible punctures are plotted by combining all possible insertion points (y-axis, between C and D, represented by y_C and Y_D) and all possible angles α on the x-axis. The puncture at point p is represented by the open blue circle. The successful (meaning that the virtual needle passes without touching bone) combinations together form the shaded area. The SAI represents the surface of this area, expressed in millimeters multiplied by degrees. The larger this area, the more space is available for a virtual needle. L, lumbar; SAI, Spinal Accessibility Index.

for the procedure,[5] a higher number of needles used[5] and a higher number of attempts.[5–8] In this context, it would be useful for the clinician performing a neuraxial puncture to have insight in the possible anatomical variation of the interspinous space. Studies describing anatomical aspects of the interspinous space do exist[9 10] but, to the best of our knowledge, not in the context of a midline neuraxial puncture.

In this study, we systematically describe the morphology and accessibility of the interspinous spaces across age groups of patients by analyzing CT scans using custom-made software. Our primary goal was to objectively estimate if the maneuver space for the needle in the interspinous space changes with age. Our secondary goal was to estimate if the optimal site and angle for midline neuraxial puncture change with age.

METHODS

Performance of this research and writing of the manuscript were in line with the applicable Strengthening the Reporting of Observational Studies in Epidemiology guidelines (Equator network).[11]

Subjects and selection of CT scans

CT scans were obtained from the Department of Radiology of the Canisius Wilhelmina Hospital in Nijmegen, which is a middle-sized (approximately 400 beds) teaching hospital located in an urban area in the east of the Netherlands.

CT scans were anonymized, with only knowledge of the sex and the age of the patients. Due to strict privacy regulations, we were not allowed to retrieve any further medical information.

We expected to find the largest differences in spinous interspace morphology at the extremes of ages. Therefore, we selected CT scans from relatively young patients (21–30 years, group Young (abbreviated Y), n=36) and from relatively old patients (80 years or more, abbreviated Old, n=46). In addition, we selected scans from the age group exactly in the middle of the two chosen extremes of age (51–60 years, group Middle-aged, abbreviated M).

Scans were retrospectively collected by members of the Department of Radiology from the database of our hospital. The numbers of available, assessed, and selected CT scans are shown in online supplemental figure 1. A scan was considered potentially suitable, if the patient belonged at the time of scanning to one of the chosen age groups and the thorax and/or the abdomen were depicted on mid-sagittal sections. By applying only these two selection criteria for the scans, we assume we avoided selection bias. The scan was reviewed (performed by MH) to see if intact, mid-sagittal spinous processes were sufficiently depicted to be analyzed by the program code. If this was the case, the scan was selected.

Analysis of mid-sagittal CT scans

The method of analysis of the CT scans, including the program code, written in MATLAB V.R2015a (The Mathworks, Natick, Massachusetts, USA) by DJvG, has been described in detail in a previous paper with the program code provided as online supplemental digital content.[12] We used the same software and technique in this paper except that we added a calculation for the area under the curve in our data analysis.

Here, we give a short explanation of our method. For an extensive explanation, we refer to online supplemental figure 2 or our previous paper.[12]

Figure 1A represents a manually delineated interspace L(umbar)2–L3 derived from a mid-sagittal CT scan. AB is part of a tangential reference line that runs along the two most dorsal points of the two adjacent spinous processes, so exactly in the midline of the virtual back of a patient. From this line, virtual punctures are performed.

The blue line represents a virtual needle that passes between the spinous processes with puncture point p on AB and angle α_p (degrees, measured relative to the horizontal).

The shaded area, also called the window size, represents all successful trajectories from point p in a mid-sagittal two-dimensional (the thickness of the CT scan section is neglected) plane of a virtual patient.

In figure 1B, the two extreme possible needle trajectories to reach the virtual ES (epidural space) are depicted with starting points C and D. CD is referred to as the *useful interspace*, expressed in millimeters.

In figure 1C, all possible virtual punctures are plotted by combining *all possible* puncture points (y-axis, between C and D, represented by y_C and y_D) and *all possible* angles α on the x-axis. The puncture trajectory depicted in figure 1A corresponds with the open blue circle in figure 1C. The shaded area represents all needle trajectories that result in a successful puncture (meaning that the virtual needle passes into the ES without touching bone).

To quantify the maneuver space for an interspace, we define the Spinal Accessibility Index (SAI) as the size of the shaded area in figure 1C. The larger this area, the more space is available for a virtual needle.

Analysis of mid-sagittal CT scans: success maps and generic optima

The shaded area in figure 1C can be considered a success map in its simplest, binary form: a chosen combination of a puncture point and angle, that is, a trajectory, results in either success or in failure. By virtually stacking all available success maps of a particular interspace level of an age group on top of each other (figure 3), an image is created which resembles an elevation map. The highest point on this represents the needle trajectory with the highest percentage of successful punctures in a chosen sample. This trajectory is called the generic optimum of this sample.

Success maps were generated for various levels of the spine, for specific thoracic and lumbar regions, and for the whole sample.

Statistical analysis

The SAI at each level of the spine was compared between age groups Y, M and Old. We did not perform an a priori power analysis. We decided to include in every age group at least 30 subjects.

As the SAI was not normally distributed, these data were presented as medians with IQRs. For all levels of the spine, potential differences in SAI among age groups were evaluated using the independent-samples Kruskal-Wallis test. In case of statistically significant differences, post-hoc analyses using pairwise multiple comparisons between age groups were performed. P values were adjusted by Bonferroni corrections for multiple testing. Statistical analyses were performed using SPSS (IBM, SPSS Statistics V.27.0), and p values lower than 0.05 were considered statistically significant.

Table 1 Studied population; summary of the studied population: numbers of subjects sorted by sex and age group

	Age		
	21–30 years (Young)	51–60 years (Middle-aged)	≥80 years (Old)
Female	15	18	22
Male	21	25	24
Total	36	43	46

RESULTS

Patient population: sex and age

CT scans of 125 patients were retrospectively collected and analyzed. A summary of the number of subjects in each age group, sorted by sex, is shown in table 1.

Morphology of the interspinous spaces and spinous processes

All delineated interspaces (1626 in total) are shown in online supplemental figure 3A–C, sorted by age group. Together, all these depicted interspaces give a good impression of the variability of the morphology at all levels of the spine in the studied age groups. In general, with progressive age, smaller and more irregularly shaped interspaces were found.

Illustrative examples of the morphology of the interspaces in CT scans are depicted in figure 2. A few patients showed ossification of the supraspinous ligaments, thereby making a theoretical approach with a spinal needle in the midline impossible. This phenomenon was previously shown by Sartoris *et al*[4] in macerated human specimens (figure 2A,B). Smooth delineated spinous processes were more prominently present in group Y (figure 2C). In group Old, we observed the highest incidence of irregularly shaped spinous processes with small interspaces and osseous deformations (figure 2D,E), including spurs and even pseudo-articulation formation (figure 2E, indicated by arrows).

SAI: comparisons between age groups

The median SAI consistently decreases with increasing age at all interspace levels (table 2, independent-samples Kruskal-Wallis test, $p<0.001$–0.047). The spread of the individual values is considerable (table 2 and online supplemental figure 4).

When making pairwise comparisons between age groups, not all differences are statistically significant. The differences between groups Y and Old are all statistically significant ($p<0.001$–0.006) except at the first thoracic level ($p=0.138$, table 2).

At the lumbar level, all pairwise comparisons between age groups are statistically significantly different ($p<0.001$–0.028).

The decreasing SAI with progressive age is the result of both decreasing *useful* interspace heights and decreasing window sizes. In contrast, the *total* interspace height remains relatively constant when comparing age groups (online supplemental table 1).

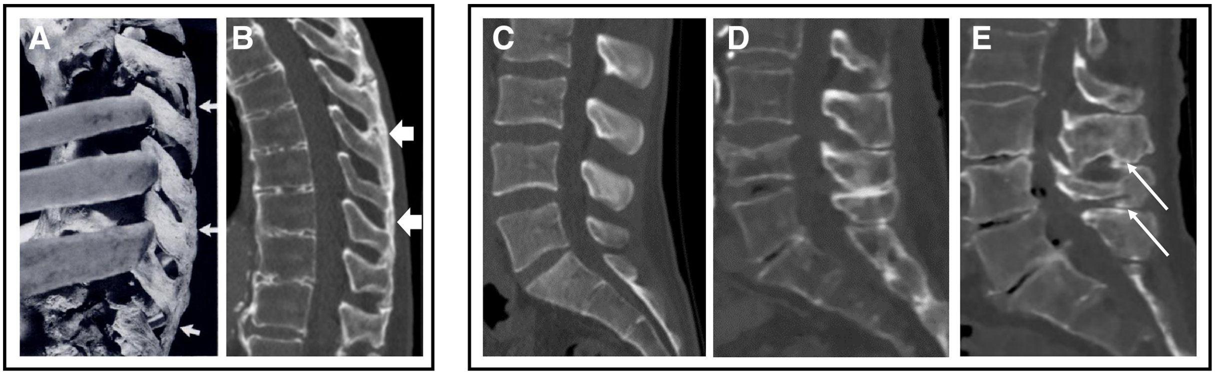

Figure 2 Morphology of spinous processes. Morphological changes of the spinous processes are shown as they appear during aging in the studied population. (A) Adapted from Sartoris *et al*[4] with permission. It shows a macerated part of a human spine with calcification of the supraspinous ligaments and bridging of adjacent spinous processes. In our series of patients, we found a few examples showing resemblance with (A). (B) A CT scan of a male patient from group Old. On a mid-sagittal section of the spine, comparable calcified supraspinous ligaments were found (arrows). Here, a midline attempt for a neuraxial puncture would be impossible. (C) The typical smooth delineated spinous processes of the lumbar spine, found in a relatively young subject (male, group Young). There is ample space for a successful attempt of a neuraxial puncture. (D) A mid-sagittal section of lumbar spinous processes of a female subject from group Old. The circumferences of the spinous processes are clearly less smooth and rounded. The spinous process are closely apposed: virtually, there is no space for a successful midline neuraxial puncture. (E) An even more extreme example of a male subject from group Old. The spinous processes are deformed, leaving no space for a virtual midline neuraxial puncture. Areas of the spinous processes suggestive for pseudo-articulation are indicated by arrows. This phenomenon is also described by Sartoris *et al*.[4]

Optimal puncture point, optimal puncture angle and highest theoretical success rate

The generic optimal puncture points at all spinal levels show small differences between age groups. We did not detect a pattern in these differences (table 3). In most cases, the optimal generic puncture point is between 0.30 and 0.60 irrespective of age, except at level Th(oracic)6–Th7 group M (0.27), at level Th7–Th8 group Old (0.24) and at level Th9–Th10 group Y (0.27).

The optimal generic puncture angles follow the steepness of the spinous processes as known from the anatomy of the spine: a relatively flat needle approach at the lumbar level (varying from 4° to 14°) and a steeper approach at the thoracic level (varying from 10° to 53°) offers the highest chance of a successful puncture. Small differences between age groups regarding optimal generic angle exist. We could not detect a pattern in these differences.

Table 2 SAI, sorted by age group and sorted by spinal level

Median SAI (IQR), degrees mm				Statistical analysis			
				Significance of differences between age groups, independent-samples Kruskal-Wallis test, p values	Pairwise comparison age groups, p values		
Interspace	Y: 21–30 years	M: 51–60 years	Old: ≥80 years		Y vs M	Y vs Old	M vs Old
Th1–Th2	78 (41–124)	69 (48–130)	53 (12–80)	0.047	1.00	0.138	0.061
Th2–Th3	55 (25–115)	53 (23–101)	22 (1–52)	0.002	1.00	0.003	0.015
Th3–Th4	41 (14–83)	35 (5–54)	10 (0–36)	<0.001	0.936	0.001	0.022
Th4–Th5	11 (0–42)	3 (0–34)	0 (0–10)	0.006	1.00	0.006	0.083
Th5–Th6	17 (0–36)	4 (0–17)	0 (0–2)	<0.001	0.536	<0.001	0.001
Th6–Th7	12 (0–42)	8 (0–21)	0 (0–4)	<0.001	1.00	<0.001	0.005
Th7–Th8	42 (5–76)	19 (1–42)	0 (0–13)	<0.001	0.167	<0.001	0.007
Th8–Th9	68 (29–130)	32 (2–61)	8 (0–24)	<0.001	0.009	<0.001	0.008
Th9–Th10	66 (28–110)	20 (4–83)	24 (3–50)	<0.001	0.003	<0.001	1.00
Th10–Th11	152 (56–272)	45 (3–166)	42 (1–114)	<0.001	0.003	<0.001	1.00
Th11–Th12	320 (165–480)	226 (145–350)	142 (74–228)	<0.001	0.527	<0.001	0.019
Th12–L1	379 (251–452)	235 (180–327)	127 (33–224)	<0.001	0.003	<0.001	0.004
L1–L2	334 (208–402)	200 (116–305)	27 (7–94)	<0.001	0.015	<0.001	<0.001
L2–L3	266 (140–334)	124 (42–203)	10 (0–43)	<0.001	0.004	<0.001	<0.001
L3–L4	184 (95–253)	55 (7–119)	1 (0–17)	<0.001	0.001	<0.001	<0.001
L4–L5	125 (67–202)	34 (1–67)	1 (0–18)	<0.001	<0.001	<0.001	0.028

The distribution of the SAI was skewed; therefore, data were presented as median value and corresponding IQR (in brackets). Differences in SAI among age groups are compared using the non-parametric independent-samples Kruskal-Wallis test, with Bonferroni correction for multiple comparisons among age groups. A higher SAI corresponds with more maneuver space for a virtual needle. The SAI consistently decreases with increasing age at all levels of the spine. Post-hoc analyses of differences between age groups were not always statistically different.

L, lumbar; M, Middle-aged; Old, older than 80 years; SAI, Spinal Accessibility Index; Th, thoracic; Y, Young.

Table 3 Maximal success rates and generic optimal puncture sites and angles

Level	Variable	Age		
		Y: 21–30 years	**M: 51–60 years**	**Old: >80 years**
Th1–Th2	Sample size	31	38	29
	Max success (%)	29	39	31
	Location (no dimension)	0.36 (0.35, 0.36)	0.52 (0.46, 0.58)	0.42 (0.39, 0.49)
	Angle (degree)	20 (20, 21)	27 (24, 31)	31 (28, 34)
Th2–Th3	Sample size	36	41	40
	Max success (%)	36	34	23
	Location (no dimension)	0.37 (0.34, 0.41)	0.35 (0.34, 0.37)	0.48 (0.47, 0.49)
	Angle (degree)	30 (28, 31)	32 (31, 34)	34 (33, 34)
Th3–Th4	Sample size	36	41	44
	Max success (%)	25	22	16
	Location (no dimension)	0.51 (0.42, 0.64)	0.45 (0.42, 0.58)	0.43 (0.26, 0.47)
	Angle (degree)	25 (19, 34)	33 (29, 35)	39 (38, 42)
Th4–Th5	Sample size	36	42	45
	Max success (%)	19	17	11
	Location (no dimension)	0.46 (0.43, 0.48)	0.57 (–)	0.34 (0.30, 0.36)
	Angle (degree)	29 (28, 30)	24 (–)	41 (40, 43)
Th5–Th6	Sample size	36	42	44
	Max success (%)	19	10	5
	Location (no dimension)	0.51 (0.47, 0.58)	0.50 (0.22, 0.63)	0.64 (0.23, 0.79)
	Angle (degree)	45 (42, 46)	44 (40, 55)	34 (25, 49)
Th6–Th7	Sample size	36	42	45
	Max success (%)	19	14	7
	Location (no dimension)	0.41 (–)	0.27 (0.17, 0.29)	0.50 (0.14, 0.59)
	Angle (degree)	47 (–)	48 (48, 49)	47 (45, 59)
Th7–Th8	Sample size	36	43	45
	Max success (%)	28	28	16
	Location (no dimension)	0.34 (0.30, 0.39)	0.32 (0.32, 0.33)	0.24 (0.22, 0.28)
	Angle (degree)	48 (46, 49)	51 (50, 51)	53 (52, 55)
Th8–Th9	Sample size	36	43	45
	Max success (%)	47	33	18
	Location (no dimension)	0.39 (0.35, 0.42)	0.39 (0.38, 0.40)	0.36 (0.25, 0.41)
Th9–Th10	Sample size	36	43	45
	Max success (%)	42	40	40
	Location (no dimension)	0.27 (–)	0.50 (0.50, 0.50)	0.40 (0.36, 0.41)
	Angle (degree)	45 (–)	35 (35, 36)	37 (36, 38)
Th10–Th11	Sample size	35	43	45
	Max success (%)	63	49	40
	Location (no dimension)	0.35 (0.34, 0.36)	0.32 (0.32, 0.33)	0.52 (0.51, 0.55)
	Angle (degree)	32 (31, 32)	31 (31, 32)	20 (17, 21)
Th11–Th12	Sample size	35	43	45
	Max success (%)	83	67	56
	Location (no dimension)	0.60 (0.59, 0.60)	0.54 (0.50, 0.59)	0.54 (–)
	Angle (degree)	10 (9, 10)	13 (7, 16)	13 (–)
Th12–L1	Sample size	35	43	45
	Max success (%)	86	70	44
	Location (no dimension)	0.48 (0.45, 0.53)	0.52 (0.50, 0.53)	0.68 (–)
	Angle (degree)	14 (6, 17)	12 (11, 14)	4 (–)
L1–L2	Sample size	35	43	45
	Max success (%)	77	56	31
	Location (no dimension)	0.52 (0.46, 0.60)	0.55 (0.54, 0.56)	0.63 (0.59, 0.68)
	Angle (degree)	13 (6, 17)	4 (2, 6)	4 (2, 5)
L2–L3	Sample size	34	42	44
	Max success (%)	82	60	20
	Location (no dimension)	0.48 (0.41, 0.53)	0.47 (0.46, 0.48)	0.47 (–)
	Angle (degree)	9 (5, 14)	8 (6, 11)	8 (–)

Continued

Table 3 Continued

Level	Variable	Age Y: 21–30 years	M: 51–60 years	Old: >80 years
L3–L4	Sample size	34	42	44
	Max success (%)	76	45	14
	Location (no dimension)	0.40 (0.38, 0.42)	0.48 (0.47, 0.49)	0.47 (0.47, 0.47)
	Angle (degree)	8 (6, 10)	1 (0, 2)	7 (7, 8)
L4–L5	Sample size	34	37	41
	Max success (%)	65	35	12
	Location (no dimension)	0.39 (0.32, 0.40)	0.35 (0.33, 0.39)	0.50 (0.34, 0.55)
	Angle (degree)	7 (6, 15)	14 (11, 17)	1 (–2, 7)

Sample sizes, maximal success rates (expressed in percentage), optimal locations for puncture and corresponding optimal angles are sorted by interspinous space level and sorted by age group. Data plots of the optimal locations and corresponding angles were visually judged to be normally distributed; therefore, data are presented as mean and corresponding 95% CI in brackets. The maximal possible success rate decreases consistently with increasing age at all levels of the spine. This confirms our observation that needle maneuver space decreases with aging. The optimal puncture sites and angles show minimal differences and no recognizable pattern between the age groups, suggesting that a similar approach for midline neuraxial blockade for all age groups at all interspinous levels seems justified.
L, lumbar; M, Middle-aged; Old, older than 80 years; Th, thoracic; Y, Young.

In contrast, the maximum achievable success rate is consistently lower with increasing age at all levels of the spine, most notably at the lumbar levels (figure 3 and table 3). The number of inaccessible interspaces increases with age, especially in the lumbar region. For example, in group Old, we observed that at level L3–L4, 27% of the interspaces were not accessible in the midline. In contrast, in groups M and Y, all analyzed interspaces were accessible at level L3–L4 (online supplemental table 2). All success maps for all age groups are available as online supplemental figure 5A–C.

DISCUSSION

In this study, we demonstrate a large variability of the anatomy of the spinous processes and the interspinous spaces in three different age groups. This is useful information for the clinician performing a neuraxial puncture, especially for novices. In addition, this study quantifies the anatomy of spinal interspaces in terms of useful interspace height and corresponding window sizes for virtual attempts of a midline neuraxial puncture. To the best of our knowledge, this information was up until now not available in the literature. The measurements are well defined and reproducible, thereby making the comparisons between age groups unbiased.

Our study demonstrates that with progressive age, the maneuver space for a virtual needle diminishes significantly. The optimal generic puncture points and angles are comparable between age groups. A similar approach, for midline neuraxial puncture in different age groups, seems therefore justified.

The decreasing needle maneuver space with aging apparently seems not to be a proportional process, since the relative decrease in SAI is larger when comparing group M with group Old, than comparing group M with group Y. In addition, we found the largest differences among age groups in the lumbar region. This can probably be best explained by the fact that the lumbar region of the vertebral column carries more weight than the thoracic part. In addition, spines of elderly patients are longer exposed to—for example, mechanical—stress, probably resulting in more morphological changes and a decreasing needle maneuver space.

We hypothesized that the SAI would decrease with increasing age. The studied age groups were chosen at the extremes of age, that is, between 20 and 30 years and more than 80 years, to have the highest chance to get a clear answer. Unfortunately, due to these considerations, we skipped the age group 60–80 years. We acknowledge that, for example, a lot of patients needing a joint replacement, often performed under a spinal anesthetic, are represented in this age group.

Previous papers compared difficulty of a neuraxial puncture in groups of different ages using clinical indexes, for example, the number of puncture attempts,[5–8] the number of needle redirections[5–8] or the time taken by the procedure.[5] These clinical indexes are most likely biased by factors that are difficult to keep constant to make reproducible comparisons, for example, the dexterity of the practitioner performing the puncture. We postulate that the comparisons among age groups using the SAI *are* objective, well defined, and reproducible. However, we acknowledge that an association between the SAI and the difficulty of a puncture is hypothetical. In addition, using the SAI as a variable representing the difficulty of a neuraxial puncture suggests that the performance of a neuraxial puncture is a stochastic event. This is of course not the case. The experienced clinician will, sometimes perhaps intuitively, know where and at what angle a puncture will most likely result in a successful procedure. In other words: even though the SAI is reproducible and objective, we do not know what, for example, a doubling of the value of the SAI means in a clinical context.

As we discussed previously,[12] the positioning of the patient is not considered in our study. The CT scans were made for diagnostic purposes and not for this research. From previous clinical studies, we know that optimizing patient position by hip flexion results in a modest increase in width—measured at an arbitrary point between two spinous processes—of the spinous interspace.[13 14] The measured increases in width varied from 1 mm or less in approximately 60% of studied cases to 1–2 mm in 30% of cases. The relative increases varied from 5% to 33%.[14] These results indicate that patient positioning alters the interspinous space, but the extent to which this affects the SAI is not known.

Furthermore, when translating our data to the clinic, palpation of the tips of the spinous processes might be difficult, for example, due to obesity. In addition, it is difficult to accurately establish the exact level where the puncture is performed.[15] Both difficulties could be circumvented by using ultrasound.

Our calculations were performed without taking the dimensions of the needle into account and under the assumption that the needle takes a straight course. From clinical experience and experimental data, we know that this is not always the case.[16]

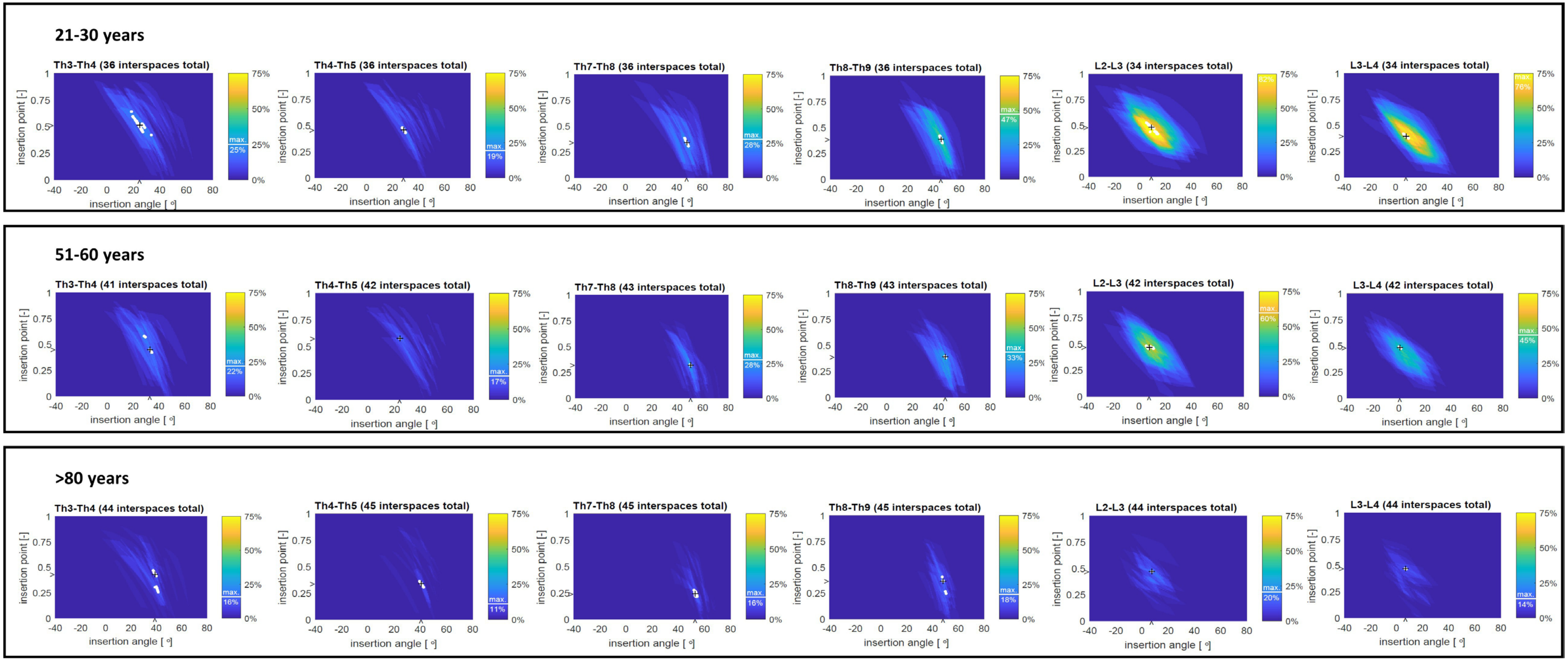

Figure 3 Success maps at thoracic (Th) (high and low) level, and at lumbar (L) level. Three age groups with success maps of six different levels of the spine are shown, where neuraxial punctures are common: high thoracic (Th3–Th4 and Th4–Th5), low thoracic (Th7–Th8 and Th8–Th9) and lumbar (L2–L3 and L3–L4). One single diagram shows the accumulated data for all subjects at that particular level of the spine for that particular age group. In each diagram, the puncture angle is shown on the x-axis (degrees), and the puncture point is indicated on the y-axis (normalized, arbitrary units, between 0 and 1). The maximal possible success percentage is shown in white in the diagrams and in the scale bar next to each separate diagram. The most successful combination of puncture point and angle is indicated by arrowheads at the axes and by a plus sign in the diagrams.

Neuraxial punctures performed with generic optimal puncture points and angles, as calculated in our success maps, would never result in a 100% success rate in a population, even when perfectly executed. Moreover, an increasing proportion of the interspaces becomes inaccessible in the midline, foremost in group Old at the mid-thoracic and at the lumbar level. This means that if one would like to improve on these numbers, a different approach should be taken. A paramedian puncture may provide a valuable alternative.[17] Unfortunately, our two-dimensional approach in the midline in a sagittal plane cannot provide an optimal puncture point and optimal needle angle in three dimensions, as would be required for a paramedian approach. The use of ultrasound might also improve the performance of neuraxial puncture, especially in patients where a more difficult puncture is expected like the elderly,[18 19] or patients having spine deformities.[20] However, it might be difficult for a patient to keep the right position for this procedure, for example, in case of a broken hip.

In summary, we have shown that the anatomy of the spinous interspace shows major changes with aging, resulting in significantly less maneuver space for a spinal needle, making a midline neuraxial puncture hypothetically more difficult. The optimal approach for a puncture in terms of puncture point and angle is comparable among age groups.

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