

Implications in Forensic Medicine - an Exploratory Lumbar Spine Analysis of Sex and Age for The Romanian Population

Madalina Maria DIAC*¹,
Gina TOMA²,
Daniel TABIAN³,
Gabriela SECHEL⁴,
Andrei SCRIPCARU⁵,
Simona Irina DAMIAN⁶,
Cornelia MIRCEA⁷,
Marin FOTACHE⁸,
Diana Bulgaru ILIESCU⁹,

¹ Forensic Medicine Sciences Department, University of Medicine and Pharmacy Grigore T Popa Iasi, Institute of Legal Medicine Iasi, Romania, madalina-maria.diac@umfiiasi.ro

² University of Medicine and Pharmacy "Grigore T. Popa" Iasi, Forensic Medicine Department "Sf. Ioan" Hospital Suceava, Romania, toma.gina24@gmail.com

³ Department of Fundamental, Prophylactic and Clinical Disciplines, Medicine Faculty, Transilvania University of Brasov, Romania, daniel.tabian@unitbv.ro

⁴ Department of Fundamental, Prophylactic and Clinical Disciplines, Medicine Faculty, Transilvania University of Brasov, Romania, gabisechel@yahoo.com

⁵ Forensic Medicine Sciences Department, University of Medicine and Pharmacy Grigore T Popa Iasi, andrei.c.scripcaru@umfiiasi.ro

⁶ Forensic Medicine Sciences Department, University of Medicine and Pharmacy Grigore T Popa Iasi, Institute of Legal Medicine Iasi, Romania, simona.damian@umfiiasi.ro, si_damian@yahoo.com

⁷ University of Medicine and Pharmacy "Grigore T. Popa" Iasi, Farmacy Faculty, Pharmaceutical Biochemistry Department, cornelia.mircea@umfiiasi.ro

⁸ Alexandru Ioan Cuza University, Iasi, Romania, fotache@uaic.ro

⁹ Forensic Medicine Sciences Department, University of Medicine and Pharmacy Grigore T Popa Iasi, Institute of Legal Medicine Iasi, Romania, bulgarudiana@yahoo.com

Abstract: *The attribution of biological sex and age are important aspects in forensic medicine investigations in establishing the identity of unknown skeletal remains. Where remains are incomplete or have been compromised by damage or fragmentation, this can affect the accuracy to which sex and age can be determined and require the development of other techniques using different bone elements or isolated bone elements. The objective of the paper was to conduct a descriptive and inferential analysis on certain parameters studied on the lumbar spine with implication in estimating sex and age. The present study used 149 images of magnetic resonance of the vertebral lumbar column, on which the authors performed a large-scale analysis of three parameters measured on the RM images from a modern Romanian population. The results of the study found that mostly all variables analysed are involved in evaluation of sexual dimorphism. Regarding age prediction, in this study we conclude that some analyzed parameters are important in providing significant age differences. The present work is a novelty in the field and brings more originality, as it took into account all 5 lumbar vertebrae. The lumbar vertebrae can reliably providing an additional element to the growing list of postcranial skeletal elements that can aid in developing the biological profile of unidentified human remains. However, we need further studies with a larger number of images and to derive population-specific discriminant and regression functions.*

Keywords: *forensic medicine; vertebral lumbar column; age prediction, sex prediction, magnetic resonance images.*

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Introducere

The spine is a complex anatomical structure that includes vertebrae and intervertebral discs. Throughout life, the spine has multiple functions, supporting daily physical activities and providing the ability to carry various loads. As a person gets older, the spine undergoes degenerative changes, such as osteoporotic and osteoarthritis alterations. All these changes lead to morpho-pathological changes of the spine, changes that can be translated into reduced size of the vertebral bodies, respectively of the intervertebral discs (Grant et al. 2001, Sevinc et al. 2008).

In other words, the evaluation of vertebral deformities is based on measurements made on vertebral bodies. There are determined parameters such as: height of the vertebral body, width of the upper surface, respectively width of the lower surface of the same vertebra. According to the literature, several types of measurements of the vertebral body have been developed as well as several indices derived from these measurements (Cheng et al. 1998, Shao et al. 2002).

Usually, vertebral morphometry is evaluated using lateral X-rays, although magnetic resonance imaging (MRI) and computed tomography (CT) have also been used (Rohmani et al. 2021, Decker et al. 2019, Davy-Jow et al. 2014, Dedouit et al. 2014) . Because MRI-based vertebral morphometry was reported to be more accurate than lateral X-ray-based morphometry, in the present study we used MR images to assess age- and sex-related changes in lumbar vertebrae morphometry.

The attribution of biological sex and age are important aspects in forensic medicine investigations in establishing the identity of unknown skeletal remains. Where remains are incomplete or have been compromised by damage or fragmentation, this can affect the accuracy to which sex and age can be determined and require the development of other techniques using different bone elements or isolated bone elements (Cattaneo, 2007; Blau et al. 2008).

The objective of the paper was to conduct a descriptive and inferential analysis on certain parameters studied on the lumbar spine with implication in estimating sex and age.

Material and method

The present study used magnetic resonance imaging focused on the lumbar spine, performed on the modern population of Romania, in a Radiology Laboratory. On these images measurements were made regarding the height of the lumbar vertebral bodies (height) L1-L5, respectively the

widths of the superior and inferior endplates of the vertebral bodies, in the incidence T1- FSE (fast spin-echo), of the lumbar spine.

The study included individuals older than 17 years old, while the presence of pathologies such as scoliosis, spinal surgery or vertebral fractures were used as exclusion criteria. Thus, out of a total of 230 cases analyzed, only 149 MRI images of the lumbar spine were included in the study, of which 93 female and 56 male. The study was based on measurements of three parameters (vertebral height, width of the upper and lower endplate of the vertebra body) of the L1-L5 lumbar vertebrae. Thus, a total number of 745 vertebrae and 2,235 parameters evaluating the degree of involvement of the lumbar spine in prediction of sex and age were analyzed. Table 1 shows the measurements made and included in the study.

Table 1 Measurements made on the vertebral column (L1-L5) (*Author's own conception*)

Measurement	Abbreviation	Vertebrae	Definition
Width of superior endplate	Width_sup_lx	L1-L5	Distance between the most lateral edges of the superior plate of the vertebrae
Width of inferior endplate	Width_inf_lx	L1-L5	Distance between the most lateral edges of the inferior plate of the vertebrae
Posterior height of the vertebral body	Height_lx	L1-L5	Posterior height of the vertebral body from the left bisecting plane at the posterior part of the vertebral body at the point, which can get the largest height

MRI image analysis and measurements were performed using Radiant Dicom Viewer using the Ruler function (figure 1, 2). The data retained and required to process the database were sex and age for each person who had an MRI scan.



Figure 1, 2. Graphic aspects of performing measurements on vertebral lumbar column
Authors' own conception

Statistical analysis

Distributions of variables describing the lumbar spine were examined using Exploratory Data Analysis. Differences of lumbar vertebral morphometry variables between sexes were assessed for statistical significance with either the parametric t-test (H_0 : mean value of the numeric variable is not statistically different between sexes) or the non-parametric Mann–Whitney test (H_0 : given X a random subset of a numeric variable for females and Y a random subset of numeric variable for males, the probability of X being greater than Y is equal to the probability of Y being greater than X), according to the results reported by the Shapiro–Wilk test of normality and the Ansari–Bradley test which assesses the homogeneity of variance (Zhou et al. 2023). Association between the age and the lumbar vertebral variables was assessed with the parametric (Pearson) and non-parametric (Spearman) test of correlation.

Data was imported, prepared, explored, and analyzed using R (R23), mainly with the tidyverse ecosystem of packages (Wickham et al. 1686). Descriptive statistics tables/figures were generated with the gtsummary package (Sjoberg et al. 2021). The ggstatsplot package (Patil, 2021) was the main support for hypothesis testing, since it displays and computes, for each test, the statistics, the p-value, the effect size, and the 95% confidence interval.

Results

The study included 149 MRI images, aged 17 to 86 years ($M = 48$, median = 46, $SD = 15$), including 56 male ($M = 47$) and 93 female ($M = 49$). Figure 2 contains descriptive statistics for age and all the lumbar vertebral variables, including the results provided by the Shapiro–Wilk test of

normality (H0: the distribution is normal) and the Ansar-Bradley test (H0: the variance of homogeneous between sexes). For each variable, the following statistics are provided: the minimal value - Min, the 1st quartile (25th percentile) - Q1, the median, the 3rd quartile (75th percentile) - Q3, the maximal value - Max, the average (Mean), and the standard deviation (SD).

Variable	Min	Q1	Median	Q3	Max	Mean	SD	Shapiro-Wilk Test	Ansari-Bradley Test
age	17	38	46	60	86	48	15	W:0.977, p-value:0.012	AB:3,450.500, p-value:0.636
height_l1	1.62	2.26	2.36	2.47	2.79	2.36	0.17	W:0.973, p-value:0.005	AB:3,590.000, p-value:0.537
width_sup_l1	2.74	3.22	3.47	3.78	4.59	3.52	0.43	W:0.981, p-value:0.037	AB:3,564.000, p-value:0.677
width_inf_l1	2.90	3.41	3.70	3.98	4.74	3.69	0.40	W:0.986, p-value:0.154	AB:3,624.500, p-value:0.373
height_l2	1.90	2.30	2.41	2.55	2.83	2.42	0.18	W:0.993, p-value:0.722	AB:3,748.500, p-value:0.063
width_sup_l2	2.93	3.49	3.77	4.05	5.10	3.80	0.44	W:0.985, p-value:0.096	AB:3,604.000, p-value:0.465
width_inf_l2	2.93	3.67	3.86	4.18	5.14	3.91	0.40	W:0.983, p-value:0.061	AB:3,471.000, p-value:0.754
height_l3	1.95	2.32	2.47	2.56	2.95	2.45	0.19	W:0.981, p-value:0.039	AB:3,456.000, p-value:0.667
width_sup_l3	3.13	3.73	4.02	4.32	5.18	4.03	0.43	W:0.988, p-value:0.202	AB:3,660.000, p-value:0.242
width_inf_l3	3.12	3.79	4.05	4.34	5.55	4.08	0.45	W:0.977, p-value:0.012	AB:3,734.000, p-value:0.080
height_l4	1.92	2.32	2.44	2.57	3.05	2.44	0.20	W:0.995, p-value:0.875	AB:3,631.000, p-value:0.346
width_sup_l4	3.12	3.82	4.19	4.48	5.35	4.17	0.48	W:0.985, p-value:0.107	AB:3,696.000, p-value:0.147
width_inf_l4	3.01	3.86	4.12	4.49	5.10	4.14	0.44	W:0.990, p-value:0.400	AB:3,676.000, p-value:0.197
height_l5	1.72	2.31	2.44	2.56	3.00	2.44	0.22	W:0.987, p-value:0.171	AB:3,695.000, p-value:0.151
width_sup_l5	3.01	3.96	4.27	4.59	5.39	4.28	0.47	W:0.993, p-value:0.653	AB:3,689.000, p-value:0.163
width_inf_l5	2.93	3.80	4.05	4.41	5.08	4.09	0.42	W:0.979, p-value:0.023	AB:3,623.500, p-value:0.377

Figure 2. Descriptive statistics, normality and variance homogeneity tests (Author's own conception (statistics source))

For all variables, the variance between sexes is homogeneous, since the reported p-values of the Ansari-Bradley test exceeds the 0.05 significance level. According to the results provided by the Shapiro-Wilk test, distribution of variables age, height_l1, width_sup_l1, height_l3, width_inf_l3, width_inf_l5 is normals, whereas for the remaining numeric variables the distribution is not normal. Consequently, further tests involving normal-distributed variables will be parametric (t-test, Pearson correlation test), whereas for the non-normal distributed variables the statistical tests will be non-parametric (Mann-Whitney, Spearman correlation test).

Figures 3 to 7 compare differences between sexes on measurements of each lumbar vertebrae. The test employed depended on the normality and variance tests in figure 2. All the figures were generated by the ggstatplot package. For the parametric tests, the package includes the results of the bayesian analysis. We do not cover here the bayesian analysis, but we kept its results for the comparison of the effect size with the frequentist approach.

For L1, variable *width_inf_l1* was normally distributed, so the student test (figure 3-right) was applied. Reported p-value (5.55×10^{-5}) is far smaller

than the 0.05 significance level, and the H_0 is rejected. The effect size is large (-0.71) and the 95% confidence interval is [-1.05, -0.36]. All p-value, effect size and the confidence interval support the assertion that, for *width_inf_l1*, differences between sexes are significant and medium-large.

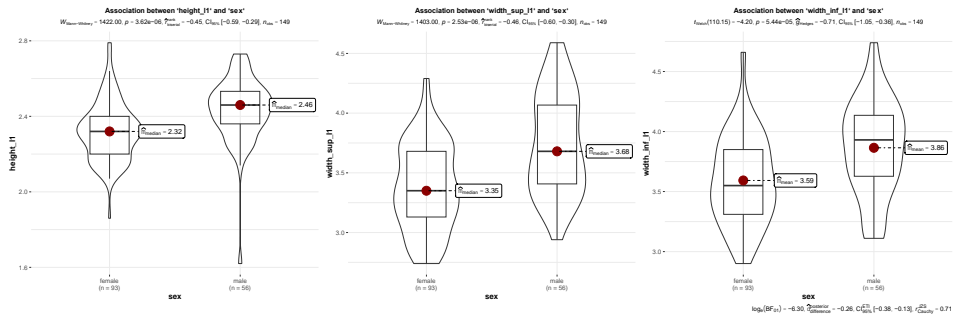


Figure 3. Differences between sexes for L1 measurements (Author's own conception (statistics source))

For the other two variables related to L1, *height_l1* and *width_sup_l1*, differences between sexes were assessed with the non-parametric Mann-Whitney test since their distribution is not normal. For *height_l1* the test reported (figure 3-left) $W=1422$, p-value < 0.001, effect size = -0.45, 95% CI [-0.59,-0.29]. These also suggest that, for *height_l1*, differences between sexes are significant and very large. Results for *width_sup_l1* were similar ($W=1403$, p-value < 0.001, effect size -0.46, 95% CI [-0.60, -0.30]).

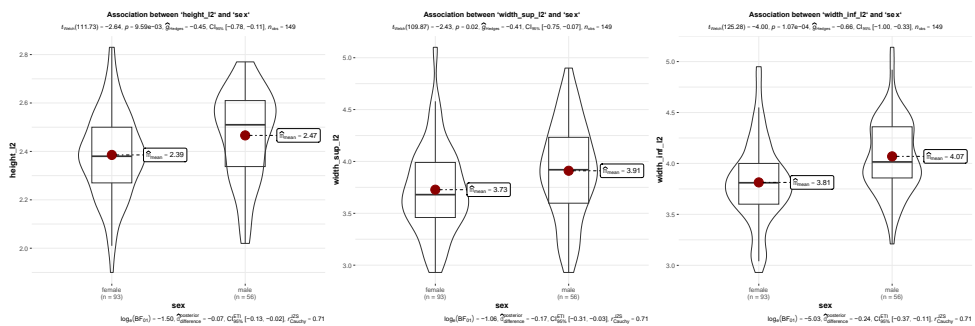


Figure 4. Differences between sexes for L2 measurements (Author's own conception (statistics source))

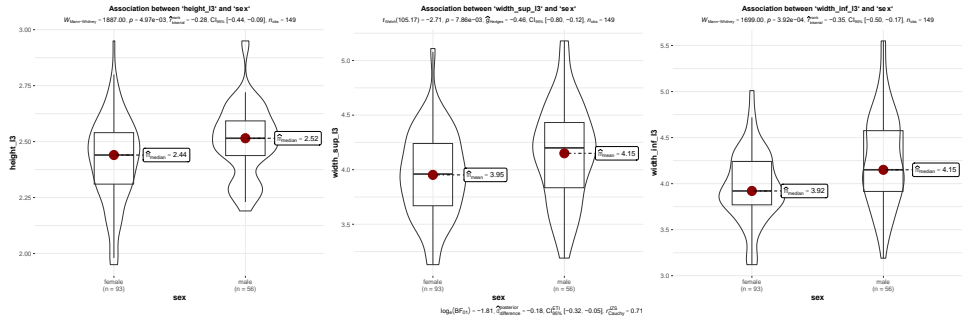


Figure 5. Differences between sexes for L3 measurements (Author's own conception (statistics source))

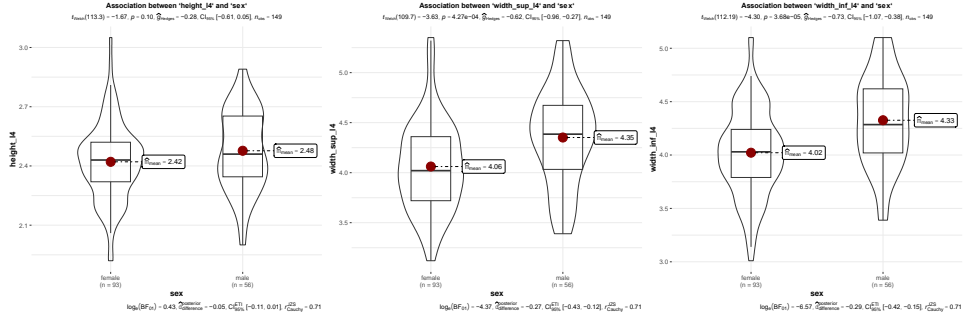


Figure 6. Differences between sexes for L4 measurements Author's own conception (statistics source)

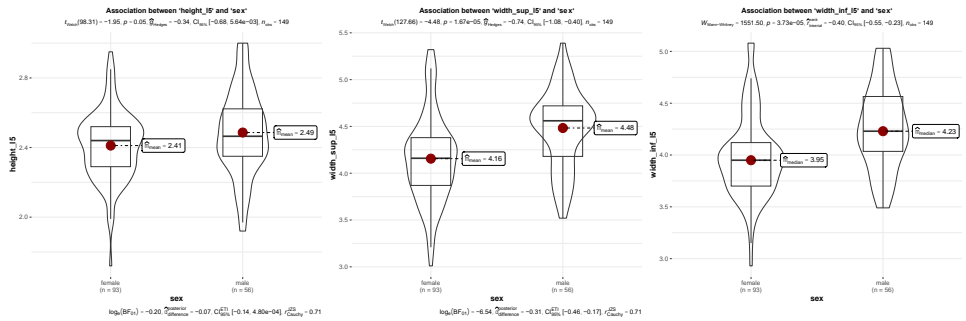


Figure 7. Differences between sexes for L5 measurements Author's own conception (statistics source)

The descriptive analysis of the lumbar vertebrae included in the study and the differences in sexual dysmorphism is shown in figure 2. (Author's own conception (statistics source))

Variable	Means and t-test						Medians and the Wilcoxon test			
	Overall (N=149)	**Females (N=93)**	**Males (N=56)**	**Mean Difference**	95% CI ¹	p-value	**Overall (N=149)**	**Females (N=93)**	**Males (N=56)**	p-value
age	48	49	47	1.7	-3.2, 6.5	0.5	46	45	47	0.7
height_l1	2.36	2.32	2.43	-0.11	-0.17, -0.06	<0.001	2.36	2.32	2.46	<0.001
width_sup_l1	3.52	3.38	3.75	-0.37	-0.50, -0.23	<0.001	3.47	3.35	3.68	<0.001
width_inf_l1	3.69	3.59	3.86	-0.27	-0.40, -0.14	<0.001	3.70	3.55	3.93	<0.001
height_l2	2.42	2.39	2.47	-0.08	-0.14, -0.02	0.010	2.41	2.38	2.51	0.004
width_sup_l2	3.80	3.73	3.91	-0.18	-0.33, -0.03	0.017	3.77	3.68	3.92	0.007
width_inf_l2	3.91	3.81	4.07	-0.26	-0.38, -0.13	<0.001	3.86	3.81	4.02	<0.001
height_l3	2.45	2.42	2.51	-0.09	-0.15, -0.03	0.002	2.47	2.44	2.52	0.005
width_sup_l3	4.03	3.95	4.15	-0.20	-0.34, -0.05	0.008	4.02	3.96	4.20	0.009
width_inf_l3	4.08	3.97	4.26	-0.29	-0.45, -0.14	<0.001	4.05	3.92	4.15	<0.001
height_l4	2.44	2.42	2.48	-0.06	-0.12, 0.01	0.10	2.44	2.43	2.46	0.11
width_sup_l4	4.17	4.06	4.35	-0.29	-0.45, -0.13	<0.001	4.19	4.02	4.39	<0.001
width_inf_l4	4.14	4.02	4.33	-0.30	-0.44, -0.16	<0.001	4.12	4.03	4.29	<0.001
height_l5	2.44	2.41	2.49	-0.07	-0.15, 0.00	0.054	2.44	2.44	2.47	0.053
width_sup_l5	4.28	4.16	4.48	-0.33	-0.47, -0.18	<0.001	4.27	4.16	4.56	<0.001
width_inf_l5	4.09	3.99	4.26	-0.27	-0.41, -0.14	<0.001	4.05	3.95	4.23	<0.001

¹CI = Confidence Interval

Figure 8 shows significant differences between male and female for almost all study parameters. With the exception of the height of the vertebral bodies L4 and L5, statistically significant differences between the sexes are otherwise present for all parameters.

Figures 9 to 13, also produced with the ggstatsplot package, displays the results of the parametric and non-parametric correlation tests (H0: variables displayed in each plot are not correlated).

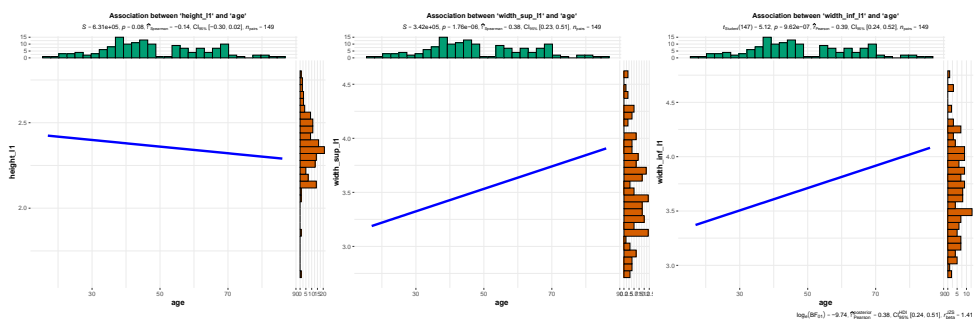


Figure 9. Association between L1 measurements and age (Author's own conception (statistics source))

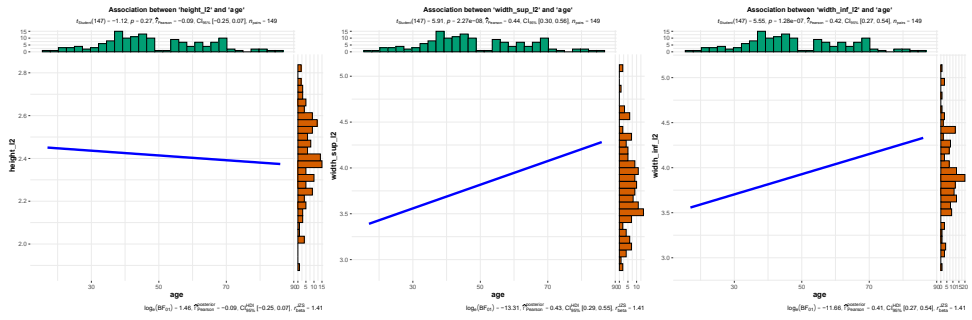


Figure 10. Association between L2 measurements and age (Author's own conception (statistics source))

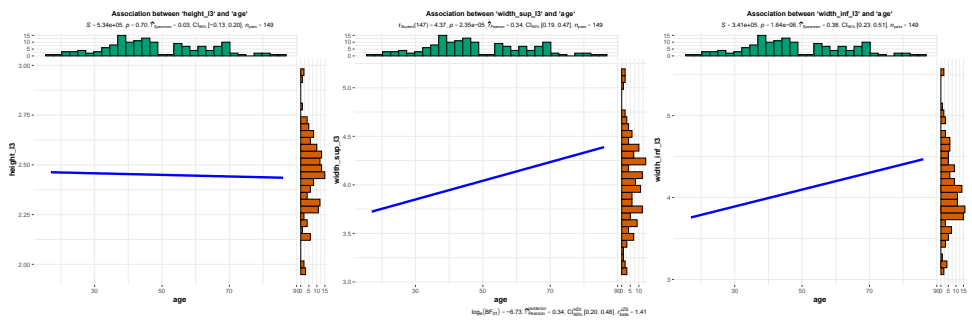


Figure 11. Association between L3 measurements and age (Author's own conception (statistics source))

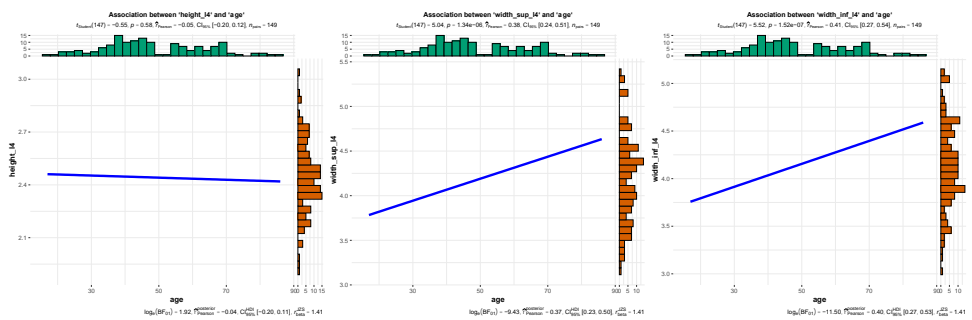


Figure 12. Association between L4 measurements and age (Author's own conception (statistics source))

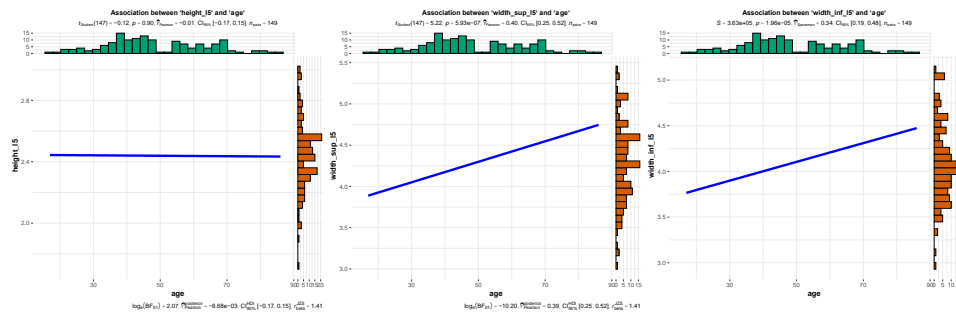


Figure 13. Association between L5 measurements and age (Author's own conception (statistics source))

Discussion

Our study evaluates sexual dysmorphism of the lumbar spine, respectively its importance in determining age in a modern European population, namely the Romanian population. The study used MRI imaging as a database, with virtual measurements. MRI and computer tomography (CT) imaging is increasingly used in forensic identification, being considered an alternative with good results in forensic anthropology. The latest studies in the field reveal a new subfield, namely virtual forensic anthropology (Davy-Jow et al. 2014; Dedout et al. 2014).

It is important and necessary to explore as many alternative methods as possible in forensic identification, and more specifically in forensic anthropology. While the importance and fidelity of the morphological analysis of the skull and pelvis in estimating sex is known, there are few studies involving other bones of the human skeleton useful in differentiating between sexes, if the skull and/or pelvis are missing or in a state of advanced degradation. As for the involvement of the human skeleton in determining age, it is, was and will be a controversial topic, since for this parameter to be determined it is particularly important to consider as many methods as possible, and continuous and extensive studies are also necessary in this sense (Mavrych et al. 2014, Aly & Amin, 2013).

The literature mentions few studies showing the involvement of the spine in sex estimation; most of these are focused more on the thoracic spine, followed by the cervical spine and finally the lumbar spine, or a combination of the last thoracic vertebrae and the first lumbar vertebra. According to said research, C2, T12 and L1 were the most widely used vertebrae for sex estimation in several populations (Rohmani et al. 2021, Choong et al. 2020).

Regarding the present study, after analyzing the degree of involvement of the L1-L5 vertebrae in sex and age prediction, through the three measurements performed (posterior height, width of the superior and inferior endplate of each vertebrae), we note that the inferential analysis (figures 3-7) reveals significant differences between sexes, except for the height of the lumbar vertebra L4 and L5 respectively. For these last two lumbar vertebrae, the inferential analysis shows that they do not have significant influences for determining the sex of an unknown individual.

Also, following the inferential analysis we notice that the measured widths, both for the upper and lower plateaus of the lumbar vertebrae L1-L5, provide statistically significant data for determining age, L1 and L2 having the strongest values of pSpearman. On the other hand, we note that the height parameter is not involved in providing significant relationships in determining age for any lumbar vertebra.

From the analysis of the figures, we identify that with age, the height on the one hand decreases and the width on the other side increases, which confirms the morphological and pathological aspects that take place throughout the life of each individual, regarding the spine.

The present work is a novelty in the field and brings more originality, as it took into account all 5 lumbar vertebrae, with three measurements each, the posterior height, respectively the widths of the upper and lower surfaces of the vertebrae.

According to the specialized literature, the study confirms sexual dysmorphism of the spine and for the Romanian population, focusing on the lumbar spine. Compared to the studies found, in which, for example, for the population of Northern Finland L4 showed the highest accuracy regarding sexual dysmorphism, a study also conducted on the image of RM, we notice that for the Romanian population, the height of the L4 vertebra does not provide significant relationships regarding sex determination, actually being the most insignificant. Similar is the case with a study conducted in the African population, in which L4 shows increased sexual dysmorphism (Ostrofsky et al. 2015, Oura et al. 2018)

Another study conducted on a North American population, observed that L3 showed the best accuracy in determining of sex, which also corresponds to the results of our study conducted on the Romanian population, the L1-L3 vertebrae showing significant differences between sexes (Sakaran et al. 2023, Garoufi et al, 2020).

The descriptive analysis indicated that males had higher average values than females for the vertebral measurements involved in the study.

Regarding the involvement of the spine in estimating age, the literature focuses on degenerative changes of the spine, and much less on different measurements of vertebrae. Thus, from this point of view, comparable aspects between the studies cited in the literature and our study are relatively absent (Franklin, 2010). We see in the present study that the widths of the upper and lower endplate of the lumbar vertebrae are the most important in providing significant differences according to age, of the 5, with the L2 vertebra having the highest values. The aforementioned aspect can be translated into the emergence of degenerative changes in the spine, as the presence of osteophytes and of lipping-ului, with age lead to an increase of the vertebral body width.

Conclusions

In conclusion, the results of this study indicate that the lumbar vertebrae reveal a large degree of sexual dimorphism and can be used for sex determination when more traditionally used skeletal elements are not available or as an aide to the use of more traditional sexing methods. However, results suggest that measures of the lumbar vertebrae can reliably estimate sex, providing an additional element to the growing list of postcranial skeletal elements that can aid in developing the biological profile of unidentified human remains. Regarding age prediction, in this study we conclude that some analyzed parameters are important in providing significant age differences. Still, we need further studies with a larger number of images and to derive population-specific discriminant and regression functions.

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