Research Article / Araştırma Makalesi

Determination of Gender By Machine Learning Algorithms, Through Using Craniocervical Junction Parameters and Dimensions of the Cervical Spinal Canal

Kraniyoservikal Bileşke Parametreleri ve Servikal Spinal Kanal Boyutları Kullanılarak Makine Öğrenimi Algoritmaları ile Cinsiyetin Belirlenmesi

[1]Gamze Taşkın Şenol, [1]İbrahim Kürtül, [1]Abdullah Ray, [1]Gülçin Ahmetoğlu,[2]Yusuf Seçgin, [3]Zülal Öner

[1] Bolu Abant Izzet Baysal University, Faculty of Medicine, Department of Anatomy, Bolu, Türkiye,
[2] Karabük University, Faculty of Medicine, Department of Anatomy, Karabük, Türkiye
[3] İzmir Bakirçay University, Faculty of Medicine, Department of Anatomy, İzmir, Türkiye

Abstract: Gender determination is the first step for biological identification. With the widespread use of machine learning algorithms (MLA) for diagnosis, the significance of applying them also in gender determination studies has become apparent. This study has therefore aimed at determining gender from the parameters obtained out of magnetic resonance images (MRI) of the cranio-cervical junction and cervical-spinal canal by using MLA. MRI of the craniocervical junction and cervical-spinal canal of 110 men and 110 women were included in this study. The 15 parameters were tested with Decision Tree (DT), Random Forest (RF), Logistic Regression (LR), Linear Discriminant Analysis (LDA), Quadratic Discriminant Analysis (QDA) algorithms. Accuracy (Acc), Specificity (Spe), Sensitivity (Sen), F1 score (F1), Matthews-correlation coefficient (Mcc) values were used as performance criteria. The Acc, Spe, Sen, F1, and Mcc were found to be 1.00 in the LR, LDA, QDA and RF algorithms. The ratios of the Acc, Spe, Sen, and F1 were 0.98, and of the Mcc was 0.96 in the DT algorithm. It was found that the ratio between the SHAP analyzer of the RF algorithm and the belt of the ratio between the arch of the atlas and the anterior-posterior distance of the dens (R3) parameter had a higher contribution to the estimation of gender compared to other parameters. It was concluded that the LDA, QDA, LR, DT and RF algorithms applied to the parameters acquired from the MRI of the craniocervical junction and cervical-spinal canal, could determine the gender with very high accuracy.
Keywords: Craniocervical Junction; Cervical Spinal Canal; Magnetic Resonance Imaging; Sex Determination; Machine Learning Algorithms

Özet: Cinsiyet belirleme, biyolojik tanımlama için ilk adımdır. Makine öğrenmesi algoritmalarının (MLA) teşhis için yaygın olarak kullanılmasıyla birlikte, cinsiyet belirleme çalışmalarında da uygulanmasının önemi ortaya çıkmıştır. Bu nedenle bu çalışmada, MLA kullanılarak kranio-servikal bileşke ve servikal-spinal kanalın manyetik rezonans görüntülerinden (MRG) elde edilen parametrelerden cinsiyetin belirlenmesi amaçlanmıştır. Bu çalışmaya 110 erkek ve 110 kadının kraniyoservikal bileşke ve servikal-spinal kanal MR görüntüleri dahil edildi. 15 parametre Karar Ağacı (DT), Rastgele Orman (RF), Lojistik Regresyon (LR), Doğrusal Diskriminant Analizi (LDA), Kuadratik Diskriminant Analizi (QDA) algoritmaları ile test edilmiştir. Performans kriterleri olarak Doğruluk (Acc), Özgüllük (Spe), Duyarlılık (Sen), F1 skoru (F1), Matthews-korelasyon katsayısı (Mcc) değerleri kullanılmıştır.Sonuçlar: Acc, Spe, Sen, F1 ve Mcc değerleri LR, LDA, QDA ve RF algoritmalarında 1.00 olarak bulunmuştur. DT algoritmasında Acc, Spe, Sen ve F1 oranları 0.98, Mcc oranı ise 0.96 olarak bulunmuştur. RF algoritmasının SHAP analizörü ile atlasın kavisi ile densin ön-arka mesafesi arasındaki oranın kemeri (R3) parametresinin cinsiyet tahminine katkısının diğer parametrelere kıyasla daha yüksek olduğu bulunmuştur. Kraniyoservikal bileşke ve servikal-spinal kanal MRG'sinden elde edilen parametrelere uygulanan LDA, QDA, LR, DT ve RF algoritmalarının cinsiyeti çok yüksek doğrulukla belirleyebildiği sonucuna varılmıştır.
Anahtar Kelimeler: Kraniyoservikal Bileşke, Servikal Spinal Kanal, Manyetik Rezonanans Görüntüleme, Cinsiyet Tayini, Makine Öğrenim Algoritması

ORCID ID of the authors: GTŞ. 0000-0001-5587-1055, İK. 0000-0002-9218-6468, AR. 0000-0002-8124-6402, GA. 0000-0002-0417-1806, YS. 0000-0002-0118-6711, YÖ. 0000-0003-0459-1015

Received 02.05.2023 ***Accepted*** .21.07.2023 ***Online published*** 24.07.2023

Correspondence: Gülçin AHMETOĞLU-- Faculty of Medicine, Department of Anatomy, Bolu Abant Izzet Baysal University, Bolu, Türkiye
e-mail: g.ahmetoglu00@gmail.com

Taskın Senol G, Kurtul I, Ray A, Ahmetoglu G, Secgin Y, Oner Z .Determination of Gender By Machine Learning Algorithms, Through Using Craniocervical Junction Parameters and Dimensions of the Cervical Spinal Canal, Osmangazi Journal of Medicine, 2023;45(5): 672-677 ***Doi:*** *10.20515/otd.1291030*

1. Introduction

Identity is estimated and determined in general by using certain peculiarities including body weight and height, and gender (1). Gender determination, surely the first step of the identification, has long been performed by several classic methods using different anatomical components. In extraordinary situations like natural disasters, contemporary methods for gender determination have become extremely essential since no proper anatomical parts can occasionally be obtained at certain circumstance. Even though DNA analyses seem to be the most reliable contemporary method -indeed it issince it requires professionals, advance laboratories, and high costs, new suitable methods are in need. Bones such as cranium, pelvis, and long bones have amply been used in gender determination since they display the highest dimorphism (2–6). Discriminant analysis has also been used previously for the gender determination (7). As mentioned above, processes of the gender determination have differed profoundly with the use of technology, and lower cost, less laboratory work and fast results have become important. MLA, an artificial intelligence technology, have recently been used most frequently in research on the gender determination particularly those on cranium. This is mostly due to a massive data increase in visualization technology on health sciences. Higher accuracy rate has led the researchers to focus on MLA, resulting in a broad and new era in gender determination. Craniocervical junction, the most moveable component of the body, attaching the cranium to the trunk (8). With its complex anatomy and structural balance, it protects the spinal cord, and it should be considered, both anatomically and radiologically, as a unity which differs from the cranium or cervical vertebrae alone (9). Anomalies or pathologies in this junction affects the flow of the CSF and venous circulation, deteriorating the drainage. Studies have measured several parameters of the craniocervical junction and cervical spinal canal and their variations (8,10–13). Upon taking into consideration of the importance of this region, this research has focused on the gender determination using the various parameters of the craniocervical junction and cervical spinal canal, via MLA. The MRI technique applied in this study is of valuable in evaluating both the soft and bony peculiarities of the cervical canal, as mentioned in the literature (12). In the study, Linear discriminant analysis (LDA), Quadratic discriminant analysis (QDA), Logistic regression (LR), Decision tree (DT), and Random Forest (RF) algorithms, all being classification algorithms of the controlled learning, have been performed. Linear discriminant analysis makes relatively simple and effective classification even at very complex situations. Quadratic discriminant analysis is effective particularly where covariant and variant levels are not homogenous. Logistic regression is used for the double classification. Tree algorithms can be applied to both classification and regression models.

2. Materials and Methods

2.1.Population Sample and Protocol for the Magnetic Resonance Imaging (MRI)

The study has ethically been approved by the Clinical Research Ethics Committee (Date: 26.04.2022, Decision No: 2022/110). The image set used in the study has randomly been retrospectively selected MRI images of 220 individuals (110 male, 110 female) with the age of 18-65. All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki. Exclusion criteria was the presence of any pathology or chirurgic procedure at craniocervical intersection. MRI images have been obtained from the 1.5 T Signa Explorer MRI Scanner (GE Medical Systems, Milwaukee, Wisconsin, USA) at the Department of Radiology, Faculty of Medicine, Bolu Abant Izzet Baysal University. MRI images of T2 segmentation were examined while taking measurements.

2.2Image Processing

The images obtained as DICOM format were transferred to Radiant DICOM Viewer program (Version 2021.2). All measurements were performed at actual 100% magnification. The lengths of the following parameters were measured; dens height (DH), anterior-posterior distance of the dens (APDD), anterior-superior distance of the dens (ASDD), length of the apical ligament of the dens (LALD), sagittal diameter of the foramen magnum (SDFM), the length of the total cervical vertebra (TCVL), length of the retropharyngeal space (LRS), anterior-posterior diameter of the spinal canal (APCSD), anterior-posterior diameter of the spinal cord (APSCD), anterior-posterior distance between of the arches of the atlas (DBAA), and the sagittal diameter of the body of C3 (C3SD) (Figure 1).

The dens angle (DA) was also measured in the study (Figure 2).

In the study, Torg Pavlov ratio (R1), the ratio between the sagittal diameter of the vertebral canal and the anterior-posterior distance of the dens (R2), the ratio between the arch of the atlas and the anterior-posterior distance of the dens (R3) were calculated. The formula for the ratios were displayed in Equation 1.

$$R1 = \frac{APCSD}{C3SD}, R2 = \frac{APCSD}{APDD}, R3 = \frac{DBAA}{APDD}$$

Equation 1. Formalization of the ratios

2.3.Machine Learning Algorithms (MLA)

For the ML modelling, Python program (version 3.7.1) and sckit-learn (version 0.20.0) were used, using a computer (i7, 8 Gb Hp-Folio 1040). Linear Discriminant Analysis (LDA), Quadratic Discriminant Analysis (QDA), Logistic Regression (LR), Decision Tree (DT), and Random Forest (RF) algorithms were chosen for the modelling.

2.4.Performance Criteria

Accuracy (Acc), Specificity (Spe), Sensitivity (Sen), F1 score (F1), and the level of Matthews correlation coefficient (Mcc) were specified as the performance criteria (Equation 2).

$$\mathrm{Acc} = \frac{\mathrm{TP}}{\mathrm{TP+FN+FP+TN}}$$

$$\mathrm{Sen} = \frac{\mathrm{TP}}{\mathrm{TP+FN}}$$

$$Spe = \frac{TN}{TN+FP}$$

$$\mathrm{Mcc} = \frac{\mathrm{TP\times TN - FP\times FN}}{\sqrt{(\mathrm{TP+FP})\times(\mathrm{TP+FN})\times(\mathrm{TN+FP})\times(\mathrm{TN+FN})}}$$

$$\mathrm{F1} = 2\frac{\mathrm{Specificity\times Sensitivity}}{\mathrm{Specificity+Sensitivity}}$$

Equation 2. Formalization of the performance criteria (TP: True positive, FP: False positive, TN: True negative, FN; False negative).

2.5.Statistical Analyses

Median, min. & max. values of the data were acquired, and Anderson Darling test was applied for the suitability of the data to normal distribution. Mann-Whitney U test was used for the comparison of nonparametric data in terms of the gender. Minitab 17 and Python programs were used for the statistical analyses, and $p \leq 0.05$ was accepted as the significance value.

3. Results

The median value of the male and female ages were 40 and 38, respectively. Statically significant results were determined with regard to gender on the parameters of DH, APDD, ASDD, LALD, TCVL, APSCD, C3SD, DBAA, R1, R2, and R3. The values of TCVL, DH, ASDD, LALD were significantly higher in males, and those of APDD, APSCD, C3SD, R1, and R3 in females ($p<0.05$, Table 1, Table 2).

Acc Spe, Sen, F1 and Mcc performance criteria ratios were found to be 1.00 in LR, LDA, QDA and RF algorithms. While the ratios of Acc, Spe, Sen and F1 criteria were all 0.98 in the DT algorithm, the ratio of Mcc criteria was found to be 0.96. The performance criteria of the algorithms are shown in Table 3.

Confusion matrix tables obtained by algorithms were shown in Figure 3. In the algorithms possessing the highest Acc ratio,

all the genders of the 21 males and 23 females in the test set were determined correctly.

SHAP analyzer model of the RF algorithm was used to evaluate the effect of the parameters to the results, and R3 parameter was found to contribute at highest degree, as displayed in Figure 4.

4. Discussion

There has been ample research in the literature on the gender determination, using very commonly the cranium, pelvis, and long bones with high accuracy ratio (2–5,14). A gender study done on the cranial skeleton, using MLA from CT images, has determined the Acc ratios as 88% by LDA and 83% by QDA models (6). Likewise, another research has used pelvis CT images, finding the Acc ratios as 91-93% by DT model (15). Another gender determination study performed on the femoral bone of the Portugal population has found the Acc ratio as 84-91%, using RF algorithms (16). Indeed, in our study, gender determination ratio of the Acc has been revealed as 100% using same algorithms, which seems to be very convenient result on the gender determination studies. We have also found the Acc ratio 98%, measured by DT model in our study. Recent studies have concentrated particularly on the specified and detail parameters of different anatomical components which have not been in question previously (17–19). This study has accordingly focused on the gender determination using the parameters obtained by MR imaging of the craniocervical intersections and cervical spinal canal, applying MLA. The results of the DH, APDD, ASDD, LALD, TCVL, APSCD, C3SD, DBAA, R1, R2, and R3 have been found to be significantly different as the gender concerned ($p \leq 0.05$), as depicted in the Table 1. After the DT algorithm, the results of Acc 0.98, Spe 0.98, Sen 0.98, F1 0.98, and Mcc 0.96, have been found upon the trial of ML. The other performance criteria after the LR algorithm have been determined as 1.00. Consequently, upon applying confusion matrix, the accuracy of gender determination was 100% in the images of 21 males and 23 females used in this study. Gender determination is a method defining and analyzing the differences of the various anatomical components between male and female, based on the analysis of sexual dimorphism (21). The important parameters for the description of biological profile of an unidentified person are age, body length, ancestry, and gender. Hence, the parameters of the age and length of the body are particularly considered as the first step to make a biological profile for the gender determination since their determination is relatively easy (3,14,21–23). Gender determination has historically been improved by the use of various procedures such as metric methods, morphological observations and/or molecular analyses (24–27). It has become critically essential for analyses various areas including paleodemography, anthropology, radiology, and basic sciences such as anatomy and forensic medicine. In this study, MLA have been applied through the MRI technique, which is relatively faster, reliable, and costing less. The results have also shown that the accuracy of it is very high as compared to the other techniques, just as displayed in Table 3. As the literature reports on the gender determination are summarized, a study has performed progressive discriminant functional analysis on the BT images of 224 atypic axis bones, with the Acc ratio of 92.6% (28). Likewise, another gender determination study done on the C7, T1, T11, and T12 vertebrates of European whites living in South Africa and black people from North Africa, has found this ratio as 89% and 85%, respectively (18). Another further research on gender determination performed in London has compared two different discriminant analysis method applying to C2, calculating the Acc ratios as 76.99% and 83.3% (17). Similarly, Acc ratios of 86.7% in trial and 89.7% in education tests, have been determined in a gender determination research on Portugal population, using LR model in C2 (30). Finally, a study has conducted on 70 BT (35 women and 35 men) images the C2 and C7 from Iranian population, finding these values as 81.4% and 78.6%, respectively (30). In our study, the Acc ratio has been obtained as 100%, applying LR algorithms for the gender determination. Overall, literature possesses studies that have dealt with the

morphometrical analyses of the craniocervical and spinal canal parameters (10,11). Our study, on the other hand, is the first research, as to our knowledge, that has focused on the gender determination out of these parameters.

5. Conclusions

Consequently, identity determination is particularly essential out of the anatomical remnants acquired from the disasters like fire, flood, war, and deadly accidents. Upon the advanced technological developments, artificial intelligence studies have more frequently been employed on gender determination, resulting in the suggestion that it will be used as a vital assistant tool in medical area. Likewise, results of the studies on gender determination just as the case in our study, relatively easy and without too much work load, are also very suitable means in confirming normal anatomical and pathological limits by specialist. Introducing these results in gender differentiation to the artificial intelligence formats will surely results in categorizing the gender data, thus yielding to faster and more appropriate diagnoses. After all, our research using MRI technologies for gender determination by MLA, have shown that it can be performed within a very short period of time with very high accuracy. We have obtained 100% Acc ratio by the LDA, QDA, DT, and RF algorithms, and 98% Acc ratio by the DT algorithm, which contributes profoundly to the future MLA studies.

REFERENCES

1. Zeyfeoğlu Y, Hancı İH. İnsanlarda Kimlik Tespiti. *Sted*. 2001;10(10):375–7.
2. Durić M, Rakočević Z, Donić D. The reliability of sex determination of skeletons from forensic context in the Balkans. *Forensic Sci Int.* 2005;147(2-3 SPEC.ISS.):159–64.
3. Kranioti EF, Apostol MA. Sexual dimorphism of the tibia in contemporary Greeks, Italians, and Spanish: forensic implications. *Int J Legal* Med. 2015;129(2):357–63.
4. Tellioglu AM, Karakas S. Humerus'tan morfometrik yöntemlerle cinsiyet tayini. *FÜSağBilTıp Derg*. 2013;27(2):75–9.
5. Tellioglu AM, Durum Y, Gök M, Karakas S, Polat AG, Karaman CZ. Suitability of foramen magnum measurements in sex determination and their clinical significance. *Folia Morphol.* 2018;77(1):99–104.
6. Toy S, Secgin Y, Oner Z, Turan MK, Oner S, Senol D. A study on sex estimation by using machine learning algorithms with parameters obtained from computerized tomography images of the cranium. *Sci Rep* [Internet]. 2022;12(1):1–11.
7. Güleç E, Sağır M, Özer İ. İnsan İskeletlerinde Foramen Magnum'dan Cinsiyet Tayini. *Ankara Üniversitesi Dil ve Tarih-Coğrafya Fakültesi Derg*. 2003;43(1):1–9.
8. Seçme Özkaya Z, Aslan A. Kranioservikal Bileşke Travmalarında Tanı Yöntemleri. Arşiv *Kaynak Tarama Derg.* 2016;25(3):335–50.
9. Offiah CE, Day E. The craniocervical junction: embryology, anatomy, biomechanics and imaging in blunt trauma. Insights Imaging [Internet]. 2017;8(1):29–47.
10. Korkmaz M, Kilincer C. Derleme Türk Nöroşir Servikal Dar Kanalda Doğal Seyir ve İzlem Araçlarının Yeri Natural Course of Cervical Spinal Stenosis and Follow-up *Tools. Derg.* 2018;28(2):159–64.
11. Malas MA, Salbacak A, Aler A, Yardımcı C. Lumbal canalis vertebralis orta sagittal çaplarının magnetic resonance görüntüleme ile belirlenmesi. *Sdü Tip Fakültesi Dergisi. 1*997;4(3):7–11.
12. Sunar M, Kapakin S. Morphometric evaluation of craniocervical junction by magnetic resonance imaging method. *Asian J Neurosurg*. 2019;14(3):702–9.
13. Ulbrich EJ, Schraner C, Boesch C, Hodler J, Busato A, Anderson SE, et al. Normative MR cervical spinal canal dimensions. *Radiology*. 2014;271(1):172–82.
14. Kranioti EF, Vorniotakis N, Galiatsou C, Işcan MY, Michalodimitrakis M. Sex identification and software development using digital femoral head radiographs. *Forensic Sci Int.* 2009;189(1–3):113.e1-113.e7.
15. Secgin Y, Oner Z, Turan M, Oner S. Gender prediction with parameters obtained from pelvis computed tomography images and decision tree algorithm. Med Sci | *Int Med J.* 2021;10(2):356.
16. Curate F, Umbelino C, Perinha A, Nogueira C, Silva AM, Cunha E. Sex determination from the femur in Portuguese populations with classical and machine-learning classifiers. *J Forensic Leg Med* [Internet]. 2017;52:75–81.
17. Marlow EJ, Pastor RF. Sex Determination Using the Second Cervical Vertebra—A Test. J Forensic Sci. 2011;56(1):165–9.
18. Ünlütürk Ö, İşcan MY. Tanınabilir Vertebralardan Cinsiyet Tayini. Bull Leg Med. 2014;18(1):4–13.
19. Rohmani A, Shafie MS, Nor FM. Sex estimation using the human vertebra: A

systematic review. *Egypt J Forensic Sci*. 2021;11(1).
20. Gülhan Ö. Pelvis'ten radyolojik yöntemler ile cinsiyet tayini: Türkiye örneklemi. *Antropoloji*. 2018;36:53–69.
21. Gill GW. Racial Variation in the Proximal and Distal Femur: Heritability and Forensic Utility. *J Forensic Sci.* 2001;46(4):15049J.
22. Inskip S, Scheib CL, Wohns AW, Ge X, Kivisild T, Robb J. Evaluating macroscopic sex estimation methods using genetically sexed archaeological material: The medieval skeletal collection from St John's Divinity School, Cambridge. *Am J Phys Anthropol*. 2019;168(2):340–51.
23. Scheuer L. Application of osteology to forensic medicine. *Clin Anat.* 2002;15(4):297–312.
24. Ahmed AA. Estimation of sex from the upper limb measurements of Sudanese adults. J *Forensic Leg Med* [Internet]. 2013;20(8):1041–7.
25. Ali Z, Cox C, Stock MK, Zandee vanRilland EE, Rubio A, Fowler DR. Estimating Sex Using Metric Analysis of the Scapula by Postmortem Computed Tomography. *J Forensic Sci.* 2018;63(5):1346–9.
26. Colman KL, de Boer HH, Dobbe JGG, Liberton NPTJ, Stull KE, van Eijnatten M, et al. Virtual forensic anthropology: The accuracy of osteometric analysis of 3D bone models derived from clinical computed tomography (CT) scans. *Forensic Sci Int* [Internet]. 2019;304:109963.
27. Colman KL, van der Merwe AE, Stull KE, Dobbe JGG, Streekstra GJ, van Rijn RR, et al. The accuracy of 3D virtual bone models of the pelvis for morphological sex estimation. *Int J Legal Med.* 2019;133(6):1853–60.
28. Torimitsu S, Makino Y, Saitoh H, Sakuma A, Ishii N, Yajima D, et al. Sexual determination based on multidetector computed tomographic measurements of the second cervical vertebra in a contemporary Japanese population. *Forensic Sci Int* [Internet]. 2016;266:588.e1-588.e6.
29. Gama I, Navega D, Cunha E. Sex estimation using the second cervical vertebra: a morphometric analysis in a documented Portuguese skeletal sample. *Int J Legal Med*. 2015;129(2):365–72.
30. Mostafavi RS, Memarian A, Amiri A, Motamedi O. Estimating Sex from second and seventh cervical vertebras in Iranian adult population using Computed Tomography scan images. *Nucl Med Med Imaging* [Internet]. 2020;1–13.

Etik Bilgiler

Etik Kurul Onayı: Çalışma Eskişehir Osmangazi Üniversitesi Girişimsel Olmayan Etik Kurulu'ndan tarafından onaylanmıştır (Karar no: 14, Tarih: 21.11.2017).
Onam: Bu çalışma için katılımcılardan sözlü onam alınmıştır.
Telif Hakkı Devir Formu: Tüm yazarlar tarafından Telif Hakkı Devir Formu imzalanmıştır.
Hakem Değerlendirmesi: Hakem değerlendirmesinden geçmiştir.
Yazar Katkı Oranları: Fikir/kavram: GTŞ, İK, AR, GA, YS,ZÖ Tasarım: GTŞ, İK Veri Toplama: AR, GA, YS Veri İşleme: AR, GA, YS Analiz/Yorum: GTŞ, İK, AR, GA, YS,ZÖ Literatür taraması: GTŞ, İK, AR, GA, YS,ZÖ Yazma: GTŞ, İK, AR, GA, YS,ZÖ.
Çıkar Çatışması Bildirimi: Yazarlar çıkar çatışması olmadığını beyan etmişlerdir.
Destek ve Teşekkür Beyanı: Yazarlar bu çalışma için finansal destek almadıklarını beyan etmişlerdir.