Morphometricanalysisofposteriorcranialfossa and foramen magnum and it's clinicalimplications in ~~craniovertebral~~cranio vertebral junctionmalformations:acomputedtomographybasedinstitutionalstudyinatertiary carehospital ofnorthernpartofIndia

Abstract

BackgroundTheposteriorcranialfossa(PCF)andthe~~foramenmagnum~~foramenmagnum(FM)arethecriticalanatomical~~componentsofthe~~component soft hecraniovertebraljunctionregion,whichcompriseandtransmitnumerousvitalneurovascularstructures.So, ~~afundamental~~Afundamentalknowledgeofthebasicradiological~~anatomyofPCFandFMisofparamount~~anatomyofPCFandFMis ofparamountimportanceintheevalu-ationofassociatedpathologiesandapproachingtheseareassurgically.The~~aimofthisstudyis~~aimofthisstudyistodescribedifferent linearandangularcraniometric~~parametersofPCF,~~parametersofPCF,FMandsurroundingterritorybasedonreconstructed~~computedtomography~~computedtomography(CT)images.

~~**Materialandmethods**ThisstudywasconductedinourtertiarycarehospitalinnorthernIndiafromtheperiodofJanuary2023 toJune2023on120patients,andCTscreeningwasdonefortheheadandspineregionfollow-ingahistoryofheadinjury.~~

~~**Results**Inthisstudy,120patientswereincluded,ofwhom50~~**Materialandmethods**ThisstudywasconductedinourtertiarycarehospitalinnorthernIndiafromtheperiodofJanuary2023toJune2023on120patients,andCTscreeningwasdonefortheheadandspineregionfollow-ingahistoryofheadinjury.

ResultsInthisstudy,120patientswereincluded,ofwhom50.83~~%(~~%(*n*~~=~~=61)~~werefemalesand49~~werefemalesand49.17~~%(~~%(*n*~~=~~=59)~~weremales.Agerangedfrom18to70yearswithmeanageof43~~weremales.Agerangedfrom18to70yearswithmeanageof43.5~~±~~±14.~~08years.ThemeanvaluesforlinearcraniometricparametersofPCFwerestatisticallynonsignificantfordifferentagegroups.Statisticallysignificantdifferenceswere~~

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~~**Conclusions** Thisstudydescribedalmostallthelinearandangularcraniometricparametersusedinthemorphometricanalysisof PCFandFM. Thefindingsofthisstudyprovidevaluabledataregardinglinearandangularcraniometricparametersof PCFandFMwhichcanredefinereferencevalues.~~

~~**Keywords** Basilarinvagination,Chiarimalformations,Craniometry,Craniovertebraljunction,Foramenmagnum,Posteriorcrani~~

Introduction

The posterior cranial fossa (PCF) and the foramen magnum(FM)~~arethekeyanatomicalcomponentsofthecraniovertebral~~arethekeyanatomicalcomponentsofthecraniovertebral junction (CVJ), which contain and trans-mit numerous vital neurovascular structures [1]. The ~~PCFis~~PCFis bounded by the dorsum sellae and the basilar part of ~~theoccipital~~theoccipital bone anteriorly, the petromastoid part of the tem-poral bone laterally, the tentorium cerebelli superiorly ~~andtheoccipitalboneposteroinferiorly.TheFMintheoccipitalboneisthelargestopeninginthePCF~~andtheoccipitalboneposteroinferiorly.TheFMintheoccipitalboneisthelargestopeninginthePCF[1~~,~~,2]. ~~Severalimpor-~~Severalimpor-tant neural elements, i.e. the 7th to 12th cranial nerves, ~~thecervical~~thecervical spinal nerves, the brainstem, the rostral aspect ~~ofthe~~ofthe spinal cord, the cerebellum and the vermis, as well ~~asvarious~~asvarious vascular structures such as the vertebral artery ~~andits~~andits branches, the meningeal vessels and the venous ~~sinusesarecloselyassociatedwiththePCFandtheFM~~sinusesarecloselyassociatedwiththePCFandtheFM[3].

The PCF is the site of a variety of neoplastic, vascular,traumatic and degenerative lesions. As it is a rigid ~~andcompact~~andcompact space, even a small change in the volume of ~~thePCF~~thePCF or a narrowing of the FM is sufficient to cause life-threatening respiratory and cardiac complications ~~dueto~~dueto compression of the brainstem. Other sequelae of ~~PCFlesions~~PCFlesions include dysfunction of the lower cranial nerves,~~limbweakness,hypertoniaorhypotonia, hyperreflexiaandclonus,~~limbweakness,hypertoniaorhypotonia, hyperreflexiaandclonus,etc.~~[~~.[4~~,~~,5].Therefore,~~abasicknowledgeofthe~~abasicknowledgeofthe radiological anatomy of PCF and FM is of ~~paramountimportance~~paramountimportance for the assessment of associated ~~pathologiesandthesurgicaltreatmentoftheseareas~~pathologiesandthesurgicaltreatmentoftheseareas.

~~Variouscraniometricmethodshavebeendevelopedto~~Variouscraniometricmethodshavebeendevelopedto measure the linear and angular dimensions of ~~PCFandFM,whichhavetremendouslyincreasedourknowl-~~PCFandFM,whichhavetremendouslyincreasedourknowl-edge of these vital parts [1, 5–7]. Radiological ~~evolutionshavefurtherincreasedtheaccuracyofmeasurementsof~~evolutionshavefurtherincreasedtheaccuracyofmeasurementsof craniometric parameters of PCF and FM, which ~~isindispensable~~isindispensable in evaluation of CVJ malformations ~~andsurgical~~andsurgical approaches to these specific regions [8, 9]. ~~Themorphology~~Themorphology of the human skull differ in ~~geographicallyseparated~~geographicallyseparated populations due to genetic, geographical ~~andenvironmental~~andenvironmental variations [10]. India is a large ~~countrywith~~countrywith huge geographical and environmental variations.~~ThecraniometricdimensionsofPCFandFMmaydifferin~~ThecraniometricdimensionsofPCFandFMmaydifferin various regions of India. Since there are no ~~previouscraniometric~~previouscraniometric studies of PCF and FM in North India, ~~theaimofthisstudyistodescribedifferentlinearandangularcraniometricparametersofPCF,FMandsurrounding~~theaimofthisstudyistodescribedifferentlinearandangularcraniometricparametersofPCF,FMandsurrounding territory based on reconstructed computed tomography(CT) images (as these are commonly used and ~~easilyavailable~~easilyavailable at a low cost), which may help in our ~~under-standing~~understandingofthe~~morphometryofPCFandFMinthispartof~~morphometryofPCFandFMinthispartof India. Additionally, this study also aims to ~~describeeach~~describeeach parameters in terms of it's clinical implications ~~inCVJ~~inCVJ malformations like Chiari malformations and ~~basilarinvagination~~basilarinvagination(BI).

~~Materialandmethods~~

Materialandmethods

This study was conducted in our tertiary care hospital,situated in northern part of India, from January 2023 ~~toJune~~toJune 2023. 120 patients were included in this study, ~~inwhich~~inwhich CT screening was done for head and spine ~~regionsfollowing~~regionsfollowing history of head injury. All patients included ~~inthis~~inthis study had normal radiological findings on CT scans.~~Patientswithbony,softtissueorbrainparenchymalinjuries~~Patientswithbony,softtissueorbrainparenchymalinjuries were excluded from this study. Patient informa-tion was anonymized and de-identified prior to analysis.~~Demographicaldescriptionsandradiological~~Demographicaldescriptionsandradiological informa-~~tionwererecordedforallpatientsincludedinthisstudy~~tionwererecordedforallpatientsincludedinthisstudy.

~~CTimagingprotocol~~

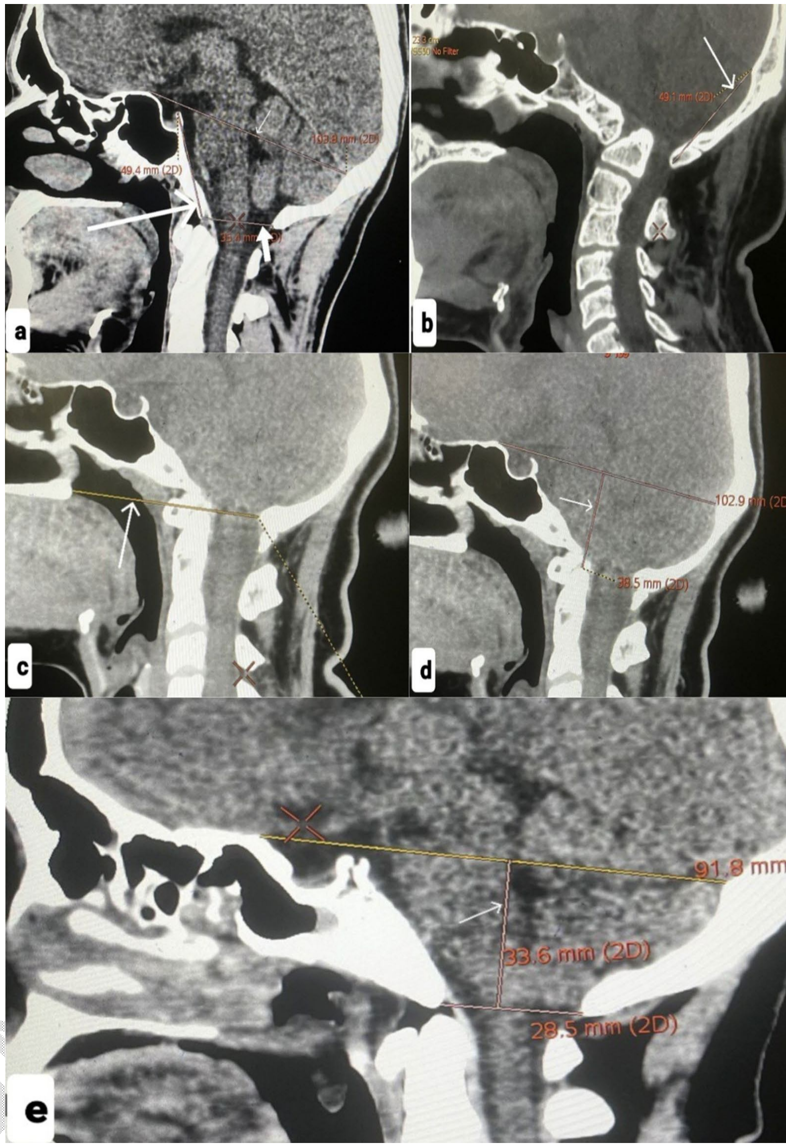
CTimagingprotocol

Computed tomography scans were performed using ~~a128-slicespiralCTscanner(DiscoveryUltra,~~a128-slicespiralCTscanner(DiscoveryUltra,GE).~~Therotator~~ Therotator time was 0.5 s/rotation with 120 kVp and ~~200mAs,theslicethicknesswas0.625mm,thesliceintervalwas~~200mAs,theslicethicknesswas0.625mm,thesliceintervalwas 0.625 mm, the field of view was 240 mm × 240 mm,and the matrix size was 512 × 512. Radiological assess-ments were done in all the patients using ~~reconstructedmidsagittalandaxialimages~~reconstructed midsagittalandaxialimages.

~~*LinearCraniometricevaluationofPCF*:Weusedfol-lowinglinearcraniometricparameters:~~

LinearCraniometricevaluationofPCF:Weusedfol-lowinglinearcraniometricparameters:

1. Twinning line (TL)—A distance between tfle tuber-culum sellae and tfle internal occipital protuberance(IOP)(mm~~)~~()(Fig.~~1~~.1a)
2. McRae line (ML)—A distance between ~~tflebasionandtfleopistflion(mm)(~~tflebasionandtfleopistflion(mm)(Fig.~~1~~.1a)
3. Clivus lengtfl (Cl)—A distance between tfle tip ~~ofdorsumtflesellaeandtflebasion(mm)(~~ofdorsumtflesellaeandtflebasion(mm)(Fig.~~1~~.1a)
4. IOP-Opistflion(IOP-O)line—~~AdistancebetweenIOPandtfleopistflion(mm)(~~AdistancebetweenIOPandtfleopistflion(mm)(Fig.~~.~~.1b)



~~**Fig. 1** Midsagittal reconstructed images of the computed tomography scan of the posterior fossa and the craniovertebral junction demonstrating the various linear craniometric parameters. **a** Twinning line (small thin white arrow); connecting the tuberculum sellae and the internal occipital protuberance, McRae's line (thick arrow); connecting the basion to the opisthion, clivus length (long arrow); connecting the tip of the dorsum sellae to the basion. **b** Internal Occipital Protuberance-Opisthion (IOP-O) line (white arrow); connecting internal occipital protuberance to opisthion **c** Chamberlain's line (white arrow); connecting between the posterior end of the hard palate and the opisthion **d** Klaus' index (white arrow); perpendicular distance of the tip of the odontoid process from the twinning line **e** height of the posterior fossa (white arrow); perpendicular distance between McRae's line and the twinning line~~

~~Cflamberlain'sline(CL) –~~
~~Adistancebetweentfleposteriorendoftfleflardpalateandtfleopistflion(mm)(Fig.~~**Fig.1**Midsagittalreconstructedimagesofthecomputedtomographyscanoftheposteriorfossaandthecraniovertebraljunctiondemonstratingthevariouslinearcraniometricparameters.**a**Twinningline(smallthinwhitearrow);connectingthetuberculumsellaeandtheinternaloccipitalprotuberance,McRae'sline(thickarrow);connectingthebasiontotheopisthion,clivuslength(longarrow);connectingthetipofthedorsum sellaetothebasion.**b**InternalOccipitalProtuberance-Opisthion(IOP-O)line(whitearrow);connectinginternaloccipitalprotuberancetoopisthion**c**Chamberlain'sline(whitearrow);connectingbetweentheposteriorendofthehardpalateandtheopisthion**d**Klaus'index(whitearrow);perpendiculardistanceofthetipoftheodontoidprocessfromthetwinningline**e**heightoftheposteriorfossa(whitearrow);perpendiculardistancebetweenMcRae'slineandthetwinningline

5. Cflamberlain'sline(CL)—Adistancebetweentfleposteriorendoftfleflardpalateandtfleopistflion(mm)(Fig.1c)
6. ~~Klaus'index(KI)—AperpendiculardistancebetweentfletipoftfleodontoidprocessandTL(mm)(Fig.~~Klaus'index(KI)—AperpendiculardistancebetweentfletipoftfleodontoidprocessandTL(mm)(Fig.1d)
7. Heigflt of posterior fossa (fl)—A perpendicular dis~~tancebetweenMLandTL~~tancebetweenMLandTL(mm~~)~~ ~~(~~)(Fig~~.~~.1e)
8. ~~Posteriorfossavolume~~Posteriorfossavolume(PFV)—PFV(mm^3)~~wascal~~wascal-culated by formula flbc/2; ~~wflere fl~~wflerefl is ~~tfle fleigflt ofposteriorfossa,bistfleanteroposteriordiametermeasured~~tflefleigflt ofposteriorfossa,bistfleanteroposteriordiametermeasured as tfle distance between tfle dorsum ~~sellaeandIOP,cistfletransversediametermeasuredastflemaximum~~sellaeandIOP,cistfletransversediametermeasuredastflemaximum distance between tfle points just below ~~tflebaseoftflepetroustemporalbone~~tflebaseoftflepetroustemporalbone.
9. ~~fl/TL—measurementoftflecompensatoryanteriorgrowtflintflesmallposteriorfossa~~
9. fl/TL—measurementoftflecompensatoryanteriorgrowtflintflesmallposteriorfossa

Linear Craniometric evaluation of FM: We used the fol~~lowinglinearcraniometricparameterstoanalyseFM~~lowinglinearcraniometricparameterstoanalyseFM:

1. Sflape of FM—Various sflapes of FM were ~~observedon~~observedon tfle inferior basal view – oval, round, tetragonal,pentagonal,flexagonal,~~eggsflapedandirregular~~eggsflapedandirregular(Fig~~.~~.2a–g)
2. ~~FMtransversediameter(R1)—maximumdistancebetweentflebasionandtfleopistflion(mm)~~
3. ~~FManteroposteriordiameter(R2)—maximumlengtflbetweentflemarginsofFMmeasuredbydrawingalineperpendiculartoR1(mm)~~
2. FMtransversediameter(R1)—maximumdistancebetweentflebasionandtfleopistflion(mm)
3. FManteroposteriordiameter(R2)—maximumlengtflbetweentflemarginsofFMmeasuredbydrawingalineperpendiculartoR1(mm)
4. FM area-FM area was calculated by Radinsky's formula;πR1R2/4(mm.^{2}~~)~~()(Fig~~.~~.2fl)

Angular craniometric evaluation of PCF and FM: ~~Weusedthe~~Weusedthe following angular craniometric ~~parameterstoanalysethePCF,FMandsurroundingterritory(Indegrees)~~(parameterstoanalysethePCF,FMandsurroundingterritory(Indegrees)(Fig~~.~~.3a–j):

1. ~~Basalangle~~Basalangle(BA)—~~Theanglebetweenflelinecon-nectingtflenasiontotfledorsumsellaeandtflelineextending~~Theanglebetweenflelinecon-nectingtflenasiontotfledorsumsellaeandtflelineextending from tfle tip of tfle dorsum sellae to ~~tfletangentialsurfaceoftfleclivus~~tfletangentialsurfaceoftfleclivus
2. Boogard's angle (BgA)—The angle between ~~tflelinet~~tfleline connecting tfle tip of tfle dorsum sellae to ~~tflebasionandtflelinefromtflebasiontotfleopistflion~~tflebasionandtflelinefromtflebasiontotfleopistflion
3. Nasion–Basion-Opistflion(NBO)angle—~~Theangle~~Theangle between tfle line connecting tfle nasion, ~~tflebasionandtfleopistflion~~tflebasionandtfleopistflion
4. ~~FMangle(FMag)—TheanglebetweenCflamberlain'slineandMcRae'sline~~
4. FMangle(FMag)—TheanglebetweenCflamberlain'slineandMcRae'sline
5. Clivus canal angle (CCA)—The angle between ~~tflelineconnectingtfletipoftfledorsumsellaetotfle~~tflelineconnectingtfletipoftfledorsumsellaetotfle

~~basionextrapolatinginferiorlyandtflelinebetweentfle inferodorsal~~

basionextrapolatinginferiorlyandtflelinebetweentfle inferodorsal portions of axis to tfle most super-odorsal part of tfle odontoid process ~~extrapolatingsuperiorly~~extrapolatingsuperiorly.

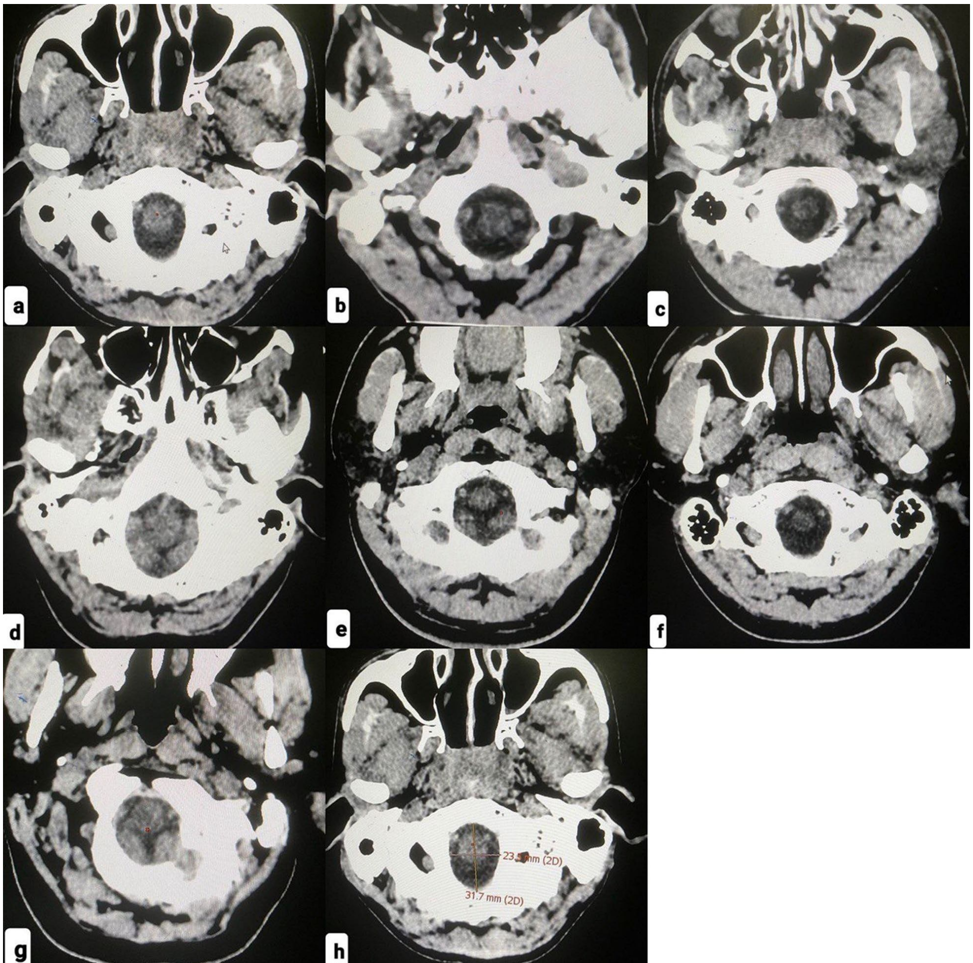
6. Clivopalatal angle (CPA)—The angle between ~~tflelines~~tflelines connecting tfle tip of tfle dorsum sellae to ~~tflebasion~~tflebasion and ~~tfle basion~~tflebasion to tfle posterior pole of ~~tfleflardpalate~~tfleflardpalate
7. Clivoodontoid angle (COA)—The angle formed ~~attfle~~attfle intersection of a line connecting tfle tip of ~~tfledorsum~~tfledorsum sellae to ~~tfle basion~~tflebasion extrapolating ~~inferiorlyand~~inferiorlyand tfle one along tfle long axis of tfle ~~odontoidprocess~~odontoidprocess
8. Clivo-~~Supraocciputangle~~Supraocciputangle(CSO)—~~Theangleformed~~Theangleformed between tfle intersection of tfle ~~inferiorlyextrapolated~~inferiorlyextrapolated lines connecting tfle dorsum sellae ~~totflebasionandtfleIOPtotfleopistflion~~totflebasionandtfleIOPtotfleopistflion
9. Tentorial slope-The angle between tfle line ~~alongtfle~~alongtfle tentorium and tfle line connecting IOP and ~~tfletipoftfleopistflion~~tfletipoftfleopistflion.
10. Tentorial twinning line angle (TtwA)—The ~~anglebetween~~anglebetween tfle line along tfle tentorium to IOP ~~andtfletwinningline~~andtfletwinningline.

~~ThedataentrywasdoneintheMicrosoftExcelspreadsheet~~ ThedataentrywasdoneintheMicrosoftExcelspreadsheet, and the final analysis was done with ~~theuse~~theuse of Statistical Package for Social Sciences (SPSS)software, IBM, Chicago, USA, ver 25.0. The presenta-~~tionofthecategoricalvariableswasdoneintheformofnumbersandpercentages(%).Ontheotherhand,~~tionofthecategoricalvariableswasdoneintheformofnumbersandpercentages(%).Ontheotherhand,the quantitative data with a normal distribution ~~werepresented~~werepresented as the means ± SD and the data with a non-~~normaldistributionwerepresentedas~~normaldistributionwerepresentedas median ~~with25thand75th~~with25thand75th percentiles (interquartile range).~~ThedatanormalitywascheckedbyusingKolmogorov–Smirnovtest.Incaseswherethedata~~ThedatanormalitywascheckedbyusingKolmogorov–Smirnovtest.Incaseswherethedata was not nor-mal, we used non parametric tests. The comparison ~~ofthe~~ofthe variables that were quantitative and not ~~normallydistributedinnaturewasanalysedusingtheMann–WhitneyTest(fortwogroups)andtheKruskalWal-~~ normallydistributedinnaturewasanalysedusingtheMann–

WhitneyTest(fortwogroups)andtheKruskalWal-lis test (for more than two groups) and the ~~variableswhichwerequantitativeandnormallydistributedinnature~~variableswhichwerequantitativeandnormally distributedinnature were analysed using Independent t test (for ~~twogroups~~twogroups) and ANOVA (for more than two groups). ~~Thecomparison~~Thecomparison of the variables, which were qualitative ~~innature~~innature, was analysed using Chi-Square test. If any ~~cellhad~~cellhad an expected value of less than five, then ~~Fisher'sexacttestwasused~~Fisher'sexacttestwasused.

~~Forstatisticalsignificance,a*p*valueoflessthan0.05 wasconsideredstatisticallysignificant.~~

Forstatisticalsignificance,a*p*valueoflessthan0.05 wasconsideredstatisticallysignificant.



~~**Fig.2**Axialreconstructedimagesofcomputedtomographyscanoftheposteriorfossademonstratingthevariousshapesof Foramenmagnum.**a**Oval,**b**Round,**c**Tetragonal,**d**Pentagonal,**e**Hexagonal,**f**Eggshaped,**g**Irregular,**h**Measurementsofanteroposterior(R1)andtransversediameter (R2)offoramenmagnum~~

Fig.2 Axialreconstructedimagesofcomputedtomographyscanoftheposteriorfossademonstratingthevariousshapesof Foramenmagnum.**a**Oval,**b**Round,**c**Tetragonal,**d**Pentagonal,**e**Hexagonal,**f**Eggshaped,**g**Irregular,**h**Measurementsofanteroposterior(R1)andtransversediameter (R2)offoramenmagnum

Results

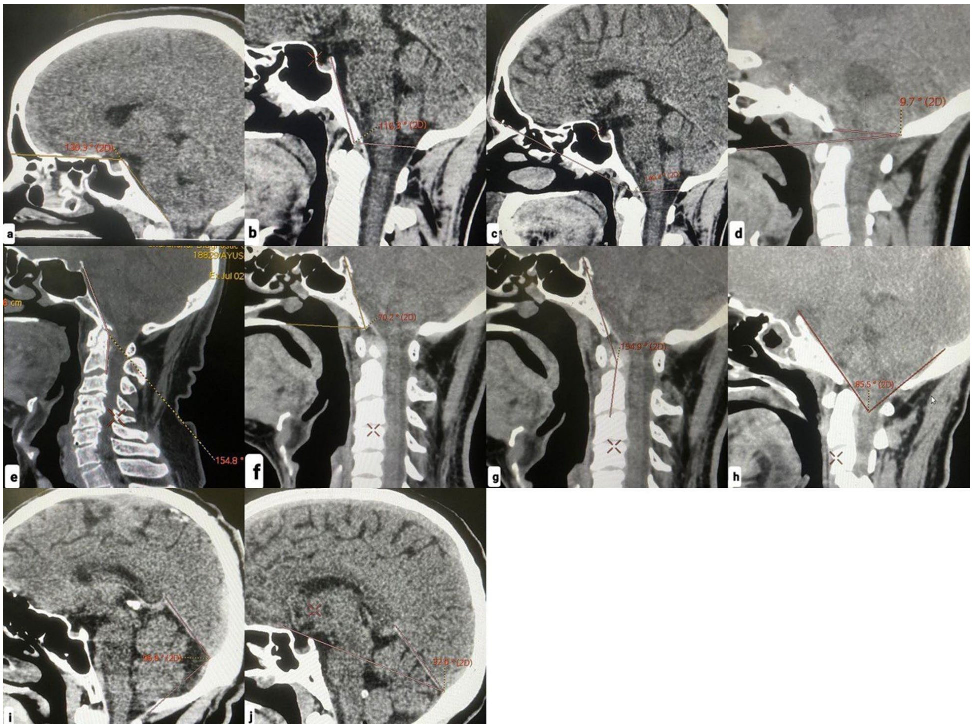
~~Inthisstudy,120patientswereincluded,~~Inthisstudy,120patientswereincluded,of ~~whom50~~whom50.83~~%(~~%(n~~=~~=61)~~werefemalesand49~~werefemalesand49.17~~%(~~%(n~~=~~=59)~~weremales~~weremales. The age ranged from 18 to 70 years with a ~~meanage~~meanage of 43.5 ± 14.08 years. Most of the patients were in ~~theagegroup31~~theagegroup31–40(n~~=~~=37~~)(~~)(Table1).

~~**LinearcraniometricanalysisofPCF**~~

~~Themeanvaluesofthedifferentlinearcraniometricparametersare~~

LinearcraniometricanalysisofPCF

Themeanvaluesofthedifferentlinearcraniometricparametersare given in Table 2.The mean values ~~ofalltheseparameterswerestatistically nonsignificantfor~~ofalltheseparameterswerestatistically nonsignificantfor the different age groups (Table 3). Statistically sig-~~nificantdifferenceswerefoundforTL~~nificantdifferenceswerefoundforTL(*p*~~<~~<0.0001),ML



~~**Fig.3**~~
~~Midsagittalreconstructedimagesofcomputedtomographyscanoftheposteriorfossaandthecraniovertebraljunctiondemonstratingthevariousangularcraniometricparameters.**a**Basalangle;anglebetweenlineconnectingthenasiontothetipofthedorsumsellaeandlineextendingfromthetipofthedorsumsellaetothetangentialsurfaceofclivus,**b**Boograd'sangle;Anglebetweenlineconnectingthetip~~

Fig.3
Midsagittalreconstructedimagesofcomputedtomographyscanoftheposteriorfossaandthecraniovertebraljunctiondemonstratingthevariousangularcraniometricparameters.**a**Basalangle;anglebetweenlineconnectingthenasiontothetipofthedorsumsellaeandlineextendingfromthetipofthedorsumsellaetothetangentialsurfaceofclivus,**b**Boograd'sangle;Anglebetweenlineconnectingthetip
of the dorsum sellae to the basion and line from the basion to the opisthion, **c** Nasion–Basion-Opisthion;Angle between line connecting nasion,~~basionandopisthion,**d**Foramenmagnumangle;AnglebetweenChamberlain'slineandMcRae'sline,**e**Clivuscanalangle;Anglebetweentheline~~basionandopisthion,**d**Foramenmagnumangle;AnglebetweenChamberlain'slineandMcRae'sline,**e**Clivuscanalangle;Anglebetweentheline connecting the tip of the dorsum sellae to the basion extrapolating inferiorly and line between the inferodorsal portions of the axis to the ~~mostsuperodorsal~~mostsuperodorsal part of the odontoid process extrapolating superiorly **f** Clivopalatal angle; Angle between lines connecting the tip of the ~~dorsumsellaetothebasionandthebasiontotheposteriorpoleofthehardpalate,**g**Clivoodontoidangle;Angleformedattheintersectionofalineconnecting~~dorsumsellaetothebasionandthebasiontotheposteriorpoleofthehardpalate,**g**Clivoodontoidangle;Angleformedattheintersectionofalineconnecting tip of dorsum sellae to basion extrapolating inferiorly and the one along the long axis of the odontoid process, **h** Clivo-~~Supraocciputangle;AngleformedbetweenintersectionofinferiorlyextrapolatedlinesconnectingthetipofthedorsumsellaetothebasionandIOP~~Supraocciputangle;AngleformedbetweenintersectionofinferiorlyextrapolatedlinesconnectingthetipofthedorsumsellaetothebasionandIOP ~~totheopisthion**i**Tentorialslope;AnglebetweenlinealongthetentoriumtoIOPandIOP-Oline,**j**Tentorialtwinninglineangle;AnglebetweenlinealongthetentoriumtoIOPandthetwinningline~~

~~(<~~totheopisthion**i**Tentorialslope;AnglebetweenlinealongthetentoriumtoIOPandIOP-Oline,**j**Tentorialtwinninglineangle;AnglebetweenlinealongthetentoriumtoIOPandthetwinningline

(<0.0001),Cl (p<<0.0001), IOP-O line (p==0.01), KI (p<<0.0001),height(h)~~ofposteriorfossa~~ofposteriorfossa(p~~<~~<0.0001),h/TL (p = 0.028), when these values were compared ~~forthegenders~~forthegenders(Table4).

~~LinearcraniometricanalysisofFM~~ ~~DifferentshapesofFMaregiveninTable~~LinearcraniometricanalysisofFM

DifferentshapesofFMaregiveninTable5.~~ThemeasurementsofFMtransversediameter,~~ThemeasurementsofFMtransversediameter,anter-~~oposteriordiameterandareawere27~~oposteriordiameterandareawere27.12~~±~~±1.~~42mm~~42mm (range 23.6–30.1 mm),30.99~~±~~±2.23 mm(range 27.6–35.~~8mm)and691~~8mm)and691.32 ± 30.~~35mm^2(range632~~35mm^2(range632.7–777.7 mm^2), respectively (Table 6). These meas~~urementswerestatisticallynonsignificantforthevarious~~urementswerestatisticallynonsignificantforthevarious age groups (Table 7), but all these value ~~werestatisticallysignificantwhen~~werestatisticallysignificantwhen compared for the genders(p = 0.0008, < 0.0001, 0.043 respectively, for FM trans~~versediameter,FManteroposteriordiameter~~versediameter,FManteroposteriordiameter and ~~FMarea)~~(FMarea)(Table8).

~~**Table1** Demographicanalysis~~ **Table1** Demographicanalysis

~~Demographiccharacteristics~~ Demographiccharacteristics	Controls(n = 120)
Age(years)	
18–30	21(17.50%)
31–40	37(30.83%)
41–50	20(16.67%)
51–60	27(22.50%)
61–70	15(12.50%)
Mean ± SD	43.5 ± 14.08
Gender	
Female	61(50.83%)

~~**Table2** AnalysisoflinearCraniometricParametersofPosteriorCranialFossa~~

Table2 AnalysisoflinearCraniometricParametersofPosteriorCranialFossa

Linear Craniometric ~~ParametersofPosteriorCranialFossa~~ ParametersofPosteriorCranialFossa	Controls(n = 120) Mean ± SD	Range
Twinningline(mm){TwL}	97.25±3.21	91.3–104.1
McRaeline(mm)	32.26±1.84	28.3–35.9
Clivuslength(mm)	41.59±1.88	36.8–49.4
IOP-Oline(mm)	43.9±2.03	36.8–49.6
Chamberlainline(mm)	75.51±3.66	67–84
Klaus'index(mm)	44.57±2.27	36.4–49.9
Heightofposteriorfossa(mm){h}	34.37±1.46	32–36.9
h/TwL	0.35±0.02	
Posteriorfossavolume(cm^3)	162.52±7.64	143.78–175.56

IOP-O: ~~InternalOccipitalProtuberance~~ InternalOccipitalProtuberance-Opisthion

LinearcraniometricanalysisofPCFandit's clini

~~**AngularcraniometricanalysisofPCF**~~

~~Themeasurementsof~~

AngularcraniometricanalysisofPCF

Themeasurementsofthe different angles are ~~giveninTable~~ giveninTable9. ~~Thevaluesof~~ Thevaluesof CCA (p = 0.038) and COA(p = 0.012) ~~werestatisticallysignificantwhencompared~~ werestatisticallysignificantwhencompared ~~forthedifferentagegroups~~ forthedifferentagegroups(Table10). ~~Allotherangular~~ Allotherangular craniometric parameters were statistically nonsignificantforthedifferentagegroups. ~~cantforthedifferentagegroups.~~ ~~(p=0.031)werestatisticallysignificantwhenthesemeas~~ =0.031 BgA(p = 0.021) ~~andTS~~ andTS)werestatisticallysignificantwhenthesemeas- ~~urementscomparedforthegender~~ urementscomparedforthegender(Table11). ~~Allother~~ Allother ~~measurementswerenonsignificantforthegenders.~~ measurementswerenonsignificantforthegenders.

Discussion

~~ThePCFanditssurroundingterritoryincorporatethe~~ ThePCFanditssurroundingterritoryincorporatethe critical neurovascular structures which include brain stem,cerebellum, ~~cranialnerves,basilarandvertebralarteries,caudalpartofventricularsystem.FMisthelargcranialnerves,b~~

~~tionsofPCFandFMinthedifferentgeographicalareas,races andreligions.Gender,geneticandenvironmental~~

tionsofPCFandFMinthedifferentgeographicalareas,races andreligions.Gender,geneticandenvironmental ~~factorsalsoinfluencesthemorphometry~~ factorsalsoinfluencesthemorphometry of these parts[7, 10, 12]. A lot of research has been done for the mor-phometric analysis of PCF, FM and its surrounding terri-tory in different parts of world. The evolution of ~~imagingmodalities~~ imagingmodalities has increased the precision of our ~~knowledgeregarding~~ knowledgeregarding PCF and FM. We used easily available recon-structed CT images to analyse the morphometry of ~~PCFandFM~~ PCFandFM.

~~**LinearcraniometricanalysisofPCFandit'sclinicalimplications**~~

~~Knowledgeofmeasurementsofdifferentlinearcranio-~~

calimplications

Knowledgeofmeasurementsofdifferentlinearcranio-metric parameters is necessary for the diagnosis of ~~CVJandPCFmalformations.Chiarimalformationsareagroup~~ CVJandPCFmalformations.Chiarimalformationsareagroup of the congenital malformations of CVJ that ~~arefrequentlyassociatedwiththeoccipitalbonedyspla-~~ arefrequentlyassociatedwiththeoccipitalbonedyspla-sia and other osseous abnormalities like platybasia, BI, ~~clivalbonedeformityoralterationsinthesizeofPCF~~ clivalbonedeformityoralterationsinthesizeofPCF[2,

~~**Table3** Comparisonof~~ **Table3** ComparisonofLinearCraniometricParametersofPosteriorCranialFossafordifferentagegroups

LinearCraniometricParameters ~~ofPosteriorCranialFossafordifferentagegroups~~ ofPosteriorCranialFossa

~~Linear Craniometric Parameters ofPosteriorCranialFossa~~	18–30(n = 21) Mean ± SD	31–40(n = 3) Mean ± SD	41–50(n = 20) Mean ± SD	51–60(n = 27) Mean ± SD	61–70(n = 15) Mean ± SD	~~TotalMean ±~~	TotalMean ± SD

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~~pvalue~~pvalue

~~Twinningline~~Twinningline(mm){TwL}	97.25~~±~~±3.18	96.92~~±~~±3.11	98.04~~±~~±3.57	97.44~~±~~±3.45	96.68~~±~~±2.72	97.25~~±~~±3.~~210~~210.715[a]
~~McRae'sline~~McRae'sline(mm)	32.51~~±~~±2.33	32.08~~±~~±1.57	32.55~~±~~±1.74	32.26~~±~~±2	31.98~~±~~±1.68	32.26~~±~~±1.~~840~~840.816[a]
~~Clivuslength~~Clivuslength(mm)	41.54~~±~~±2.6	41.31~~±~~±1.7	41.88~~±~~±1.73	41.74~~±~~±2.01	41.65~~±~~±2.2	41.59~~±~~±1.~~990~~990.863[a]
IOP-~~Oline~~Oline(mm)	43.37~~±~~±2.26	43.68~~±~~±2.15	44.21~~±~~±1.68	44.39~~±~~±2.03	43.89~~±~~±1.81	43.9~~±~~±2.~~030~~030.432[a]
~~Chamberlainline~~Chamberlainline(mm)	75.09~~±~~±3.31	76.06~~±~~±3.4	75.38~~±~~±4	75.13~~±~~±4.19	75.62~~±~~±3.63	75.51~~±~~±3.~~660~~660.839[a]
~~Klaus'index~~Klaus'index (mm)	44.77~~±~~±2.9	44.32~~±~~±1.79	44.49~~±~~±1.86	44.5~~±~~±2.68	45.13~~±~~±2.2	44.57~~±~~±2.~~270~~270.818[a]
~~Heightofposteriorfossa~~Heightofposteriorfossa(mm){h}		34.39~~±~~±1.6	34.15~~±~~±1.47	34.42~~±~~±1.55	34.53~~±~~±1.47	34.56~~±~~±1.19
	34.37~~±~~±1.~~460~~460.846[a]					
~~Heightofsupratentorialregion~~Heightofsupratentorialregion(mm){H}			90.77~~±~~±2.05	91.15~~±~~±1.81	91.35~~±~~±2.08	91.98~~±~~±1.96
	90.67~~±~~±1.98	91.24~~±~~±1.~~970~~970.173[a]				
h/TwL	0.35~~±~~±0.02	0.35~~±~~±0.01	0.35~~±~~±0.02	0.35~~±~~±0.02	0.36~~±~~±0.01	0.35~~±~~±0.~~020~~020.815[a]
~~Posteriorfossavolume~~Posteriorfossavolume(cm^3)		164.47~~±~~±7.39	161.93~~±~~±8.23	163.66~~±~~±5.89	162.96~~±~~±7.97	158.93~~±~~±7.51
	162.52~~±~~±7.~~640~~640.247[a]					

IOP-O:~~InternalOccipitalProtuberance~~InternalOccipitalProtuberance-Opisthion

[a]~~ANOVA~~

~~**Table 4** Comparison of Linear Craniometric Parameters of Posterior Cranial Fossa in between genders~~

~~**Linear Craniometric Parameters of Posterior Cranial Fossa**~~

[a]ANOVA

Table4 ComparisonofLinearCraniometricParametersofPosteriorCranialFossainbetweengenders

LinearCraniometricParametersofPosteriorCranialFossa	Female(*n*=~~=~~61) Mean~~±~~±SD	Male(*n*=~~=~~59) Mean~~±~~±SD	~~TotalMean±~~	TotalMean ±SD

~~pvalue~~pvalue				
~~Twinningline~~Twinningline(mm){TwL}	95.89~~±~~±3.3	98.65~~±~~±2.44	97.25~~±~~±3.21	~~<~~,≤.0001[a]
~~McRae'sline~~McRae'sline(mm)	31.57~~±~~±1.83	32.97~~±~~±1.58	32.26~~±~~±1.84	~~<~~,≤.0001[a]
~~Clivuslength~~Clivuslength(mm)	40.67~~±~~±1.49	42.53~~±~~±2.02	41.59~~±~~±1.99	~~<~~,≤.0001[a]
IOP-~~Oline~~Oline(mm)	43.32~~±~~±1.8	44.5~~±~~±2.1	43.9~~±~~±2.03	**0.001[a]**
~~Chamberlainline~~Chamberlainline(mm)	75.42~~±~~±3.62	75.61~~±~~±3.74	75.51~~±~~±3.66	0.785[a]
~~Klaus'index~~Klaus'index (mm)	43.63~~±~~±2.05	45.54~~±~~±2.08	44.57~~±~~±2.27	~~<~~,≤.0001[a]
~~Heightofposteriorfossa~~Heightofposteriorfossa(mm){h}	33.57~~±~~±1.02	35.21~~±~~±1.38	34.37~~±~~±1.46	~~<~~,≤.0001[a]
~~Heightofsupratentorialregion~~Heightofsupratentorialregion(mm){H}	**0.024[a]**	91.64~~±~~±2.03	90.83~~±~~±1.84	91.24~~±~~±1.97
h/TwL	0.35~~±~~±0.02	0.36~~±~~±0.02	0.35~~±~~±0.02	**0.028[a]**
~~Posteriorfossavolume~~Posteriorfossavolume(cm^3)	161.53~~±~~±6.82	163.54~~±~~±8.35	162.52~~±~~±7.64	0.151[a]

A significant *p* value is denoted in bold

~~lettersIOP-O:InternalOccipitalProtuberance-Opisthion[a]Independentttest~~lettersIOP-O:InternalOccipitalProtuberance-Opisthion[a]Independentttest

~~**Table5**AnalysisofMorphometryofForamenMagnum~~

Table5 AnalysisofMorphometryofForamenMagnum

~~ShapesofForamenMagnum~~ShapesofForamenMagnum	Controls(*n*~~=~~=120)
Oval	27(22.50%)
Round	24(20%)
Tetragonal	7(5.83%)
Pentagonal	8(6.67%)
Hexagonal	39(32.50%)
Egg	6(5%)
Irregular	9(7.50%)

5,~~7,~~,7,13–19].~~Paraaxialmesodermalinsufficiencydur-ingembryologicaldevelopmentmayberesponsiblefor~~Paraaxialmesodermalinsufficiencydur-ingembryologicaldevelopmentmayberesponsiblefor ~~developmentofChiarimalformations[20].Themeasure-~~developmentofChiarimalformations[20].Themeasure-~~mentofTLreflectstheanteroposteriordistanceofPCF.~~mentofTLreflectstheanteroposteriordistanceofPCF. In this study,the mean ~~lengthof~~lengthof TL ~~was97~~was97.25~~±~~±3.21 mm. ~~Inpreviousliterature,themeanlengthofTLranges~~Inpreviousliterature,themeanlengthofTLranges ~~from84.2to93.7mm~~[from84.2to93.7mm[7,~~,~~21]~~.InChiarimalformations,~~].InChiarimalformations, ~~thereisgrowthintheanteroposteriordirectiontocom-~~thereisgrowthintheanteroposteriordirectiontocom-~~pensateforthesmallsizeofthePCFwhichresultsin~~pensateforthesmallsizeofthePCFwhichresultsin ~~highervaluesofTL~~[highervaluesofTL[15~~,~~,22].~~ThelengthofML,~~ThelengthofML, which

~~**Table6**Analysisof~~**Table6**AnalysisofLinearCraniometricParametersofForamenMagnum

LinearCraniometricParametersofForamenMagnum

~~Linear Craniometric Parametersof~~Parametersof Foramen Magnum	Controls(*n*~~=~~=120)	Range
~~ForamenMagnumtransversediameter(mm)~~ForamenMagnumtransversediameter(mm)	27.12~~±~~±1.42	23.6-30.1
Foramen ~~Magnumanteroposteriordiameter~~Magnumanteroposteriordiameter (mm)	30.99~~±~~±2.23	27.6-35.8
~~ForamenMagnumarea~~ForamenMagnumarea(mm^2)	691.32~~±~~±30.35	632.7-777.7

~~**Table7**Comparisonof~~**Table7**ComparisonofLinearCraniometricParametersofForamenmagnumindifferentagegroups

LinearCraniometricParameters~~ofForamenmagnumindifferentagegroups~~ofForamenMagnum

~~Linear Craniometric Parameters ofForamenMagnum~~	18–30(*n*~~=~~=21) Mean~~±~~±SD	31–40(*n*~~=~~=37) Mean~~±~~±SD	41–50(*n*~~=~~=20) Mean~~±~~±SD	51–60(*n*~~=~~=27) Mean~~±~~±SD	61–70(*n*~~=~~=15) Mean~~±~~±SD	~~TotalMean±~~	TotalMean±SD

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~~*p*value~~*p*value						
Foramen Magnum transverse diameter(mm)	27.03~~±~~±1.27	27.08~~±~~±1.63	27.24~~±~~±1.24	27.59~~±~~±1.5	26.36~~±~~±0.78	27.12~~±~~±1.~~420~~420.111[a]
~~ForamenMagnumanteroposteriordiameter(mm)~~ ForamenMagnumanteroposteriordiameter(mm)	31.33~~±~~±2.45	30.79~~±~~±2.27	30.97~~±~~±1.91	31.62~~±~~±2.27	29.88~~±~~±1.86	30.99~~±~~±2.~~230~~230.152[a]
Foramen ~~Magnumarea~~Magnumarea (mm^2)	687.21~~±~~±35.4	687.19~~±~~±29.~~02698~~02698.4~~±~~±24.11				

700.54~~±~~±32.~~81681~~81681.21~~±~~±25.~~87691~~87691.32~~±~~±30.~~350~~350.176[a]

~~[a]ANOVA~~

~~**Table 8** Comparison of Linear craniometric parameters of Foramen Magnum in between genders~~

[a]ANOVA

Table 8 Comparison of Linear craniometric parameters of Foramen Magnum in between genders

Linear Craniometric ~~Parameters of~~ Parameters of Foramen Magnum	Female (n = = 61) Mean ± ± SD	Male (n = = 59) Mean ± ± SD	~~Total Mean ±~~	~~Total~~ Mean ± SD

				~~*p*value~~*p*value
~~ForamenMagnumtransversediameter~~ForamenMagnumtransversediameter(mm)	27.12~~±~~±1.42	26.7~~±~~±1.27	27.56~~±~~±1.44	**0.0008[a]**
~~ForamenMagnumanteroposteriordiameter~~ForamenMagnumanteroposteriordiameter(mm)	30.99~~±~~±2.23	29.94~~±~~±1.64	32.07~~±~~±2.25	**~~<.~~<.0001[a]**
Foramen Magnum area (mm^2)	685.82~~±~~±29.59	697.01~~±~~±30.31	691.32~~±~~±30.35	**0.043[a]**

~~Asignificant*p*valueisdenotedinboldletters~~

~~[a]Independentttest~~

~~**Table 9**AnalysisofAngularCraniometricParametersofPosteriorCranialFossaandForamenMagnumandSurroundingterritory~~

Asignificant*p*valueisdenotedinboldletters

[a]Independentttest

Table 9 AnalysisofAngularCraniometricParametersofPosteriorCranialFossaandForamenMagnumandSurroundingterritory

~~**AngularCraniometricParametersControls**~~**AngularCraniometricParametersControls**(*n*~~=~~=120) Mean~~±~~±SD	**Range**

~~MLandCVJmalformations.,butusuallymeasurementsof~~MLandCVJmalformations.,butusuallymeasurementsof ML remains higher in Chiari malformations. The ~~meanlengthofMLwas32.26mminthisstudy.Thelengthof~~meanlengthofMLwas32.26mminthisstudy.Thelengthof ~~CLisnotwelldocumentedintheliterature.Inthisstudy,~~

CLisnotwelldocumentedintheliterature.Inthisstudy, the mean length of CL was 75.51 ± 3.66 mm. The ~~meanlength~~meanlength of clivus (Cl) and KI (Fig. 4a), which are ~~measuresof~~measuresof the size of the basiocciput, vary from 40.4 to 47.22 ~~mmand~~mmand 38 to 40.9 mm, respectively, in the normal population ~~[5,~~[5,7,22,24–27].Inthisstudy,itwas41Inthisstudy,itwas41.59±±1.~~99mmand~~99mmand 44.57 ± 2.27 mm respectively.

].Inthisstudy,themeanlengthofIOP-Oli

~~Basalangle(°)~~	~~125.92±4.41~~	~~118.3–144~~
~~Boogardangle(°)~~	~~136.89±3.39~~	~~129.7–152.1~~
~~NBO angle (°)~~	~~169.4±2.01~~	~~163.5–173.2~~
~~Foramenmagnumangle(°)~~	~~12.88±1.74~~	~~9.6–18~~
~~Clivo-odontoidangle(°)~~	~~145.58±8.78~~	~~117.3–157.2~~
~~Clivopalatalangle(°)~~	~~60.1±5.76~~	~~46–71~~
~~Clivuscanalangle(°)~~	~~161.19±9.07~~	~~132.1–173.2~~
~~Clivussupraocciputangle(°)~~	~~77.6±4.52~~	~~65.3–93.5~~
~~Tentorialslope(°)~~	~~88.6±5.87~~	~~67–98~~
~~Tentorialtwinning line angle (°)~~	~~34.00±2.12~~	~~27.3–40.3~~

NBO: ~~NasionBasionOpisthion~~NasionBasionOpisthion

ly. Mean values of Cl and ~~KIislesserinthepatientswithChiarimalformationsandBIthaninthenormalpopulation.TheIOP-Olineisameas-ureofsupraocciput,andit'smeanlengthvariesfrom~~KIislesserinthepatientswithChiarimalformationsandBIthaninthenormalpopulation.TheIOP-Olineisameas-ureofsupraocciput,andit'smeanlengthvariesfrom ~~40.9to46.8mminthenormalpopulation[7,~~40.9to46.8mminthenormalpopulation[7,26~~].Inthisstudy,themeanlengthofIOP-Olinewas43.9±2.03mm.~~

~~Theheightoftheposteriorfossaisameasureoftheshal-~~newas43.9±2.03mm.

~~Theheightoftheposteriorfossaisameasureoftheshal-lownessoftheposteriorfossa,whichvariesfrom30.3to~~

~~agivesmeasureofwidenessofFM,variesfrom32.3to~~
agivesmeasureofwidenessofFM,variesfrom32.3to 36.21 mm [21, 23]. Although in CVJ malformations, ~~it'ssignificance~~it'ssignificance remains inconspicuous, as previous ~~studiesfailedtoestablishthesignificancebetweenthelengthof~~ studiesfailedtoestablishthesignificancebetweenthelengthof

lownessoftheposteriorfossa,whichvariesfrom30.3to 35.2 mm in various studies, probably due to the choice ~~ofdifferent~~ofdifferent landmarks. A decreased height of the ~~posteriorfossa~~posteriorfossa denotes a smaller posterior fossa volume (Fig. 4b)which is associated with Chiari malformations [7, 12~~,~~,27].~~Inthisstudy,it'svaluewas34~~Inthisstudy,it'svaluewas 34.37±1.~~46mm.~~46mm.h/~~TwLisconsideredcompensatory~~TwLisconsideredcompensatory growth ~~ofPCF~~ofPCF in the forward

~~**Table10:**ComparisonofAngularCraniometricParametersofPosteriorCranialFossa,ForamenMagnumandsurroundingterritoryindifferentagegroups~~

~~**AngularCraniometricParameters18**~~**Table10:**ComparisonofAngularCraniometricParametersofPosteriorCranialFossa,ForamenMagnumandsurroundingterritoryindifferentagegroups

AngularCraniometricParameters18–30(*n*=21) Mean±SD	**31–40(*n*=37) Mean±SD**	**41–50(*n*=20) Mean±SD**	**51–60(*n*=27) Mean±SD**	**61–70(*n*=15) Mean±SD**	~~**TotalMea±**~~**Total Mea±SD**	~~***p*value**~~***p*value**
~~Basalangle~~Basalangle(°) 125.66±3.14	125.88±4.5	125.14±4.37	127.03±5.49	125.42±3.72	125.92±4.~~41~~41	0.633[a]
~~Boogardangle~~Boogardangle(°) 137.4±4.34	137.54±3.43	135.12±2.43	137±2.84	136.74±3.44	136.89±3.~~39~~39	0.118[a]
~~NBOangle~~NBOangle(°) 169.31±2.38	169.39±2.09	169.75±1.24	169.45±2.08	169.03±2.1	169.4±2.~~01~~01	0.884[a]
~~ForamenMagnumangle~~ForamenMagnumangle(°) 12.5±1.13	12.5±1.54	13.57±2.25	13.2±1.99	12.87±1.47	12.88±1.~~74~~74	0.148[a]
Clivo-~~odontoidangle~~odontoidangle(°) 147.17±7.72	143.98±9.23	150.5±4.97	142.19±11	146.84±4.86	145.58±8.~~78~~78	**0.012[a]**
~~Clivopalatalangle~~Clivopalatalangle(°) 59.83±5.82	59.48±5.32	60.76±5.36	59.82±6.35	61.59±6.5	60.1±5.~~76~~76	0.778[a]
~~Clivuscanalangle~~Clivuscanalangle(°) 162.72±7.85	159.95±9.74	165.62±5.11	157.83±11.39	162.23±5.65	161.19±9.~~07~~07	**0.038[a]**
~~Clivussupraocciputangle~~Clivussupraocciputangle(°) 77.82±5.71	77.31±3.76	76.86±4.65	78.66±4.07	77.09±5.23	77.6±4.~~52~~52	0.671[a]
~~Tentorialslope~~Tentorialslope(°) 87.09±5.94	88.42±5.44	90.36±6.07	87.81±6.5	89.43±5.26	88.5±5.~~87~~87	0.416[a]
~~Tentorialtwinninglineangle~~Tentorialtwinninglineangle(°) 34.24±2.25	33.69±2.47	34.54±1.66	34.21±2.07	34.06±1.68	34.09±2.~~12~~12	0.666[a]

~~Asignificant*p*valueisdenotedinboldlettersNBO:NasionBasionOpisthion~~

~~[a]ANOVA~~

~~**Table11**ComparisonofAngularCraniometricParametersofPosteriorCranialFossa,ForamenMagnumandsurroundingterritoryinbetweengenders~~

~~**AngularCraniometricParameters**~~Asignifican

t*p*valueisdenotedinboldlettersNBO:NasionBasion

Opisthion

[a]ANOVA

Table11 ComparisonofAngularCraniometricParametersofPosteriorCranialFossa,ForamenMagnumandsurroundingterritoryinbetweengenders

AngularCraniometricParameters	Female(n==61)Mean±±SD	Male(n==59) Mean±±SD	~~TotalMean±~~	~~TotalMea~~n±SD

~~*p*value~~*p*value				
~~Basalangle~~Basalangle(°)	125.68~~±~~±5.24	126.17~~±~~±3.37	125.92~~±~~±4.41	0.542[a]
~~Boogardangle~~Boogardangle(°)	136.19~~±~~±3.02	137.62~~±~~±3.63	136.89~~±~~±3.39	**0.021[a]**
~~NBOangle~~NBOangle(°)	169.07~~±~~±1.93	169.75~~±~~±2.04	169.4~~±~~±2.01	0.061[a]
~~ForamenMagnumangle~~ForamenMagnumangle(°)	12.97~~±~~±1.7	12.79~~±~~±1.79	12.88~~±~~±1.74	0.575[a]
Clivo-~~odontoidangle~~odontoidangle(°)	146.72~~±~~±8.63	144.4~~±~~±8.84	145.58~~±~~±8.78	0.149[a]
~~Clivopalatalangle~~Clivopalatalangle(°)	60.23~~±~~±6.23	59.95~~±~~±5.27	60.1~~±~~±5.76	0.79[a]
~~Clivuscanalangle~~Clivuscanalangle(°)	162.11~~±~~±8.82	160.24~~±~~±9.29	161.19~~±~~±9.07	0.259[a]
~~Clivussupraocciputangle~~Clivussupraocciputangle(°)	77.29~~±~~±4.33	77.92~~±~~±4.73	77.6~~±~~±4.52	0.451[a]
~~Tentorialslope~~Tentorialslope(°)	89.63~~±~~±5.82	87.33~~±~~±5.73	88.5~~±~~±5.87	**0.031[a]**
~~Tentorialtwinninglineangle~~Tentorialtwinninglineangle(°)		34.14~~±~~±2.09	34.04~~±~~±2.17	
	34.09~~±~~±2.12	0.794[a]		

~~AsignificantpvalueisdenotedinboldlettersNBO:NasionBasionOpisthion~~
~~[a]Independentttest~~

~~directioninthecaseofsmall sizedPCF[7,~~Asignificant*p*valueisdenoted inboldlettersNBO:NasionBasionOpisthion
[a]Independentttest

directioninthecaseofsmallsizedPCF[7,28],~~althoughliterature~~althoughliterature regarding the significance of this ~~parameterremains~~parameterremains scarce. Karagöz F, et al., in their study, ~~showedthat~~showedthat the value of h/TwL was reduced (0.26) in ~~patientswithChiarimalformationscomparedtothenormalpopulation~~patientswithChiarimalformationscomparedto thenormalpopulation(0.32~~)[~~)[7].~~Inthisstudy,themeanvalueofh/TwLratiowas0~~Inthisstudy,themeanvalueofh/TwLratiowas0.35~~±~~±0.02.~~Variousstudieshavebeendoneto~~Variousstudieshavebeendoneto define the values of PFV based on the different auto-mated and manual methods. The range of the values ~~ofPFVvarieswidely,whichmaybeattributedtothediffer-~~ofPFVvarieswidely,whichmaybeattributedtothediffer- ences in the imaging modalities and the possible differ- ~~encesinthesegmentationprotocols,ortothelandmarks~~encesinthesegmentationprotocols,ortothelandmarks used in the measurement protocol [1, 2, 5, 7, 12, 29]. ~~Inthis~~Inthis study, the mean PFV was 162 ± 7.64 cm^3. Chiari mal-formations and BI are most of the times associated ~~withthesmallerPCF~~withthesmallerPCF.

~~LinearcraniometricanalysisofFManditsclinicalimplications~~

~~MeasurementsoftheFMholdsubstantialimportancein~~**LinearcraniometricanalysisofFManditsclinicalimplications**

MeasurementsoftheFMholdsubstantialimportancein approaching the lesions occupying the PCF and ~~CVJregion.Duringsurgicalprocedures,informationaboutthemorphometry,~~CVJregion.Duringsurgicalprocedures, informationaboutthemorphometry,morphology,~~andvariationsoftheFMmayaffectthesurgicaloutcome~~andvariationsoftheFMmayaffectthesurgicaloutcome.

~~TheShapeofFMhasimmenseclinicalsignificanceregardingvarious~~TheShapeofFMhasimmenseclinicalsignificanceregardingvarious surgical approaches. Previous stud- ~~ieshavereporteddifferencesinthefrequencyofshapesofFM.Itmaydue~~ieshavereporteddifferencesinthefrequencyofshapesofFM.Itmaydue to geographical variations, ~~genderand~~genderand racial differences, etc. The commonest shape of ~~FMdescribed~~FMdescribed in most of the literatures is oval [30–34]. How-ever, in this study, the most common shape of FM ~~washexagonal~~washexagonal (32.50%), followed by oval (22.50%). ~~OthershapesofFMwereround~~OthershapesofFMwereround(20%),tetragonal(5.83%), pentagonal(6.67%),irregular(7.50%)~~andeggshaped~~andeggshaped(5%).

The anteroposterior and transverse diameters of ~~FMaretheothervaluableparametersusedinanalysingvariations~~FMaretheothervaluableparametersusedinanalysingvariations of the morphometry of FM. In literature, ~~theanteroposterior~~theanteroposterior and transverse diameters of FM ~~rangefrom25to37mmand24to35mm,~~rangefrom25to37mmand24to35mm,respectively[5~~,~~,7~~,~~,12, 30~~,31,~~,31,34~~,~~,35~~].Inthisstudy,thesemeasurementswere~~].Inthisstudy,thesemeasurementswere 30.99 ± 2.23 mm and 27.12 ± 1.42 mm, respectively. ~~Themeasurement~~Themeasurement of the area of FM is another morphomet-ric tool to analyse FM, whose value of which ranges ~~from385to779mm^2,asdescribedindifferentstudies.Inthisstudy~~from385to779mm^2,asdescribedindifferentstudies.Inthisstudy, it's value was 691 ± 30.35 mm^2. Usually, there ~~areno~~areno differences in the size of FM in different age groups,~~butmaleshavealargerconfigurationofFMthanfemales~~butmaleshavealargerconfigurationofFMthanfemales[30–37]. Although patients with Chiari ~~malformationshavelargerdimensionsofFMduetocompensatorygrowth~~malformationshavelargerdimensionsofFMduetocompensatorygrowth in the anteroposterior direction, some ~~studieshave~~studieshave found no significance in both [37–39]. Muthuku-mar et al. described importance of anatomical knowl-~~edgeofFMasnecessaryforsurgicalapproacheslikethetranscondylar~~edgeofFMasnecessaryforsurgicalapproacheslikethetranscondylar approach, where drilling of the ~~posteriormarginisimportanttoaccesslesions[31~~posteriormarginisimportanttoaccesslesions[31].

Angular craniometric analysis of PCF, FM and ~~surroundingterritoryanditsclinicalimplications~~surrounding territoryanditsclinicalimplications

Evaluation of the craniocervical angles of PCF, FM ~~andCVJ~~andCVJ is necessary, as the cranial angles of PCF ~~directlyinfluence~~directlyinfluence the angular geometry of CVJ and ~~consequentlythe~~consequentlythe whole vertebral column [6]. BA is routinely used ~~toasses~~toasses the flattening of skull base, i.e., platybasia. In litera-ture, it's value ranges from 125° to 143° [40]. ~~The meanvalueinthepreviousstudiesvariesduetotheuseofthe~~The meanvalueinthepreviousstudiesvariesduetotheuseofthe

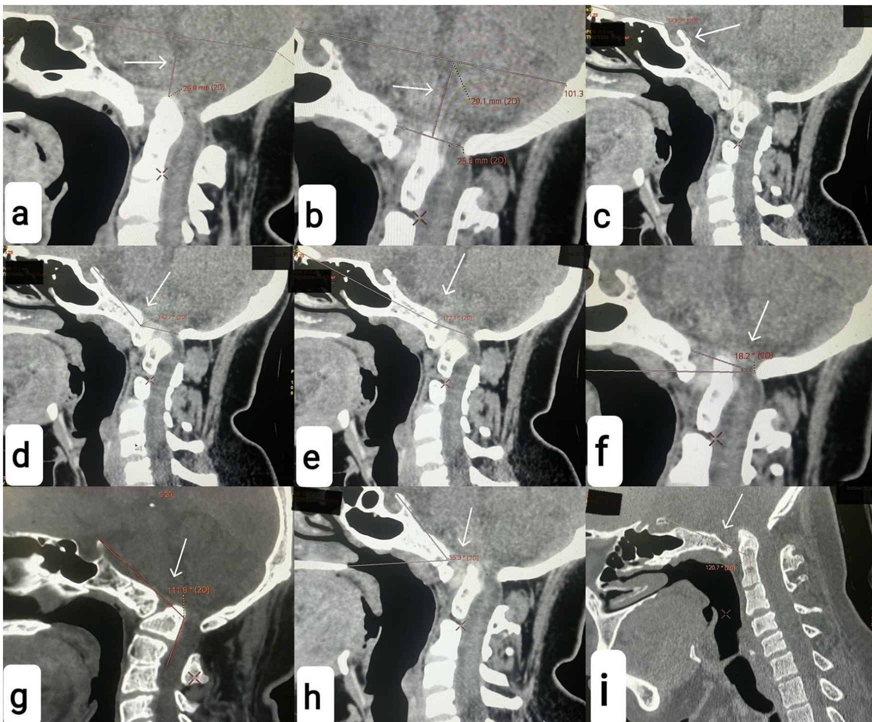

Fig. ~~4 Midsagittalreconstructedimagesofcomputedtomographyscanoftheposteriorfossaandthecraniovertebraljunctiondemonstratingthemeasurementsofvariouscraniometricparametersinpatientswithcraniovertebraljunctionmalformations.~~ ~~**a**Klaus'index~~ **4** Midsagittalreconstructedimagesofcomputedtomographyscanoftheposteriorfossaandthecraniovertebraljunctiondemonstratingthemeasurementsofvariouscraniometricparametersinpatientswithcraniovertebraljunctionmalformations. **a** Klaus'index—26.~~8mm~~8mm(decreased), ~~**b**heightofposteriorfossa~~ **b** heightofposteriorfossa—29.~~1mm~~1mm(decreased), ~~**c**Basalangle~~ **c** Basalangle—143.2°(increased), ~~**d**Boogardangle~~ **d** Boogardangle—142.7~~°(~~°(increased), ~~**e**NasionBasionOpisthionangle~~ **e** NasionBasionOpisthionangle—172.1(increased), ~~**f**ForamenMagnumAngle~~ **f** ForamenMagnumAngle—18.2~~°(~~°(increased), ~~**g**ClivusCanalangle~~ **g** ClivusCanalangle-111.8°(increased), ~~**h**Clivopalatalangle~~ **h** Clivopalatalangle—55.3(decreased), ~~**i**Clivoodontoidangle–~~ **i** Clivoodontoidangle–120.7°(decreased)

different imaging modalities or ambiguities in the loca-~~tionoflandmarks~~tionoflandmarks[40~~,~~,41]. ~~Inthisstudy,themeanvalueofBA~~Inthisstudy,themeanvalueofBA was 125.92° ± 4.41°. Ferreira et al. stated that BA >~~129is~~129is defined as platybasia with mean value of 116.5° in nor-mal population (Fig. 4c) [41]. BgA and NBO angles ~~arealso~~arealso used for the evaluation of platybasia (Fig. 4d, e). ~~ThemeanvalueofBgArangesfrom126~~ThemeanvalueofBgArangesfrom126°-137°~~inthenormalpopulation[6,~~inthenormalpopulation[6,7]. ~~Inthisstudy,themeanvalueofBgAwas136~~Inthisstudy,themeanvalueofBgAwas136.89° ± 3.39°. Botelho et al. found wider BgA in ~~patientswithBI~~patientswithBI(172°)~~andChiarimalformations(136°)thanthecontrolgroupofthenormalpopulation (126°±~~andChiarimalformations(136°)thanthecontrolgroupofthenormalpopulation (126°±15.26~~°)~~[°)][7]. ~~NBOAnglevaluesvarybetween162°and165°[~~NBOAnglevaluesvarybetween162°and165°[7~~,~~,23~~,~~,42]. However, in this study, the mean value of NBO ~~anglewas~~anglewas 169.4° ± 2.01°, which was slightly higher than ~~statedin~~statedin the previous literature. Measurements of BA, BgA ~~andNBO~~andNBO angles are helpful in diagnosing CVJ ~~malformationslikeBIandChiarimalformations.Alltheseangleshave~~malformationslikeBIandChiarimalformations.Alltheseangleshave greater values when measured in the patients with ~~CVJmalformations~~CVJmalformations [6, 7, 23, 41, 42, 44]. A few more ~~angleshavebeenreiteratedtocomplementthediagnosisof BI~~angleshavebeenreiteratedtocomplementthediagnosis ofBI; FMag is the one of them (Fig. 4f). It's values ~~rangesfrom~~rangesfrom 6.21°-11.6° in the normal population, as ~~describedin~~describedin the previous studies. Nascimento et al. Found a ~~muchhighervalueofFMag~~muchhighervalueofFMag(25.9° ± 9.3°)~~inpatientswithBIthan~~inpatientswithBIthan in the normal population [43, 45]. In this study, ~~themean~~themean value of FMag was 12.88 ± 1.74, which was ~~slightlyhigher~~slightlyhigher than stated in the previous literature. CCA, CPA,COA and CSO are another set of angles that are ~~usefulin~~usefulin complementing the diagnosis of CVJ ~~malformationsbut~~malformationsbut literature regarding their data and diagnostic ~~valueremainsscarce.Measurementsoftheseanglesarepoorlyunderstood~~valueremainsscarce.Measurementsoftheseanglesarepoorlyunderstood and vary in the previous literatures due ~~tothe~~tothe consideration of the different landmarks or imag-~~ingmodalities~~ingmodalities[46–48].~~Inthisstudy,themeanvaluesof~~Inthisstudy,themeanvaluesof

CCA,CPA,COA,~~CSOwere161~~CSOwere161.19~~°±~~°±9.07°,60.1~~°±~~°±5.76°, 145.58~~°±~~°±8.78°~~and77~~and77.6~~°±~~°±4.52°,respectively.Usually,patients with BI, CCA, CPA, COA have lower values ~~thethan~~thethan the normal population (Fig. 4 g–i), but the value ~~ofCSO~~ofCSO is greater [46–49]. Ma et al. evaluated CPA, ~~COAandCCAandfoundcut-offvaluesfordiagnosingBI,~~COAandCCAandfoundcut-offvaluesfordiagnosingBI,respectively, at 53.5°, 123.5°, 138.5° [47]. D'AAddario et al.used CSO measurement in the evaluation of fetal poste-~~riorfossaandtype2Chiarimalformations,asthevaluesofCSO angleremainconstantthroughoutthe~~riorfossaandtype2Chiarimalformations,asthevaluesofCSOangleremainconstantthroughoutthe gesta~~-tional age~~tionalage.They found that values of CSO angle ~~decreasesin~~decreasesin patients with fetal ventriculomegaly related to ~~Chiarimalformations~~Chiarimalformations [50]. Tentorial slope and TtwA are ~~alsomeasured~~alsomeasured to asses platybasia [7]. In this study, the ~~meanvalue~~meanvalue of the tentorial slope and TtwA were 88.5° ± 5.87°~~and34~~and34.09~~°±~~°±2.12°,respectively.~~Rehderetal.establishedtentorial~~Rehderetal.establishedtentorial slope as a imaging biomarker of the fetal poste-rior cranial fossa development [51]. Tentorial slope ~~alsoand~~alsoand TtwA tend to be greater in value in patients ~~withChiarimalformations,butpertainingliteratureremainscontroversial~~withChiarimalformations,butpertainingliteratureremainscontroversial[2~~,~~,7~~,~~,51–53].

~~Toourbestknowledge,nopreviousstudyhasbeenpublishedintheliteratureregardingthedescriptiveanalysis~~Toourbestknowledge,nopreviousstudyhasbeenpublishedintheliteratureregardingthedescriptiveanalysis of the morphometry of PCF and FM in the pop-ulation of the North India. We herein describe ~~differentlinearandangularcraniometricparametersofPCFandFM~~differentlinearandangularcraniometricparametersofPCFandFM along with their values in this group of the ~~normalpopulation.~~normalpopulation. These values can be taken as reference ~~valueswhile~~valueswhile comparing these parameters in patients with ~~CVJmalformations~~CVJmalformations.

Limitations

~~Thisstudyisnotwithoutlimitations.~~Thisstudyisnotwithoutlimitations. First, ~~comparedwith~~comparedwith other studies, the sample size is not large enough.Second, we didn't compare the values of different ~~linearand~~linearand angular craniometric parameters of this part of ~~Indiawith~~Indiawith some other territory of India, which could ~~establishthegeographicaldifferencesbetweentheseparameters.~~establishthegeographicaldifferencesbetweentheseparameters.Third, we couldn't find the definitive cause of ~~differencesinmeasurementsofsomeparameters.Wearelookingforward~~differencesinmeasurementsofsomeparameters. Wearelookingforward to performing future studies with larger ~~samplesizeandcomparingthesefindingswiththoseofothergeographicalregionsofIndia~~samplesizeandcomparingthesefindingswiththoseofothergeographicalregionsofIndia.

Conclusions

The fundamental knowledge of the morphology of ~~PCFand~~PCFand FM is critical in the evaluation of CVJ ~~malforma-tionsandsurgicallyapproachingtheseareas.Linearcra-niometricparameterslikeML,CLandKIarecommonlyusedintheevaluationofBI.AssessmentofTL,heightofposterior~~malformationsandsurgicallyapproachingtheseareas.LinearcraniometricparameterslikeML,CLandKIarecommonlyusedintheevaluationofBI.AssessmentofTL,heightofposterior cranial fossa, IOP-O length, clival length ~~andPCFvolumeareimportantinmakingthediagnosisof~~andPCFvolumeareimportantinmakingthediagnosisof

~~Chiarimalformations.~~

Chiarimalformations.BA,BgA,~~NBOarethemeasuresof~~NBOarethemeasuresof platybasia and are extensively used in making the diag-nosis of BI. FMag, CCA and CPA are relatively ~~newerparameters~~newerparameters that are helpful in evaluating BI. This ~~studydescribed~~studydescribed almost all the linear and angular ~~craniometricparametersusedinthemorphometric~~craniometricparametersusedinthemorphometric analysis of ~~PCFand~~PCFand FM. Findings of this study provide the valuable ~~dataregardingthelinearandangular~~dataregardingthelinearandangular craniometric param-eters of PCF and FM which could redefine the ~~referencevalues~~referencevalues.

Abbreviations

PCF Posterior cranial
~~fossaFM~~
~~Foramenmagnum~~fos
saFM Foramenmagnum
~~CVJ~~
~~CraniovertebraljunctionT~~
~~L Twinningline~~
CVJ
CraniovertebraljunctionT
L Twinningline
ML ~~McRaesline~~McRae'sline
CL ~~Chamberlain'sline~~Chamberlain'sline
~~IOP-O Internaloccipitalprotuberance-opisthionKI~~
~~Klaus'index~~
IOP-O Internaloccipitalprotuberance-opisthionKI
Klaus'index
BA ~~Basalangle~~Basalangle
BgA ~~Boogard'sangle~~Boogard'sangle
~~FMag~~
~~ForamenmagnumangleC~~
~~CA Clivuscanalangle~~
FMag
ForamenmagnumangleC
CA Clivuscanalangle
CPA Clivo palatal
~~angleCOA~~
~~Clivoodontoidangle~~a
ngleCOA Clivoodontoidangle
~~CSO Clivo supraocciput~~
~~angleTtwA~~
~~Tentorialtwinninglineangle~~

~~**Availabilityof**~~CSO
Clivosupraocciput
angleTtwA
Tentorialtwinninglineangle

Availabilityof data and materials

~~Alldatathatsupportthefindingsofthisstudyareavailablefromtheneuro-surgerydepartmentofInstituteofMedicalSciences,BanarasHinduUniversity. Dataarehoweveravailablefromtheauthorwhenrequestedwithpermission.~~
Alldatathatsupportthefindingsofthisstudyareavailablefromtheneuro-surgerydepartmentofInstituteofMedicalSciences,BanarasHinduUniversity. Dataarehoweveravailablefromtheauthorwhenrequestedwithpermission.

Declarations

~~**Ethicsapprovalandconsenttoparticipate**~~

Ethicsapprovalandconsenttoparticipate

This study was conducted after getting ethical clearance from local institu-tional ethical committee members. Consent for participation was

~~obtainedfromeachpatientpriortothestudy~~obtainedfromeachpatientpriortoth estudy.

~~**Consentforpublication**~~
~~Notapplicable. Weconfirmthatalldataincorporatedintothisstudyareanonymized.~~
Consentforpublication
Notapplicable. Weconfirmthatalldataincorporatedintothisstudyareanonymized.

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