GEOMETRIC MORPHOMETRIC COMPARISON BETWEEN MODERN *Homo sapien* SKULLS OF SOUTH INDIA AND REST OF THE WORLD

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

Bachelor of Technology

Biomedical

By

Brijesh Kumar Yadav

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Department of Biotechnology and Medical Technology
National Institute of Technology Rourkela
2011

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Under the guidance of

Prof. Sirsendu Sekhar Ray

Assistant Professor

Department of Biotechnology and Medical Engineering

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CERTIFICATE

This is to certify that the thesis entitled, "**GEOMETRIC MORPHOMETRIC COMPARISON BETWEEN MODERN *Homo sapien* SKULLS OF SOUTH INDIA AND REST OF THE WORLD**" submitted by **Mr. Brijesh Kumar Yadav** in partial fulfillment of the requirements for the award of the Bachelor of Technology in Biotechnology and Medical Engineering with specialization in "Biomedical" at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other University/ Institute for the award of any other Degree or Diploma.

Prof. Sirsendu Sekhar Ray
Assistant Professor
Dept. of Biotechnology and Medical Engineering
National Institute of Technology Rourkela
Rourkela-769008

Declaration

I, **Brijesh Kumar Yadav**, hereby declare that the thesis named “**Geometric Morphometric Comparison Between Modern *Homo sapien* Skulls Of South India And Rest Of The World**” is my original research work. This work includes the valuable contribution of others and every effort is being highlighted with due reference of literature and acknowledgment of collaborative research and discussions.

This work was done under the guidance of **Dr. Sirsendu Sekhar Ray**, Dept. of Biotechnology and medical Engineering, NIT Rourkela.

Brijesh Kumar Yadav

Dept. of Biotechnology and Medical Engineering

National Institute of Technology Rourkela

Rourkela- 769008, Orissa

India

e-mail: brijesh.intelligent1@gmail.com

Mob: +91-8984735948

Date: 12.05.2011

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Acknowledgment

I would like to express my sincere appreciation to all the people who directly or indirectly inspired me and helped me for choosing and accomplishing this work.

I want to pay my sincere respect and honor to my supervisor Prof. Sirsendu Sekhar Ray, for choosing me for this project work. I appreciate his energy and his explanation phenomena that helped me to understand the insight of the work and inspired me many times to give my best.

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Brijesh Kumar Yadav

Dept. of Biotechnology and Medical Engineering

National Institute of Technology Rourkela

Rourkela- 769008, Orissa

India

e-mail: brijesh.intelligent1@gmail.com

Mob: +91-8984735948

Date: 12.05.2011

Abstract

Morphometry can be defined as the measurement of shape irrespective of the variations of size (scale, translation and rotation). In the recent years, a lot of work has been done world-wide to analyze the variations in the human morphology.Most of the work in this direction was done mainly on African or American population. Lack of work on Indian population arouse our interest to make a study on the same. In the present work, we planned to compare the modern *Homo sepien* skull of South India and modern *Homo sepien* skull of world-wide important African male, Australian aboriginal male, African-American male etc. and tried to establish a relationship between them according to their shape. It has been successfully established the relation between the skulls according to the shape closeness. Specimen 10 (South Indian Skull)and 11 (South Indian Skull) have similarity in skull shape which shows the correctness of our result. Specimen 0 (Mongoloid Skull) and 6 (Human Male African-American Skull) show similar shape variation. Specimen 12 (Vedaface) is quite close to (Human Male Asian Skull)8 and 7 (Human Female American Indian Skull). But Specimen 9 (Mongoloid Skull) is found to be quite different from all others. A negative result is also obtained by relative warp which contradicts PCA and shows that specimen 10 (South Indian Skull) posseses similar deformation with respect to specimen 9 (Mongoloid Skull) however 11 (South Indian Skull) is also near. Also 0 (Mongoloid Skull) and 6 (Human Male African-American Skull) are far apart. The result obtained is quite enthusiastic and but further studies in this directions on Indian population is highly required.

1. Introduction

Morphometry is the term which was originated with the study of various fossils of animals and humans. The initial idea was to evaluate the similarity among various body parts for the evolutionary closeness among or outside the species. It has been used for several years to find out the differences in the human skull of various era, different regions and among population groups. Various research works have been done to focus the effect of various environmental factors on the human population. This methodology soon introduced in the medical field for pointing out the deformed diseased body parts. Diseases like schizophrenia and multiple sclerosis the anatomy of skull changes. Using morphometric analysis, it can easily be traced and diagnosed. Morphometrics requires the deep understanding of imaging, mathematical operations and statistical analysis.

Most of the works in this direction are done mainly on African or American population. Lack of work on Indian population arouse our interest to make a study on them. In the present work, we planned to compare the modern *Homo sapien* skull of South India and modern *Homo sapien* skull of world-wide important African male, Australian aboriginal male, African-American male etc. and tried to establish a relationship between them according to their shape. Various advanced softwares are used in this approach. We used tps software suit namely, tpsDig and tpsUtil, for loading the images and putting the landmarks on them respectively. For statistical analysis, Procrustes method, Generalizes Procrustes Alignment, Principle Component Analysis (PCA) and Thin-Plate Spline (TPS) and different warps are used through PAST software. These standard techniques have been world-wide used in morphometry.

The relation between the skulls according to the shape closeness is obtained successfully. Specimen 10 (South Indian Skull) and 11 (South Indian Skull) have similarity in skull shape which shows the correctness of our result. Specimen 0 (Mongoloid Skull) and 6 (Human Male African-American Skull) show similar shape variation. Specimen 12 (Vedaface) is quite close to 8 (Human Male Asian Skull) and 7 (Human Female American Indian Skull). But Specimen 9 (Mongoloid Skull) is found quite different from all others. A negative result is also obtained by relative warp which contradicts PCA and shows that specimen 10 (South Indian Skull) possesses similar deformation with respect to specimen 9 (Mongoloid Skull) however 11 (South Indian Skull) is also near. Also 0 (Mongoloid Skull) and 6 (Human Male African-American Skull) are far apart. The result obtained is quite enthusiastic but further studies in this direction on Indian population is highly required. Due to the immense diversity of climate and population itself India may be the best place for morphometrics research.

2. Literature Review

2.1 <u>Concept of Morphometrics and its use in various studies</u>: Morphometry is a quantitative way of analyzing shape. The study of variations in the geometry of shape among various samples lies in the basic of morphomerty. It has been applied to various biological studies like evolutionary changes, to study the difference between individuals or their parts, affects of environmental or geological factors on particular species or to analyse any injury. Various research works had been done to study and statistically analyze the 2D or 3D shape variations. Comparison between the human, chimpanzee and baboon is taken as the basis to develop a software having a tool which can visualize and analyze the shape variations in 3D (David F. Wiley et al., 2005). In 1980s, the taxonomic status of Homo erectus sensu lato has been challenged. It was suggested that the early African fossils may represent a different species named H. ergaster. So, to resolve this debate 3D geometric morphometry is used to quantify the overall shape variation in the cranial vault within H.erectus. Results obtained in this study revealed that the variations in H. erectus is most comparable to a single species of popionin monkeys and the genus Pan but there is no significant differences between H. ergaster and H. erectus sensu stricto (Karen L. Baab 2007). Cranial morphology is widely used to reconstruct the evolution. Some cranial regions such as face and neurocranium are believed to be influenced by environment which can affect the evolutionary process. A 3D geometric morphometrics method is used to explicitly test the cranium shape, size etc. and the influence of climate on them. It has been found that climatic conditions have only effect on facial shape (Katrina Harvati et al., 2006). A very interesting study is done to observe sensilla and sensory mechanism because it plays a very significant role in host-seeking and oviposition behaviour of mosquitoes which enable them to transmit diseases to humans. A morphometric analysis is done to investigate the various kinds of sensilla located on antenna, maxillary palp etc. of dengue vector of Asian tiger mosquito (T. Seenivasagan et al., 2009).

A quantitative analysis of human mandibular shape is done using 3D geometric morphometrics to document geographic and functional patterning in the mandibular shape of recent humans, to assess the effects of allometry on mandibular structure and to quantitatively evaluate "Neanderthal" mandibular traits through comparison with samples of geographically diverse recent humans. It has been found that the modern human mandibular shape exhibits significant geographical patterning, some aspects of mandibular morphology reflecting a climate gradient and others functional specialization (Elisabeth Nicholson et al., 2006).

2.2 <u>Landmark selection:</u>

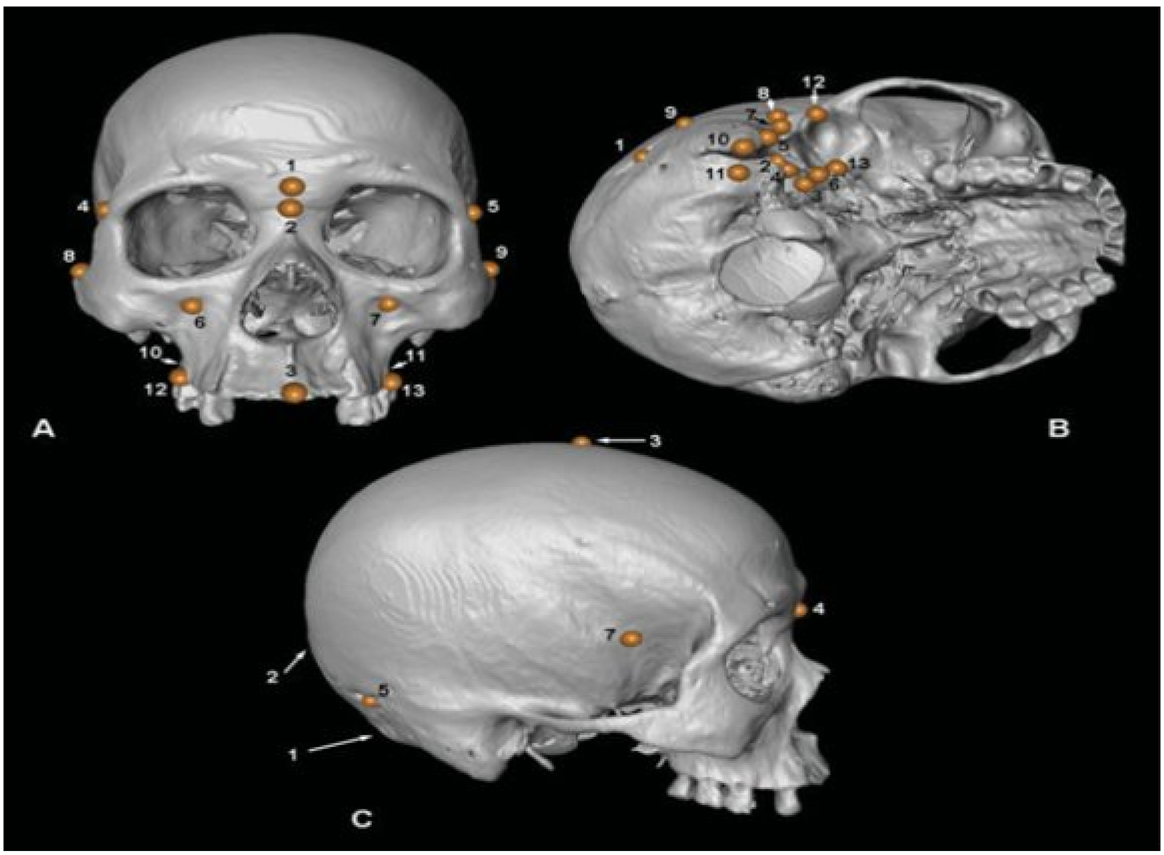

Fig. 1. 3D landmarks are shown on a human skull

Landmarks are the homologous points on the surface of the specimen which provide numerical values for analyzing a particular shape and establish a comparison with other specimens. Almost every morphometric research is done using landmarks. Various softwares are developed for easy selection of landmarks in 2D or 3D morphometry. Morpheus, Morphologika and TPS suite (tpsDig) are the software packages which are mostly used by morphologists. If a structure is almost straight then placing a few landmarks are enough but for the complete coverage of a complicated structure large number of landmarks are required. Denser the landmarks, better will be the coverage and better will be the comparison among specimens. Landmarks specification, their sequence and their numbers affect specimen's analysis.

2.3 Statistical Analysis: After getting the shape of the specimens in numerical form in terms of landmarks, analysis comes into picture for comparing them. There are countless ways to apply statistical methods and analyze them. But some methods are most frequently used in several research works. Some of these are:

2.3.1 Procrustes superimposition: This is the minimum of sum-squared distance between two landmark points over all rotations, scales and translations. Procrustes distance imposes a geometry on the landmark configuration space. But the space created in this process is non-linear shape space means direct statistical analysis cannot be done (David F. Wiley et al., 2005, Karen L. Baab 2008, Katrina Harvati et al., 2006, Elisabeth Nicholson et al., 2006).

2.3.2 General Procrustes Alignment (GPA): To overcome the problem of Procrustes distance, a consensus landmark set is chosen to minimize the total squared difference between the aligned input landmark sets and the consensus configuration. This process produces a linear space on which direct statistical analysis can be done. After GPA, we can linearly interpolate our set of input configuration (David F. Wiley et al., 2005, Karen L. Baab 2008, Katrina Harvati et al., 2006, Elisabeth Nicholson et al., 2006).

2.3.3 <u>Principal component Analysis (PCA)</u>:

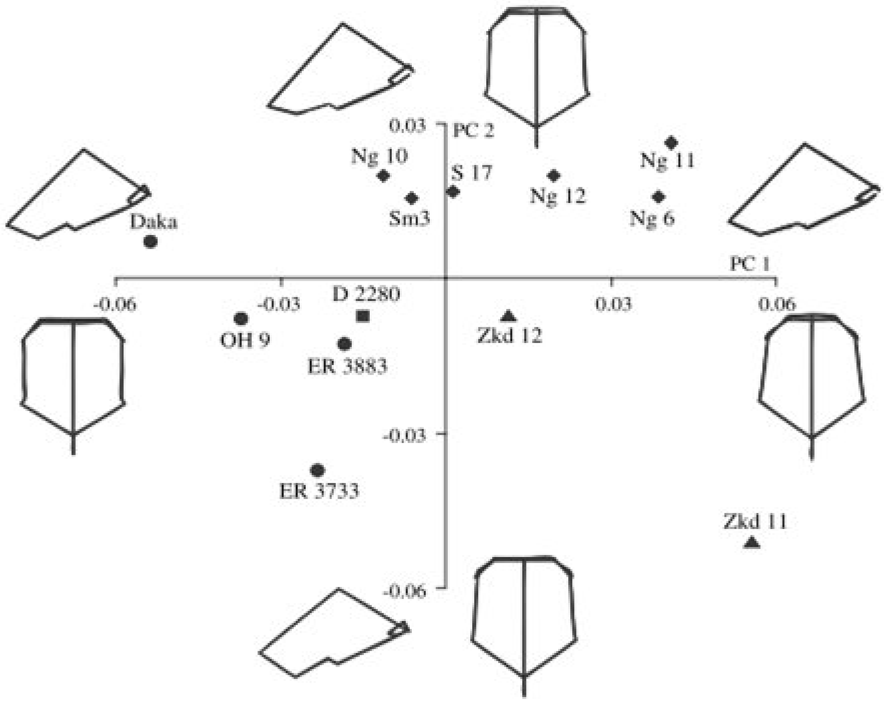

Fig.2. PCA analysis plot between PC1 and PC2

A PCA was performed on both the 16 and 32 landmark sets for H.erectus sample to analyze the neurocranial shape variation in this taxon. The smaller landmark set separates the African and Asian fossils along principle component 1 (PC1) which is 34.6% of the total variation, although the east turkana specimens score similarity to Ng 10 and Sm 3. Specimen D2280 is intermediate between the two groups on this axis. The Indonesian fossils and Daka score high on PC2 (18.4%) (Karen L. Baab 2008).

2.3.4 <u>Thin-Plate Spline (TPS) and Warps</u>: This is another mostly used method for analyzing the shape. The TPS warp is defined using an input set of landmarks and the target set of consensus landmark points and it brings the input landmarks into coincidence with the target set. The source surface mesh is deformed till the target shape is achieved. It is obtained that input surface meshes varied in size, from 797K to 433K triangles, except for the papio model, for which only a 75K triangle mesh was available (David F. Wiley et al., 2005).

3. Material and methods

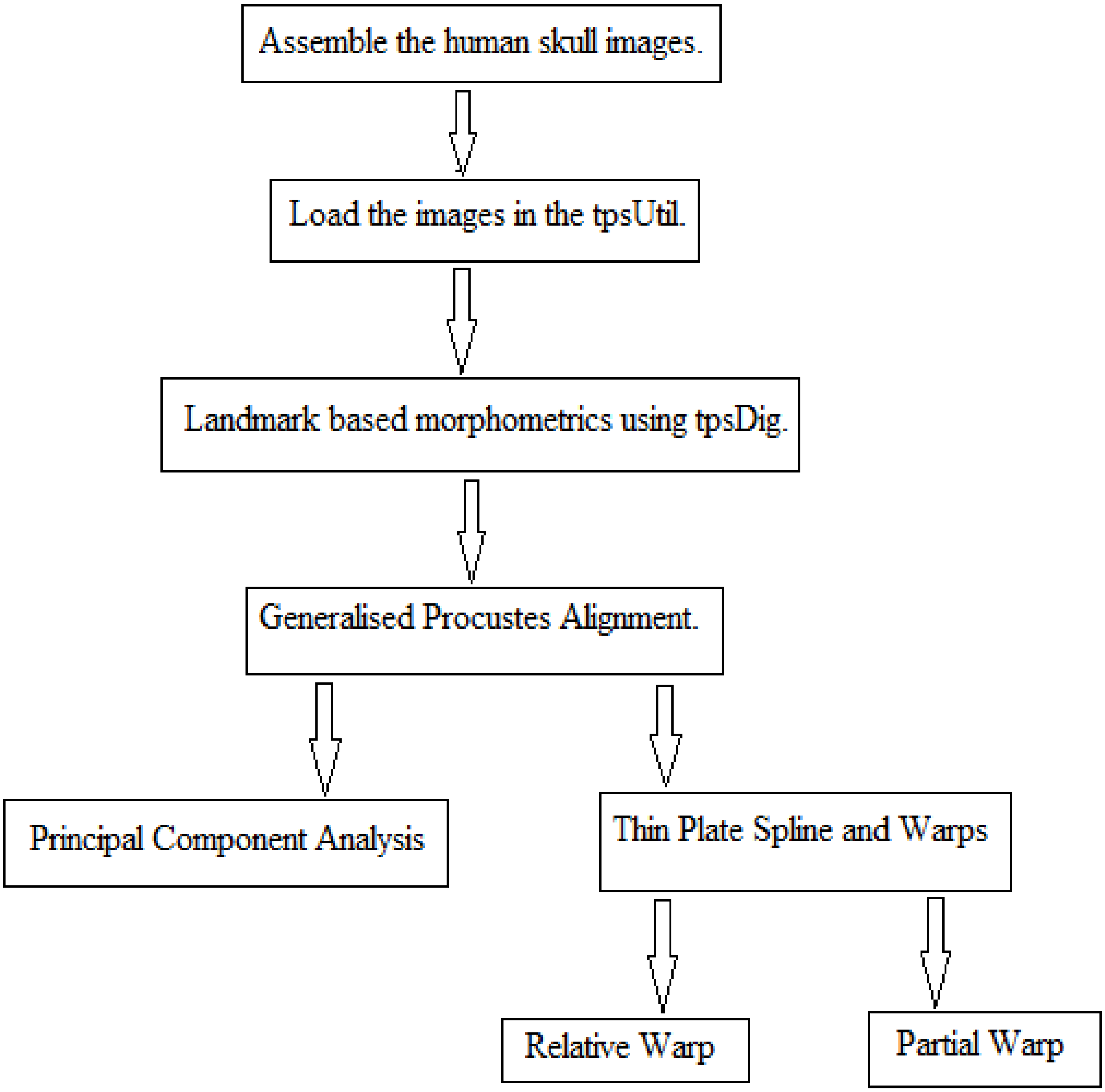

Fig.4 Flowchart of overall work

3.1 **Description of Modern *Homo sapiens* skull images (120.000 Years ago)*:**

Specimens	Description
0. Mongoloid Skull	Mongoloid are considered as among the initial people who came to India and become its native.
1. Human Male Asian Skull	The inter-ocular distance is broad, the nasal angle is sharp, the nasal aperture is broad from top to bottom; the cheekbones are wide, the palate has a somewhat rounded shape.
2. Human Male Australian Aboriginal Skull	This specimen serves as a piece around the concept of race assessment and the limitations of classification into 3 categories-European, African, and Asian.
3. Human Male European Skull	In this skull, the nasal root is prominent and the nasal angle is acute. The nasal spine is short and the lower part of the nostril has a sharp nasal sill with a very vague impression of bilateral gutters.
4. Human Male African Skull	The nasal root is depressed and the nasal angle is obtuse. The nasal aperture is broad from top to bottom. The lower part of the nostrils has a bilateral gutter and there is no sill. The incisors in the upper jaw are blade-like; however, there is a slight suggestion of shoveling on the left incisor.

5. Roman Gladiator Human Skull	This specimen shows unusual brachycephalic structure with a very high, near vertical forehead and exaggerated occiput. The exceedingly dense skull gives it weight and strength. Noteworthy on the skull is a large, healed "knot" of bone showing trauma.
6. Human Male African-American Skull	These features include a projecting profile, a depressed nasal root, an obtuse nasal angle, a short anterior nasal spine, a bilateral gutter at the lower part of the nasal aperture, a somewhat rectangular-shaped palate, and blade-like incisors in the upper jaw.
7. Human Female American Indian Skull	The facial bones are vertically aligned with a shallow nasal depression, a moderate nasal spine, an orthognathic jaw, and a vertical chin. The cranium is rounded, with bulbous parietals and a complicated lambdoid suture. The orbits are rounded or squared and the zygomaxillary suture is relatively straight.
8. Human Male Asian Skull	a full set of associated teeth provides exceptional detail. In particular, the pterygoid plates, condyles, and styloid processes are highly pronounced and complete.

9. Mongoloid Skull	-Same as Mongoloid above-
10. South Indian Skull	The South Indian skull-modern man who is not a uniform homogeneous type. He exhibits great diversity even at the earliest time of his appearance. Three of these diverse types give early indications of the three principal racial types of mankind. The Cro-magnon is associated with the modern Caucasoid and Grimaldi with the Negroid, and the Chancelade with the Mongoloid.
11. South Indian Skull	-Same-
12. Vedaface	Skull types representing the Mediterranean, Mongoloid, Negroid and Australoid people represent the races of mankind. Included in this set is a cast of a Vedda face in which the Veddid or Australiod type is seen at its best. This is the most predominant type in the aboriginal population of Peninsular India being characteristic of the Bhils of Bombay, the Gonds of the Madhya Pradesh, the Chenchus of Andhra Pradesh, the Malasar of Coimbatore and the Paniyans of Kerala.

Table 1: List of specimens with their description

* courtesy of the table: (a) http://www.chennaimuseum.org/draft/gallery/02/03/phyantho.htm

(b) http://www.boneclones.com/catalog-human-adult-skulls.htm

3.2 Important Terms: Before going to the detailed explanation of material and methods, understanding of few terms are must:

3.2.1 Size: In morphometrics, size may be defined as the measurement of an organism like length along any body axis, area, volume, weight or it may be a linear combination of all the measurable quantities which can be correlated. Size changes with the slight variation like scale, rotation and location in the image. Morphometrics keeps the concept of size and shape fully independent

3.2.2 Shape: In terms of morphometrics, shape can be defined as all the geometric informations that are obtained after filtering out location, scale and rotational effects from object.

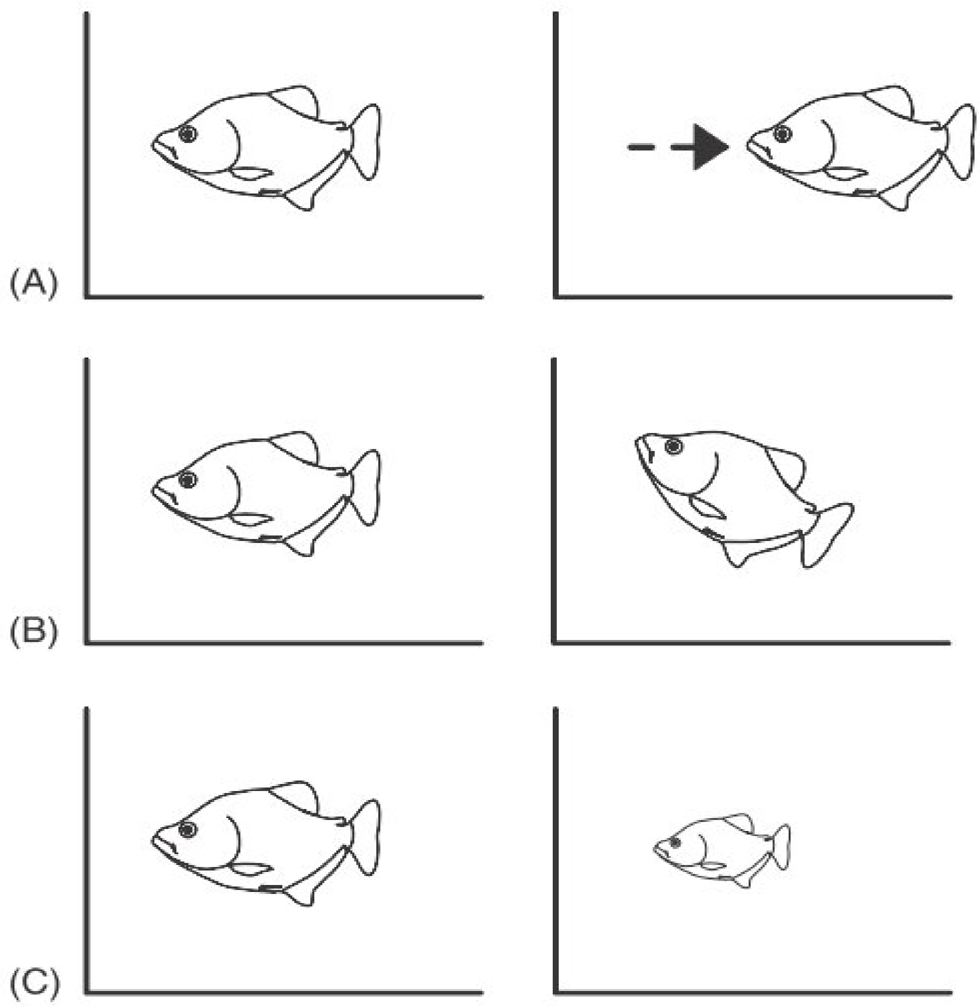

Fig.3 Size effect of (A)location, (B)rotation and (C)scale are shown.

3.2.3 <u>Landmarks:</u> Landmarks can be defined as homologous anatomical loci that don't alter their topographical positions relative to the other landmarks, provide adequate coverage of the morphology, can be found repeatedly and reliably and lie in the same plane. In morphometrics, a discrete set of K homologous landmarks are chosen on N input object surfaces;

$$L^i = (x1, x2, x3 \dots xK), 1 \leq i \leq N$$ ……………………(1)

More the number of landmarks better will be the coverage on the image and an adequate sampled shape can be represented.

3.2.4 <u>Mean:</u> Mean is the sum of items divided by the number of items;

$$\bar{X} = \sum_{i=1}^{n} Xi/n$$ ……………………….(2)

where $\bar{X}$ is mean, X is the item and n is the number of items.

3.2.5 <u>Standard Deviation:</u> It is the average distance from the mean of the data set to a point.

$$s = \sqrt{\sum_{i=1}^{n} (Xi - \bar{X})^2/(n-1)}$$ ……………………..(3)

3.2.6 <u>Variance:</u> Variance is the square of standard deviation

$$s^2 = \sum_{i=1}^{n} (Xi - \bar{X})^2/(n-1)$$ ……………………(4)

3.2.7 <u>Covariance:</u> Covariance is always calculated between 2-dimeansions, i.e.;

$$cov(X,Y) = \sum_{i=1}^{n} (Xi - \bar{X})(Yi - \bar{Y})/(n-1)$$ …………………...(5)

3.2.8 <u>Eigenvector and Eigenvalue:</u> Eigenvectors are the non-zero vectors, A, satisfying the eigenvector equation :

$$(X - \lambda I)A = 0 \qquad \text{..................(6)}$$

where the values of λ satisfying this equation are eigenvalues of X.

Eigenvectors are orthogonal of each other and provide a smallest set of axes for a vector space.

Now explanation of methods used:

3.3 <u>Procrustes fitting (Superposition):</u> Procrustes distance is the minimum of squared sum of distance between two sets of landmark, over all rotations, translations and scales.

$$D(L^i, L^j) = \sqrt{\sum_{n=1}^{K} (\ln^i - Lm^j)^2} \qquad \text{.............(7)}$$

Procrustes distance superimpose all the landmark sets of all the images with the removal of size effect namely rotation, scale and translation. It forms a non-linear space in which it imposes a geometry on the space of landmark configuration. But this kind of pair-wise superimposition doesn't produce a multiple mutual alignment of all the landmark sets which means if we have 3 sets of landmark namely, La, Lb and Lc and we aligned La to Lb and Lb to Lc, that doesn't mean La will be aligned to Lc. We can't apply statistical analysis to this non-linear space. To overcome this problem, we use Generalized Procrustes Alignment (GPA). In this special method, a particular landmark set is chosen to minimize the total squared difference between this particular landmark set and the input landmark sets. This process changes the non-linear space to a linear space so that the statistical techniques can directly be applied on them.

3.4 <u>Principal Component Analysis (PCA)</u>: Principal component analysis is simply a way to determine the patterns in the data and express the data in order to highlight the similarities and differences between them. Its a tool for finding the hypothetical variables called principal components to simplify the multivariate variation among individuals. These variables are linear combination of the original variables. PCA simply reduces the number of dimensions after finding the pattern thus it compresses the data without any significant loss of information.

Methodology involved in PCA:

Step 1: Data is arranged in a way such that coordinates (x, y) lie in the column and objects in rows.

Step 2: Subtract the mean from each of the dimensions.

Step 3: Calculate the covariance matrix $C = \begin{pmatrix} cov(xx) & cov(xy) \\ cov(yx) & cov(yy) \end{pmatrix}$

Step 4: Calculate the eigenvectors and eigenvalues of the covariance matrix

Step 5: Choosing the eigenvector having the highest eigenvalue which is the principal component of the data set. We can arrange the eigenvectors from highest to lowest eigenvalue. Now, keep the eigenvectors having the large eigenvalues and discard the rest. Finally arrange these eigenvectors in a matrix named feature matrix.

Feature Matrix = (eig1 eig2......eigN)

Step 6: Finally take the transpose of the feature matrix and multiply it with the transposed mean-subtracted data (step 2). The data we obtained finally is the original data in terms of the vectors we chose, means we reduced the dimensions by discarding low eigenvalues.

3.5 <u>Thin Plate Spline and Warps:</u> Thin-plate spline is an interpolation function used to determine the overall difference in shape between a reference and sample shape, not just at landmarks. In a simple way, one can say thin-plate spline is a transformation of source shape to a target shape by placing it on a square grid and deforming the grid and shape until the target shape is obtained. This deformation of grid and corresponding shade change gives a clear idea of variations in shape.

3.5.1 <u>Principal Warps</u>: From the given shape a multidimensional space also called as deformed space can be created where all the possible deformation of source shape to target shape is plotted as points. These coordinates not only give the displacement of landmarks from the source but also define importantly an orthogonal set of basis functions for the space which is based on the “bending energy” of the transformation. These basis functions are named as principle warps. Thus, principal warps may be defined as a space of all possible transformations away from the source shape and are independent of any target configuration. Principal warp is used to determine the partial warp.

3.5.2 Partial Warps: Irrespective of principal warps which are only dependent on source configuration, partial warps are unique with respect to a source to a given target. In a sample having collection of specimens, if the mean is taken as the source then each specimen will have its own partial warps depending upon the deformation from the mean shape to the particular specimen. A transformation is completely and uniquely defined as the weighted sum of the partial warps and affine component which is the zeroth order warp and describes the linear deformations of scaling, stretching and shearing. The main characteristic of partial warps is they are arranged according to their local corresponding deformations. The higher order warps corresponds to the local deformations while first partial warp gives information about the global and large scale deformations.

3.5.3 Relative Warps: Relative warps are the principal components of a set of thin-plate spline transformations. Relative warps are their own transformations and can be visualized by the grid deformations. They can be used as a tool for data reduction for a set of transformations by placing the original transformations as points in Principal Component Analysis scatter plot.

3.6 Softwares Used:

3.6.1 tpsUtil: This program allows to build a tps file before collecting the data which is basically a list of specimens.

Steps involved in the use of tpsUtil are given below:

Step 1: Place all the specimens/images in a single folder.

Step 2: Open tpsUtil

Step 3: Click “Select an operation” under Operation and choose “Build tps file” from drop-down list.

Step 4: Under input path or directory: Click “Input”, select the directory and click on one of the images, it'll display the path of the directory as “Data file=?”.

Step 5: Under output file: Click “Output”. Enter the file name with “.tps” extension and save, it will display the path of saved directory as “Output file=?”.

Step 6: Build the tps file: click “compute” under Actions. A list of images will appear check/uncheck as per choice. Click “create” and “close” to exit tpsUtil.

If we open the .tps extension file, it'll appear like:

LM=0

IMAGE=imagename1

LM=0

IMAGE=imagename2

Since, zero landmark is selected, it shows LM=0

3.6.2 **tpsDig:** This software is used to select landmarks on the images and save them in tps file.

Steps involved in the use of tpsUtil are given below:

Step 1: Open tpsDig.

Step 2: Open the tps file: file->Input source->File...

Step 3: Place the Landmarks: Select cross-hair icon by left-click we can select the landmarks and by right click, we can delete the selected landmark.

Step 4: Save the landmark data. File->Save data->Save.->Overwrite.

Similarly, put landmarks on each specimen and place the file. On opening it will look like:

LM=2

123.0 134.0

154.0 123.0

IMAGE=imagename1

ID=0

LM=2

100.0 200.0

300.0 500.0

IMAGE=imagename2

ID=1

3.6.3 <u>PAeontological STatistics (PAST):</u> Past is a Software package which was originally developed Paleontological data analysis but currently it is being used various fields to life science, earth science, engineering and economics.

After importing the data file (dimensions in column-specimens in rows) following statistical methods are used in PAST :

3.6.3.1. <u>Procrustes fitting:</u> select the data then Transform->Procrustes 2D/3D.

Landmark data is always recommended to bring into a standard form i.e., to Procrustes coordinates because we need to analyze the shape. Landmarks contain the size effect so by standardizing to Procrustes coordinates we remove the scaling, rotation, and translation effect. A further modification is to Procrustes residual is done my subtracting mean from the Procrustes coordinates (Transform->Subtract mean).

3.6.3.2. <u>Principal Component Analysis(PCA):</u> Multivar-> Principal components

PCA is a method used to find out hypothetic variable called principal components, which contain the maximum variance in the data and discard rest. So it reduces the dimensions to in terms of only principal components. These new variables are the linear combination of original variables. PCA determines the eigenvectors and eigenvalues of variance-covariance or correlation matrix. If variable are in the same unit then var-covar is used else correlation is opted. The eigenvalues give a measure of variance corresponding to the eigenvector. The percentage of variance is also displayed for this.

Following components are evaluated and displayed in PCA:

3.6.3.2.(a) <u>Jolliffe Cut-off:</u> It gives an indication of how many significant principal components can be taken into account. Eigenvalues below Jolliffe Cut-off can be discarded as insignificant.

3.6.3.2.(b) <u>Scree plot:</u> Its an eigenvalue plot which indicates the number of significant components. After the curve starts to flatten, the components may be regarded as insignificant.

3.6.3.2.(c) <u>Scatter Plot:</u> It shows all the data points plotted in the coordinate system of two of the principal components. "Minimal Spanning Tree" can also being plotted which is the shortest possible set of connected lines connecting the points. It may be used to group close points because it is based on the Euclidean distance. "Biplot option" shows a projection of the original axes onto scattergram. "View Loadings" plot shows the degree of original variables in the different components.

3.6.3.3. <u>Thin-plate splines and warps:</u> Geomet-> thin plate splines and warps 2D.

The data is arranged as specimens in rows and variants in columns. "Expansion factors" option displays the expansion or contraction factor around each landmark in yellow numbers which implies the local growth. The expansion shown by this factor is colour coded for all grid elements where green is for expansion and purple for contraction. Principal strain can also be displayed at each landmark with major strain in black and minor strain in brown. These vectors indicate directional stretching.

3.6.3.3(a) <u>Partial warps</u>: It can be selected from thin-plate spline window to see the partial warp for a particular spline deformation. Higher order partial warps show more local deformation while first partial warp shows global deformation. The affine component of the warp stands for linear translation, scaling, rotation and shearing. When the amplitude factor is incremented from zero to some value, the original landmark configuration and a grid will subsequently deform according to the chosen partial warp.

3.6.3.3(b) <u>Relative Warps:</u> Geomet-> Relative warp 2D.

Relative warp can be considered as the principal components of the set of thin-plate transformations from the mean shape to each of the shapes. It provides a choice to direct PCA of the landmarks. The parameter alpha can be set to any of the three values:

(a) alpha= -1 : It emphasizes local deformation/variation.

(b) alpha= 0: This is the PCA of landmarks directly. It is equivalent to the shape PCA but excluding the affine component.

(c) alpha= 1: It emphasizes the global deformation/variation.

The relative warps are ordered according to their priority. The First and second warps are generally more informative. The relative warps are analyzed by thin-plate spline transformation grids. When the amplitude factor is increased or decreased from zero, the original landmark configuration and grid deforms according to the selective relative warp.

4 Results and Discussion

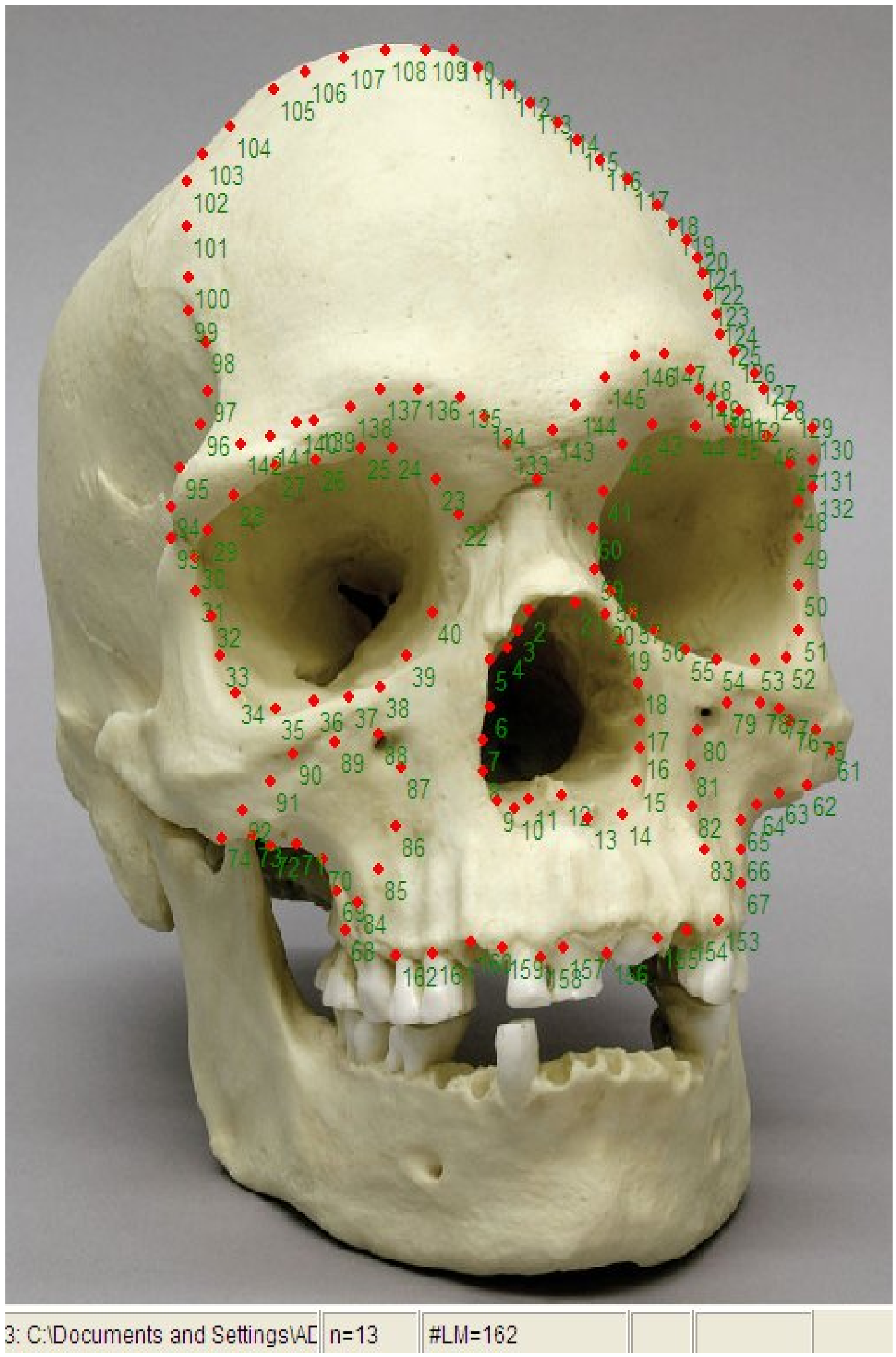

Fig.5. A skull specimen with 162 landmarks are shown.

thesisstat.TPS

File Edit Transform Plot Statistics Multivar Model Diversity Time Geomet Strat Cladistics Script

Edit mode | Edit labels | Square mode

	X1	Y1	X2	Y2	X3	Y3	X4	Y4	X5
0	113.00000	159.00000	105.00000	118.00000	95.00000	119.00000	90.00000	109.00000	85.00000
1	484.00000	570.00000	491.00000	510.00000	480.00000	499.00000	469.00000	478.00000	463.00000
2	526.00000	556.00000	536.00000	487.00000	517.00000	483.00000	507.00000	466.00000	497.00000
3	420.00000	548.00000	417.00000	473.00000	410.00000	457.00000	404.00000	440.00000	388.00000
4	502.00000	571.00000	496.00000	480.00000	480.00000	468.00000	452.00000	453.00000	434.00000
5	332.00000	536.00000	310.00000	473.00000	296.00000	459.00000	282.00000	436.00000	274.00000
6	481.00000	540.00000	475.00000	471.00000	456.00000	457.00000	443.00000	438.00000	433.00000
7	318.00000	388.00000	330.00000	305.00000	325.00000	298.00000	316.00000	296.00000	313.00000
8	472.00000	605.00000	465.00000	516.00000	450.00000	499.00000	437.00000	479.00000	430.00000
9	90.00000	122.00000	87.00000	109.00000	85.00000	107.00000	82.00000	102.00000	82.00000
10	87.00000	143.00000	80.00000	111.00000	74.00000	108.00000	69.00000	102.00000	67.00000
11	81.00000	166.00000	70.00000	141.00000	67.00000	137.00000	64.00000	132.00000	59.00000
12	123.00000	144.00000	127.00000	104.00000	120.00000	101.00000	118.00000	93.00000	117.00000

	Y5	X6	Y6	X7	Y7	X8	Y8	X9	Y9	X10
0	99.00000	82.00000	89.00000	80.00000	80.00000	79.00000	70.00000	82.00000	60.00000	87.0000
1	453.00000	451.00000	441.00000	447.00000	422.00000	447.00000	404.00000	450.00000	392.00000	459.000
2	449.00000	492.00000	420.00000	485.00000	391.00000	489.00000	372.00000	506.00000	357.00000	523.000
3	423.00000	378.00000	405.00000	371.00000	392.00000	371.00000	369.00000	384.00000	356.00000	398.000
4	428.00000	431.00000	400.00000	433.00000	373.00000	450.00000	354.00000	472.00000	343.00000	489.000
5	412.00000	275.00000	390.00000	275.00000	365.00000	275.00000	349.00000	282.00000	340.00000	290.000
6	425.00000	433.00000	412.00000	433.00000	386.00000	443.00000	371.00000	460.00000	361.00000	474.000
7	282.00000	307.00000	269.00000	302.00000	249.00000	302.00000	237.00000	302.00000	224.00000	309.000
8	460.00000	422.00000	445.00000	420.00000	429.00000	421.00000	414.00000	424.00000	402.00000	434.000
9	96.00000	79.00000	90.00000	76.00000	86.00000	76.00000	80.00000	76.00000	73.00000	82.0000
10	99.00000	66.00000	96.00000	65.00000	86.00000	67.00000	84.00000	70.00000	82.00000	74.0000
11	128.00000	57.00000	123.00000	55.00000	118.00000	55.00000	109.00000	56.00000	105.00000	61.0000
12	88.00000	115.00000	82.00000	110.00000	73.00000	109.00000	63.00000	111.00000	58.00000	117.000

Fig 6. PAST tool loaded with 162 landmark data of each 13 specimens.

- 162 landmarks are taken on 13 images using tpsDig shown in fig. 5.The landmark data is loaded in PAST with specimens in rows and coordinates in columns shown in fig. 6.

Principal Components

PC	Eigenvalue	% variance
1	0.0156283	38.229
2	0.00762818	18.66
3	0.00429697	10.511
4	0.00315278	7.7122
5	0.00249137	6.0943
6	0.00236169	5.7771
7	0.00168329	4.1176
8	0.00120294	2.9426
9	0.000966124	2.3633
10	0.000680111	1.6637
11	0.00048121	1.1771
12	0.000307452	0.75208

Table 2. Principal Components of PCA are shown with eigenvalue and % variance.

- After the process of GPA, Principal Component Analysis is done, which reduces the dimensions and gives the significant Principal components where PC1=38.229% and PC2=18.66% variance.

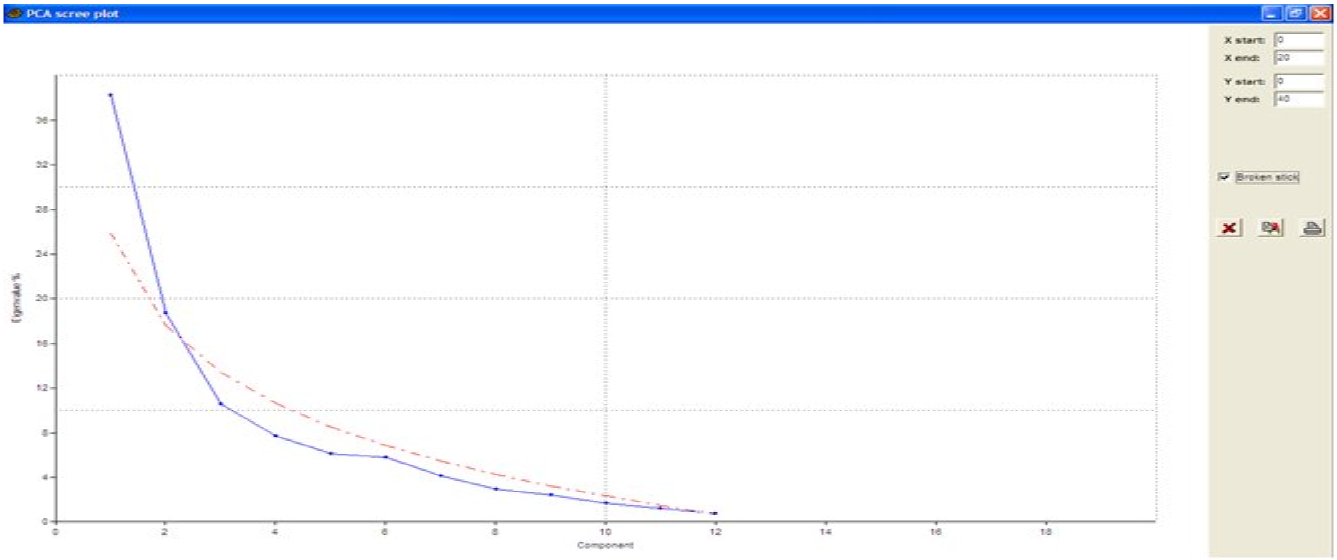

Fig 7. PCA scree plot

- PCA scree plot is another important plot which shows that the slope dies after 12 components so 13 dimensions are reduced to 12.

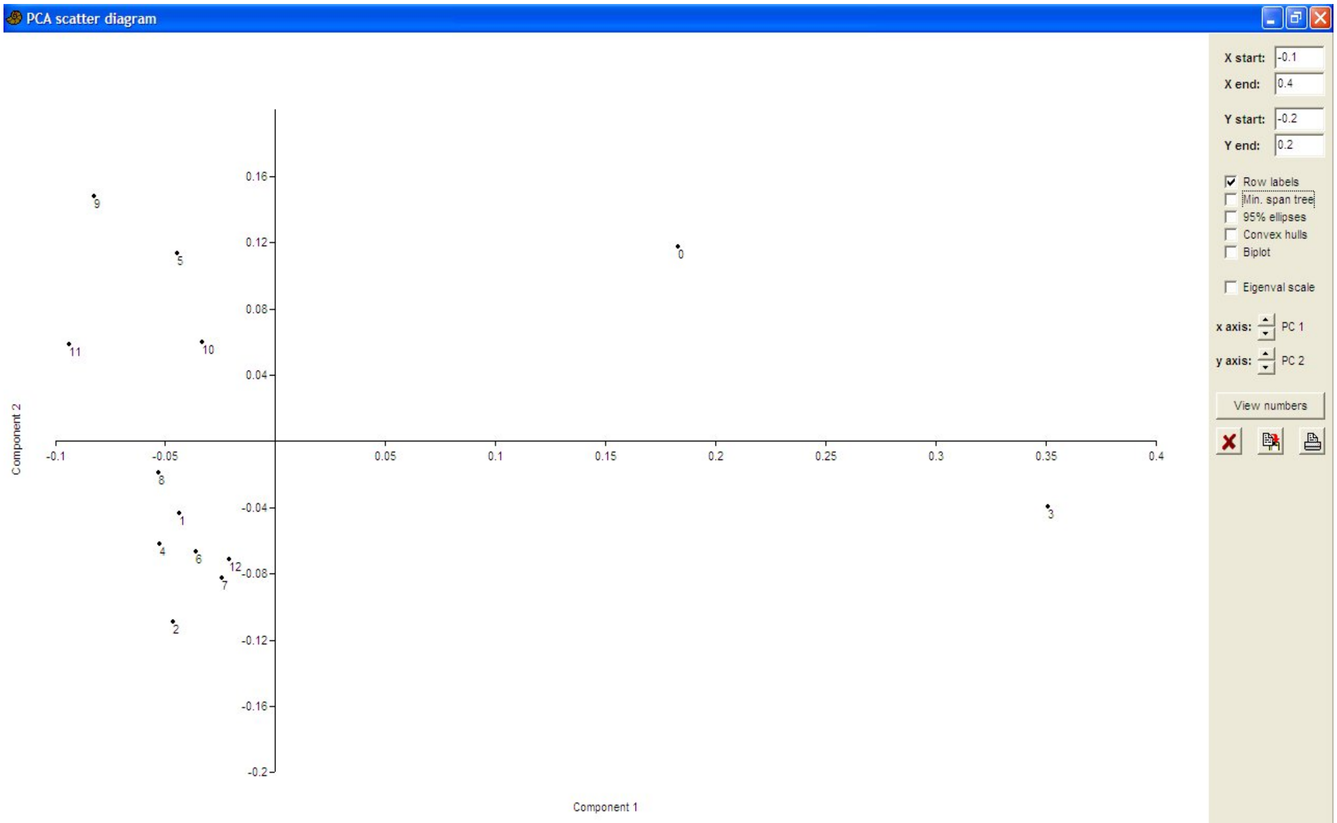

Fig 8. PCA scatter plot.

• The Scatter plot is one of the most informative tool. It shows how many species are similar in terms of shape. Specimen 10 (South Indian Skull) and 11 (South Indian Skull) share the equal distance from PC1 means they have similarity in skull shape. Whereas specimen 0 (Mongoloid) and 6 (Human Male African American Skull) show similar shape. Specimen 12 (Vedaface) is quite close to 8 (Human Male Asian Skull) and 7 (Human Female American Indian Skull). Specimen 9 (Mongoloid Skull) is found to me quite different from all others.

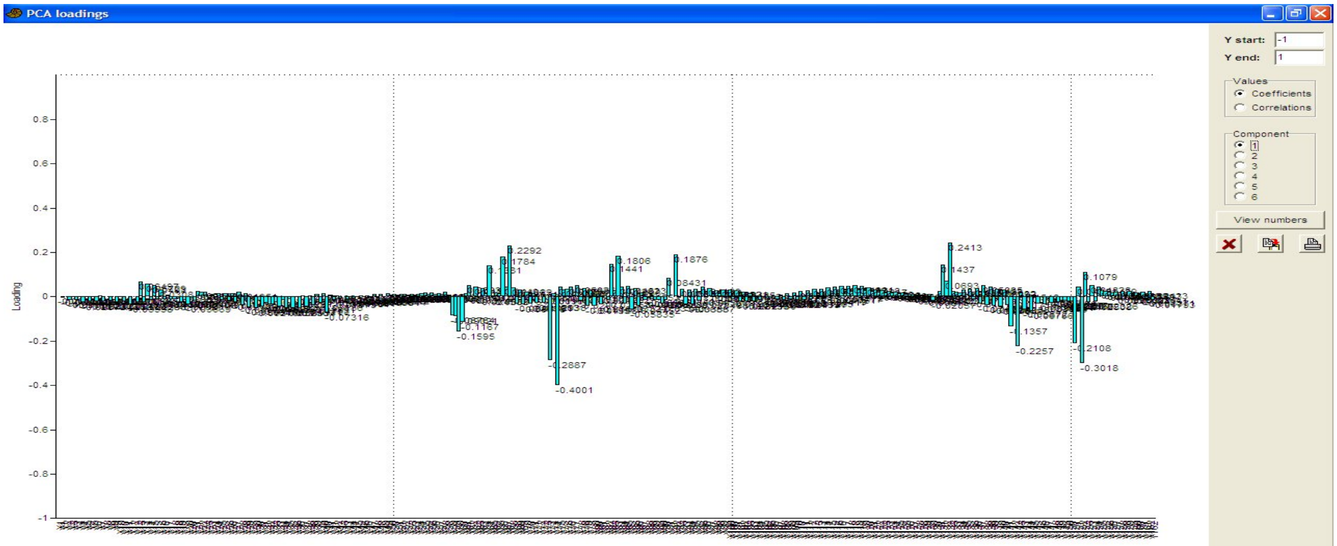

Fig 9. PCA loadings

• PCA loadings plot shows the degree of original variables in the different components.

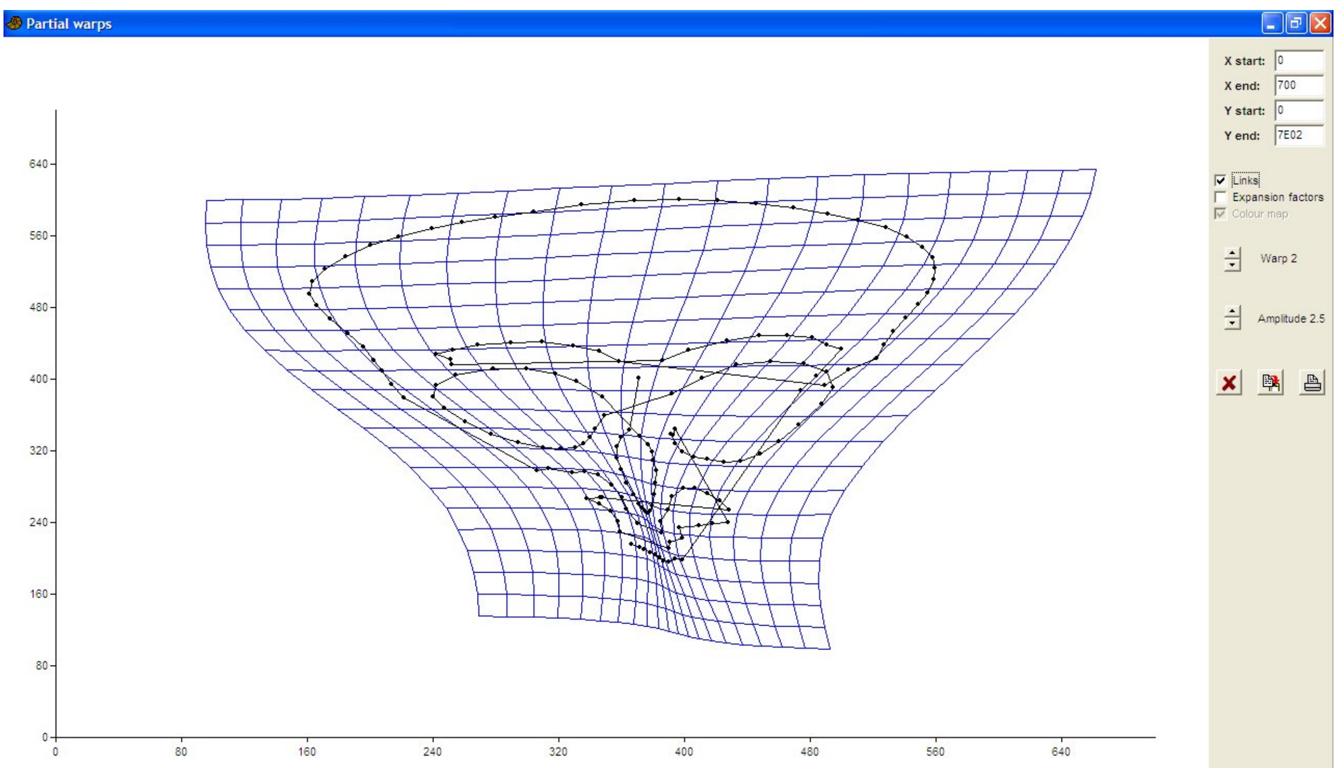

Fig 10. Partial warp 2 with amplitude 2.5.

• Partial Warps visualization shows the deformation of warp 2 with amplitude 2.5. In a similar fashion all the possible deformation of particular specimens can be seen and compared. It has been found that 10 (South Indian Skull) and 11(South Indian Skull) specimens have similar deformation while 12 (Vedaface) deformations have similarity with 8 (Human Male Asian Skull) and 7 (Human Female American Indian Skull). In the same way, 0 (Mongoloid skull) and 6 (Human Male African American Skull) are quite similar in deformations.

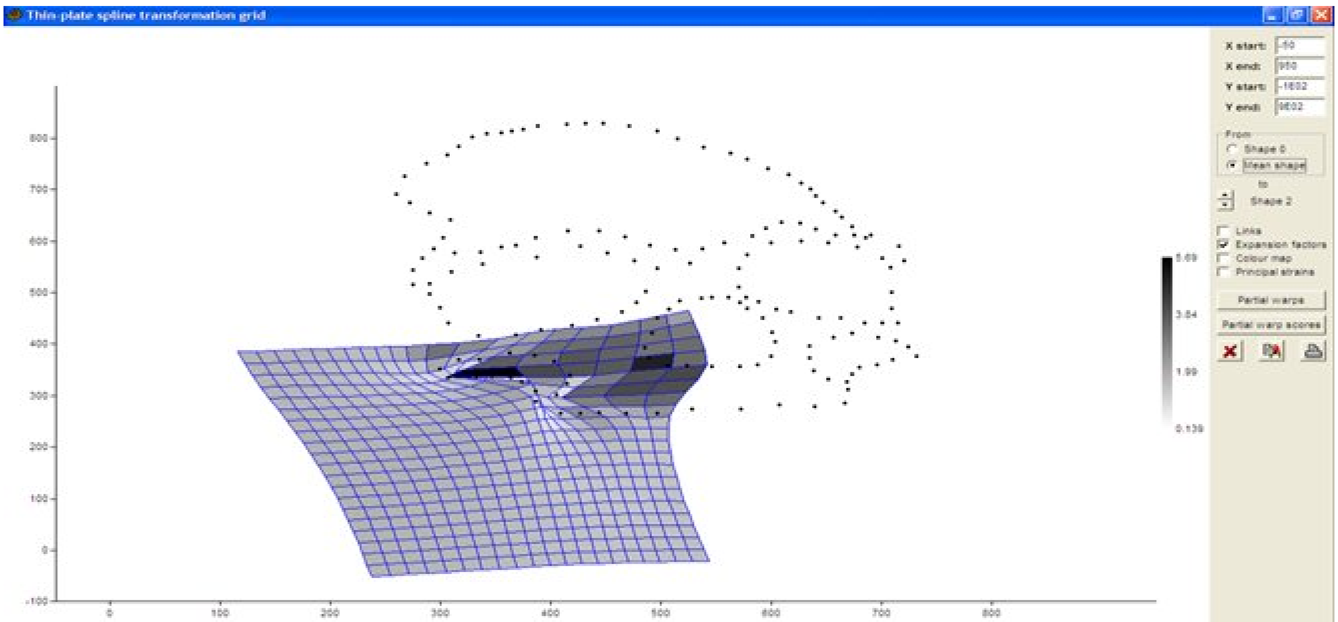

Fig.11. TPS plot

- Thin-plate spline shows the deformation of all the shapes with respect to a mean shape. In fig. 1 shape 2 (Human Male Australian Aboriginal Skull) is shown with possible deformation with respect to mean shape. It has been found that 10 (South Indian Skull) and 11(South Indian Skull) specimens have similar deformation while 12 (Vedaface) deformations have similarity with 8 (Human Male Asian Skull) and 7 (Human Female American Indian Skull). In the same way, 0 (Mongoloid Skull) and 6 (Human Male African American Skull) are quite similar in deformations with respect to mean.

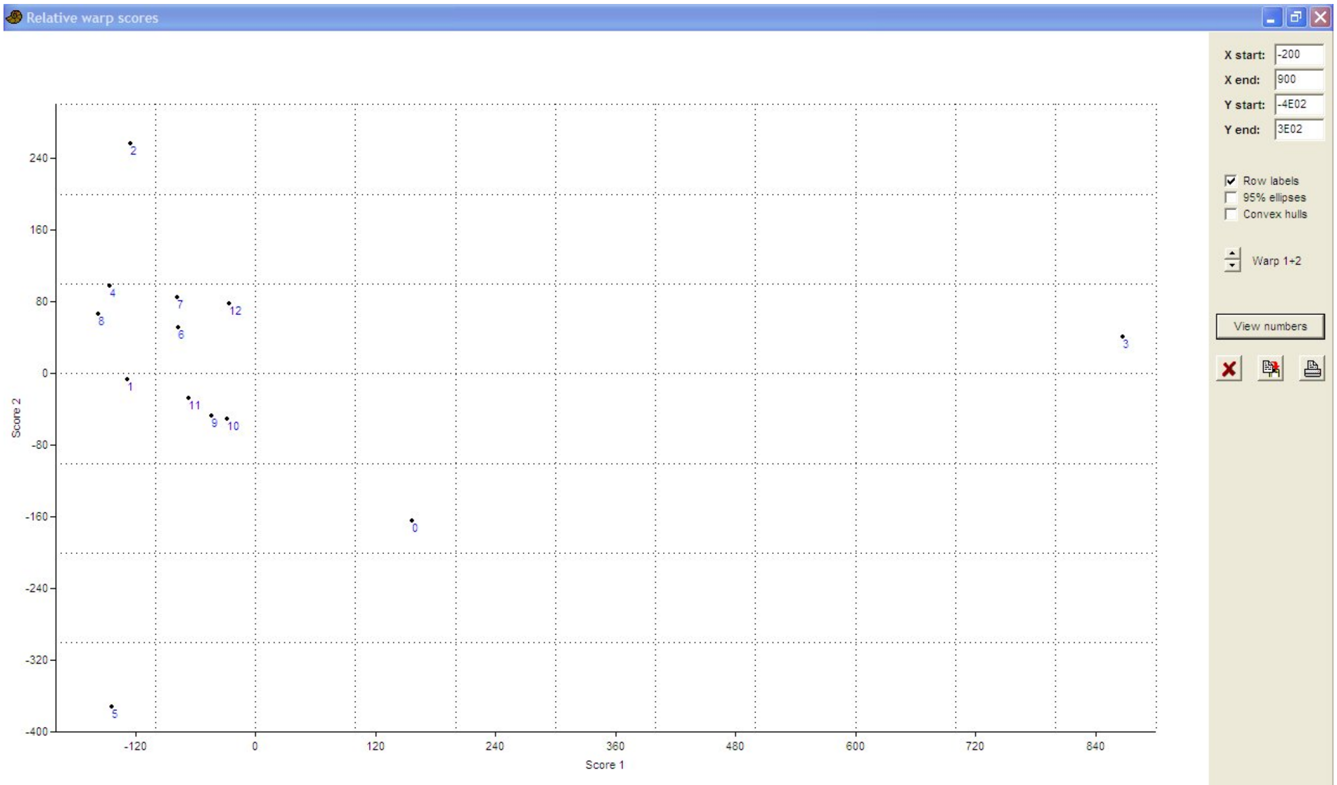

Fig.12 Relative Warp plot.

• Relative warp plot above shows the specimens in a space of two most important components of TPS like in PCA. This shows some different results from PCA like specimen 10 (South Indian Skull) possesses similar deformation with respect to specimen 9 (Mongoloid Skull) however 11 (South Indian Skull) is also near. 0 (Mongoloid Skull) and 6 (Human Male African American Skull) are far apart. But 12 (Vedaface) is near to 7 (Human Female American Indian Skull) and 8 (Human Male Asian Skull) which is same as in PCA.

5. Conclusion and Outlook

Conclusion: The main aim of this work was to study the similarity of modern *Homo sapien* skulls of South India with the *Homo sapien* skulls of rest of the world. The images are obtained very carefully to achieve a good result. 13 images are taken and 162 landmarks are dropped on each of the specimens. After Procrustes superimposition and GPA, Principal Component Analysis is successfully done. It has been found that PC1 (38.2%) and PC2 (18.66%) together share 56.86% of the variance which indicates the right direction of the analysis. Jolliffe cut-off of 0.0023847 is also found. Scree plot clearly shows the successful reduction of dimension from 13 to 12 in PCA analysis. The most important things that are found out by PCA and TPS and warps are, specimen 10 (South Indian Skull) and 11 (South Indian Skull) have similarity in skull shape. Whereas specimen 0 (Mongoloid Skull) and 6 (Human Male African American Skull) show similar shape in them. Specimen 12 (Vedaface) is quite close to 8 (Human Male Asian Skull) and 7 (Human Female American Indian Skull). But Specimen 9 (Mongoloid Skull) is found to me quite different from all others. A negative result is also obtained by relative warp which contradicts to PCA and shows that specimen 10 (South Indian Skull) possesses similar deformation with respect to specimen 9 (Mongoloid Skull) however 11 (South Indian Skull) is also near. Also 0 (Mongoloid Skull) and 6 (Human Male African American Skull) are far apart. Thus, the objective of the project is successfully achieved.

Outlook: There is a great desire to analyze the morphometry of various body parts of different regions of India because India is a land of most diversity. A population group of Himalayan region can be compared with the southern region of India or a morphometric comparison can be done among the tribal populations in India which is having a large group in forests. Similarly, in medical research, a particular disease in a particular region can be studied on a wider view on other people.

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7. Abbreviations

1. GPA = Generalized Procrustes Alignment
2. PCA = Principal Component Analysis
3. TPS = Thin Plate Spline
4. L = Landmark
5. PC = Principal Components

8. List of Figures and Tables

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