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Review on Facial Changes Across Age Progression of the same Individual and its Application in Forensics

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ABSTRACT

Introduction: It is difficult to describe or analyze face aging since it is a complex process driven by both intrinsic and extrinsic factors. Face aging differently influencesthe facial components of an individual such as the nose, mouth, and eyes.

Objective: In this paper, we have discussed reviewing facial features, that change with the progression of age and techniques available to recognize these changes.

Method: The majority of the work on face recognition has been carried out on adults and less of the work is reported on facial aging. Researchers have tried to develop algorithms for facial recognition, verification, and identification system which will have low false positive rates and high true positive rates due to the age influencing factor.

Conclusion: It will help the scientific community for better analysis and recognition.

Keywords: Facial features; Non-adult; and adult age facial features; Age progression; Factors affecting age; Facial recognition; Verification; Identification; Age estimation; Age simulation.

INTRODUCTION

"You can never see the same face twice" The assertion is not ironic. Science approved this line because facial appearance changes frequently or dynamically due to facial expression, pose, illumination, the profile of the head, aging, occlusion, moustaches, beards, cosmetics, and hairstyle, so these factors create problems in face recognition, face identification and face verification.[1,2] Aging is an inevitable and uncontrollable process. It is a slow and irreversible process. The achieved aging pattern is temporal since these temporary alterations in facial look at a certain period affect an individual's future appearance but not their past appearance. The human face is the man's identity card, and it is individual for everyone like fingerprint biometrics, iris biometrics, etc. even twins have some individuality in his/her face.[3] It has been observed that appearance of the face changes with the

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progression of age. It creates difficulty in automatic face recognition, verification and identification system. So, in this paper, an attempt has been made to mitigate the aging issue in face recognition, and also to analyse and estimate the age of individuals by studying the facial features or landmarks and for face remodelling.

AGE RELATED CHANGES IN FACE

Individuals have different aging patterns, although there may be variations or similarities which can be modelled. Even different races have different aging pattern.[4] Complexities of facial aging have been studied by studying various landmarks in faces.[5] In different age groups, facial changes happen differently. There are two distinct stages of facial growth in human life: the formative stage and the aging stage. In childhood (generally up to 20 years of age) mainly craniofacial changes occur and with advances in age mainly skin texture or morphological changes occur and minimal bony structure changes. But in senescence, bony structure changes in the maxilla due to bone resorption.[6,7] Certain hard and soft tissue changes with age that help to change the shape, size, and appearance of a person. It is also found that age related changes, especially the development of wrinkles, differ between gender. And there are individual features of every individual that affect the speed of aging differently.[8] To analyse, the morphological changes with the advancement of age, the face is divided into three-part that is the upper 1/3 (which covers the forehead and brows region), the middle 1/3 (which covers the midface and nose region), and the lower 1/3 (which covers chin, jawline, and neck region). Age related changes in adolescence are different from changes seen in adults.

Stages of facial changes in Children (Children from birth to childhood, up to 16 years)

This stage is called the formative stage which means the growth and development phase. More rapid facial changes occur during childhood. In the development phase mainly significant facial shape changes happen due to craniofacial enlargement.[2] In this phase, the forehead of the individual slopes back that helps to create space on the skull to hold the growing brain. The nose, mouth, eyes, and ears expand with the growth of an individual to cover interstitial space. The chin curves more as the cheeks expand. Facial skin remains relatively unchanged than shape. So, a circular shape face changes into an oval shape face as age increases in the younger age group due to craniofacial growth. As a result position of fiducial landmarks changes. This phenomenon helps to estimate age in the younger age group.[9]

Stages of facial changes in Adult/aging stage:

In adult age, craniofacial changes occur at the soft tissue level as well as at the hard tissue level. Hard tissue changes in adolescence and adulthood are due to skeletal growth and development, whereas bone re-modeling and resorption is the main factor in changes in hard tissue level in young adulthood to senescence. While in the case of soft tissue, begin to show aging phenomena, at the age of '20s or as early as 20s. but the aging of soft tissue is most noticeable in the '40s to '50s and becomes more pronounced at the age of 50s to '60s.[10]

Bony changes:

The dimensions of the cranium change in the vertical, horizontal and sagittal planes, as well as in the dentoalveolar area. Many of these modifications, however, are minor, ranging from 1.1mm to 1.60mm.[10] Increases in total head size, head length (from front to back), bizygomatic breadth (from cheekbone to cheekbone), and head width are all examples of horizontal alterations. These horizontal changes occur from the '20s to the '80s. Vertical changes occur in an increase of anterior face height. And this increase in height is more noticeable in the bottom half of the face than in the top half. Total face height of an individual increase by about 1.60mm where the upper face increases by about 1/5 and the lower face increase about 4/5.[21] Sagittal changes occur in a slight increase in the thickness of the cranium anterior-posteriorly. With age progression, the anterior facial skeleton displays greater convexity. The mostly dentoalveolar region is changed throughout the adult age progression.[10]

Soft tissue changes

Adult face changes more with relatively large skin texture variations and minimal variation in shape.[2] According to johan wisth, 2007, alterations in the soft tissue profile of children aged 4 to 10 years were evaluated. They have found that in this age group mainly alterations are in the soft tissue profile with that of change in skeletal profile. And in this age group mostlyface convexity changes due to nose growth. Bishara, S.E. *et al* 1998 studied what alterations occur to soft tissue profilein people aged 5 to 45 years. They found that generally the direction and magnitude of face changes in both

sexes were almost similar. But females show greater soft tissue changes earlier (within the age range of 10 to 15 years) than males (within the age range of 15 to 25 years). Soft tissue convexity angle excluding nose showed small changes between the ages of 5 and 45 years. Wysong A *et al* (2013) quantified and compared the loosening of facial soft tissue with age progression using used magnetic resonance imaging (MRI) technique. They discovered that between the ages of 30 and 60, the most significant alterations occur in the temporal, infraorbital, and lateral and medial cheek regions.[11] Adult facial soft tissue changes are best studied by splitting the face into three sections: top third, middle third, and bottom third.

Upper third

Because of loosing of skin elasticity, the impact of gravity, and recurrent periorbital muscular contractions, drooping of eyebrows appears. Upper eyelid skin folds due to decreasing skin elasticity of the skin and excess unsupported skin. The aging of the periorbital region differs among individuals, even of different sex and race. European, Indian, and Chinese have also the difference in eyebrows and eyelids features.[12,13] Kunjur *et al.*, 2006 studied facial features from photographs of these three ethnic groups: European, Indian and Chinese resulting that eyebrows of Indian and Chinese males are significantly different, but upper eyelids are significantly different between all three ethnic group and in both males and females. Palpebral fissure length was significantly different between Indian and European males and Indian male has wider palpebral fissure.

Middle third

Nasolabial fold develops due to weakening of malar fat pad. At the age of 20-30 years the nasolabial lines start to form and at the age of 40-50 years the folds increase in depth and at the age of beyond 60 years the folds further continues to be deepen. With the progression of age, Nose shifts forward and downward.

Lower third

Mainly in the 40s of individuals' life span, vertical rhytids appear above the vermilion border and ornamental grooves appear at the corners of lips as the skin thins with age. And the depth of these phenomena increases as age progress. In the 50s of an individual's life span, Buccomandibular crease, jowls, along with sagging chin appears and it appears more noticeably in the 60s of an individual's life span and beyond 60. Elongation of the lip happens and it appears to be thinner as age progress and many other additional lip related changes occur with age progression.[10]

How bony and soft tissue changes occur in different age groups is listed bellow in form of table bellow.[13-15]

Table 1: Skeltal and tissue changes observed in different age groups

Age range	Probable Skeletal changes	Probable Soft tissue changes
Childhood-Adolescence	• In this stage face shape changes due to craniofacial growth • Forehead slopes back • Circular shape face changes into oval shape face as age increases in this age group • Maximum Cranial breadth is relatively large • Upper and lower facial height increase • The upper and lower incisors protrude significantly • Eyes, ears, mouth, and nose expand • Cheeks extend and chin protrudes • The rapid expansion of the eyes in the 1st year of life causes the orbits to be bigger than the rest of the face • Maxillary dentoalveolar measurements change significantly • Prognathism of maxilla and mandible	• Facial skin moderately remain unchanged
Early adolescence – early adulthood	• The upper and lower jaw relatively stable inclination	• In comparison to the growth of soft tissue in the chin and glabella. The nose grows further forward

Table to be cont....

	• In respect to the maxillary and mandibular planes, the upper and lower incisors show retrusions	• Upper eyelid starts to droop
	• Because teeth continue to emerge, the lower anterior and posterior facial heights rise	• Eyes look smaller
	• Downward growth of mandible	• Formation of Nasolabial lines begins
		• Formation of lateral orbital lines begins
		• The Upper lid starts to retrude in females.
Early adulthood - Mid adulthood (about 47)	• Sella-nasion length increase significantly	• Length of upper lip increase (~3.2 mm)
	• Midfacial length increase significantly	• Upper lip thinning (~ 3.6 mm), upper lip flattening
	• Forward movement of maxilla	• At the pogonion point soft tissue thickness increase
	• Significant increase of mandibular length	• Columella and pronasale vertical increase. Results movement of nose downward and forward
	• Upper facial height increase significantly. Even lower facial height increases. As a result total facial height increase	• Forward growth of chin also
	• Age-related bone remodeling	• With age, the upper lip thins and the soft tissue at the chin and glabella thickens, resulting in a straighter facial profile
	• Gonial angle increase	• The formation of cireumoral striae begins. Lines begin to appear from the lateral borders of the nose to the lateral edges of the lips
	• The incisors continue to erupt although non-significantly	
	• Significant retrusion and retroclination can be seen on both the upper and lower incisors	
	• Retrognathism of maxilla and mandible due to bone remodelling	
	• Maxillary dentoalveolar measurements changes but not statistically significant	
Mid adulthood - Late adulthood (about 57)	• No change in the sella-nasion length	• Upper lip length increase continue (1.4 mm)
	• Increase in midfacial length but not significant	• Thinning of upper lip continue (1.4 mm)
	• Minimal increase of the anterior face height which is mainly lower anterior face height	• Dermis level Changes: in this age group epidermis becomes thin/lean and subcutaneous fat loss happens
	• Forward movement of maxilla consistent	• At the pogonion point, soft tissue thickness increases
	• Small increases in mandibular length	• Columella and pronasale vertical continue to increase. But significantly columella move inferiorly. And this movement of columella downwards results significant decrease in nasolabial angle.
	• Age-related bone remodeling	• Upper and lower lips continue to shift downwards which exceeded the skeletal downward growth, result les-prominent display of the upper incisor
	• Gonial angle increase	• Facial lines and folds increase continuously in depth
	• Bone remodelling	• Due to alveolar bone remodeling Concave appearance appears in cheek hollows
	• Alveolar bone remodelling	
	• Dental attrition affecting vertical facial height	
	• Alveolar bone remodel	

FACTORS AFFECTING FACIAL AGING

Hard tissue changes in the head and face may not necessarily result in predictable patterns of change in the head and face's overlaying muscles and skin. This is a significant obstacle in facial reconstruction procedures and in developing effective age progression techniques. This is because there are many intrinsic and extrinsic factors that affect the pattern of facial aging.[8] Skin on face ages in two ways, internally and externally. Human experience internal or natural aging as they gets older.

Causes of internal aging and their effect on facial appearance are listed below table:

Table 2: Causes of Internal aging and its effect in facial aging process.

Cause	Effect
Slow down of collagen production	Loss of skin firmness
Decreases in Elastin production	Loss of skin elasticity
Beginning Disappearance of fat cells	Sagging of skin
Loss of ability to retain moisture	Skin looks dull, skin tone and complexion appear uneven, and fine lines and wrinkles are more noticeable.
Muscle contraction	Frown lines, wrinkles, folds, etc. appear
As dead skin cells sheds quickly.	Flaky skin, dry patches, and clogged pores
Slightly less turnover of new skin cells (skin cell turnover or skin cell rejuvenation)	Visible sign of aging, wrinkles, age or liver spots, hyperpigmentation. Visible blemishes, acne development, whiteheads, blackheads

Many factors can influence natural face aging by delaying the process. Forces responsible for facial aging is gravity, soft tissue maturation, loss of subcutaneous fat, hormonal imbalance, mental stress, diet, work practice, drug abuse, and disease, skeletal remodeling, teeth loss, muscular facial activity, environment, orthodontic treatment, gender and solar changes or UV light. environmental and genetic factor also influence face aging patterns so much. Some of the factors of facial aging is uncontrollable as they are hereditary but many of the factors are controllable which is most of the time harmful habits like smoking. Due to factor of different facial anatomy, difference of hormones and different lifestyle etc. between male and female, shows different aging pattern.[16] It has been observed that female shows greater and faster changes than male after menopause due to hormonal changes.

APPLICATION OF FACIAL AGING STUDY IN THE CONTEXT OF FORENSIC PERSPECTIVE

Personal identification of the human in the context of forensic science is important in natural and man-made mass disasters. To establish identity of individual, skull play very important role, as face can be reconstructed by skull.[17] In that case to reconstruct skull, data of age related features is needed to give perfect appearance as much as possible. Not only in the case of post mortem identification of individual, but also in case of antemortem identification of individual face play important role for person recognition, verification and identification. And for this purpose many face recognition application has also been developed. But in the time of facial recognition, verification and identification, facial changes across age progression, may create hindrance. So, to mitigate this problem various age invariant face recognition system has been developed. And to develop this type of age invariant face recognition application, data related to facial aging is required.

Here are some importance of studying age related changes.

- ***Facial reconstruction or facial image reconstruction:*** Pan SY *et al* 2018 has studied age related changes of xinjiang uygur male facial images to construct an age estimation model and to construct individual face images of old age and young age. Their main findings is the nasolabial sulcus deepening, cheek sinking, cheek bone protruding, and eye corner drooping with age.[18] Facial shape and surface features has been combined into image reconstruction of facial appearance.[19]
- ***Age invariant facial recognition:*** Face recognition is a very sophisticated biometric tool for human identification. For that, several face recognition methods available. In the below table different facial recognition method has been listed.[20]

Table 3: Different facial recognition methods and their comparison.

Method	Working principle	Examples
Holistic matching methods	Complete face region is taken into account as input data	Eigenfaces
		Principal Component Analysis (PCA)[21]
		Linear Discriminant Analysis (LDA)[21]
		Independent component analysis
Feature based (Structural) method	Local components like eyes, nose and mouth extracted at first and their locations and local statistics (geometric and/or appearance) are put into a structural classifier	Active shape model (ASM)[22]
		Low level analysis[22]
		Feature analysis[22]
Hybrid methods	Use a combination of both holistic and feature extraction methods[23, 24]	

Data of facial aging features help to develop a good quality (high true positive rated and low false positive rated) age invariant facial recognition (AIFR) system.[25] Age invariant Face recognition system help to find lost children.[26] AFIR can be divided into generative[27-29] and non-generative methods.[30-32] Recently, deep neural network method has been used.[33-36]

Face age synthesis

- ***Age Estimation:*** in this technique age is estimated from given face image.[37,38]
- ***Age separated face recognition:*** a person's face is recognized using age separated photographs.[39]
- Homeland security and law enforcement.[40]
- Face recognition is utilized in forensic investigation like to investigate de-duplication of driver's license, identifying missing children.[41]
- ***Access control and monitoring systems:*** The age estimation system provides access control for various internet of things across different age groups. Like it can protect non-adult communities from adult and illegitimate web content.
- ***Age simulation:*** it is the technique of modelling the facial appearance across age progression.[42,2]

CONCLUSION

Child aging is more complex than adult aging due to the structural change as well as in the shape and size of the facial components. The overlaying muscles and skin of the head and face don't always follow predictable patterns of changes in the hard tissue of the head and face. This is a significant obstacle in efforts to reconstruction of face and to develop an efficient age progression techniques. It has been observed that the nose appears to be the most constant component of the face as it ages, and that females are more affected by ageing than males. There are many automatic face recognition system available which will help to recognize face. Somewhere they adders aging factors also but in real situation, images recovered for facial recognition and verification with age progression or recovered for age estimation, is of low quality. In that case present algorithms are hardly able to detect facial aging features. So in that case there need more research on face image so that if software are unable to detect these facial aging features, some manual method can be used.

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