Facial preservation following extreme mummification: Shrunken heads

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Abstract

Shrunken heads are a mummification phenomenon unique to South America. Ceremonial tsantsa are ritually reduced heads from enemy victims of the Shuar, Achuar, Awajún (Aguaruna), Wampís (Huambisa), and Candoshi-Shapra cultures. Commercial shrunken heads are comparatively modern and fraudulently produced for the curio-market, often using stolen bodies from hospital mortuaries and graves. To achieve shrinkage and desiccation, heads undergo skinning, simmering (in water) and drying. Considering the intensive treatments applied, this research aims to identify how the facial structure can alter and impact identification using post-mortem depiction.

Sixty-five human shrunken heads were assessed: 6 ceremonial, 36 commercial, and 23 ambiguous. Investigations included manual inspection, multi-detector computerised tomography, infrared reflectography, ultraviolet fluorescence and microscopic hair analysis.

The mummification process disfigures the outer face, cheeks, nasal root and bridge form, including brow ridge, eyes, ears, mouth, and nose projection. Melanin depletion, epidermal degeneration, and any applied staining changes the natural skin complexion. Papillary and reticular dermis separation is possible. Normal hair structure (cuticle, cortex, medulla) is retained. Hair appears longer (unless cut) and more profuse following shrinkage. Significant features retained include skin defects, facial creases, hairlines and earlobe form. Hair conditions that only affect living scalps are preserved (e.g. nits, hair casts). Ear and nose cartilage helps to retain some morphological information. Commercial heads appear less distorted than ceremonial tsantsa, often presenting a definable eyebrow shape, vermillion lip shape, lip thickness (if mouth is open), philtrum form, and palpebral slit angle. Facial identification capabilities are considered limited, and only perceived possible for commercial heads.

1. Introduction

Head shrinking was formerly a ritualistic war trophy custom notoriously practiced by the Shuar, but also the Achuar, Awajún (Aguaruna), Wampís (Huambisa) and Candoshi-Shapra. These inter-related cultures inhabit the Amazon rainforest in the southern lowlands and eastern montaña of Ecuador and northern Peru [1–3]. They were originally a means of appeasing the victor's ancestral spirits, following a long tradition of feuding and blood revenge [1–3]. Its design was intended to trap the enemy spirit in the head by pinning the mouth (the central orifice for respiration and speech), so to demobilise it from escaping and sorting revenge against a chosen individual, most likely (but not always) its killer; and to suppress and enslave the spirit via shrinkage, where it was believed to work as a talisman for the victor's community till its potency had perceivably depleted (typically following 1.5–2 years) [1–3]. Once exhausted of power, the head was subsequently disposed, kept as a keepsake, or since the mid-19th century, exchanged with European goods for the curio-market [2–5]. Culturally referred to as tsantsa, this paper designates these heads as ceremonial tsantsa.

Since 1872, there was an emergence of shrunken heads being produced specifically for the curio-market by outsiders to the Amazon head shrinking cultures [2,6]. These are described as commercial shrunken heads. They were produced en masse across much of South and Middle America, using human corpses or animal skins designed to resemble human shrunken heads; often produced by low-earning doctors, mortuary technicians and taxidermists, who had ready access to the deceased (typically via hospital mortuaries and graves), contemporary surgical equipment and gloves [2,3,5]. The majority (estimated up to 80%) of shrunken heads circulating private and public collections today are understood to be commercial [7,8].

Reports offering a chronological sequence on how head shrinking was performed can be contradictory, due to it being largely dependant on second-hand information collected during the 17th to mid-20th centuries [9]. As an overview however, head shrinking was achieved by first removing the skull and internal tissues, thus only retaining the skin [1–5,9,10]. The eyelids, mouth and incision made for skull removal were fastened shut. The skin was entered into a cooking pot filled with river water and placed over a fire. As the water reached temperatures over 63 ^{o}C, the skin's collagen begins to contract and shrink, allowing the head to reduce to a third its original size [11–13]. Once the water reached near boiling point, the skin was immediately removed to avoid scalding the skin (resulting in tissue splits) and hair roots (causing hair loss). To desiccate the skin, a fire-heated pebble was dropped into the head through the neck opening (traditionally supported by a ring of flexible vine), where it was rotated to sear the internal skin. As the pebble cools, it was replaced with another hot pebble. Once the head was too small for further pebble insertion, hot sands were successively applied until the head was fully desiccated; the head being typically reduced to approximately one fifth its original size. During desiccation, ceremonial shrinkers would iron the outer face with a hot flat pebble to help cure the external skin while singeing away the light vellus hairs that cover the face and are emphasised dramatically by shrinkage [1–5]. Carbon ashes were also smudged into the skin to darken its complexion. To conclude, a suspension cord was traditionally applied at the head's vertex [1–5]. Commercial shrinkers would sometimes prepare heads identically to ceremonial tsantsa, but most

were prone to deviate from traditional methods and produce more variable results. Table 1 details common characteristics that distinguish commercial shrunken heads from ceremonial tsantsa [2,3,5,9,14–17].

Shrunken heads demonstrate an extreme form of mummification. Considering the intensive treatments applied and degree of shrinkage achieved, this research aims to identify what biological components are successfully preserved, and how this might vary between ceremonial tsantsa and commercial shrunken heads. Lacking skeletal information, this investigation will incorporate a series of forensic enquiries on the retained mummified skin, which can be relevant to other aspects of mummy studies. Analytical techniques include infrared reflectography (IRR), ultraviolet fluorescence (UVF), multi-detection computerised tomography (MDCT) and microscopic hair analysis. The prospect of DNA and further elemental analysis will also be discussed, though was not accessible for this study. All available findings will indicate how head shrinking impacts human identification, while utilising a proposed method of post-mortem depiction.

Ceremonial *tsantsa*	**Commercial shrunken head**
1. Long narrow face, often presenting a 'pinched' impression at the temples, a forcibly upturned and spread nose, and intentionally distended lips, creating an elongated profile with a sloping brow and receding chin.	1. More convincingly proportioned face and an upright profile. Rounded to domed shaped scalp.
2. Size approximately a fifth of a full scale head, equal to a clenched human fist	2. Variable scale
3. Skull-removal incision located at posterior median of head	3. Variable skull-removal incision locations
4. Sutures are often wide and uneven – performed using a thick and inflexible flat bamboo needle with coarse chambira fibre	4. Stitches are usually more precise, discrete and consistent – due to access to finer, sharper, metal needles and thinner suture threads
5. Sutures are typically made using 'over and over' stitches	5. Sutures are typically made using 'baseball' stitches
6. Loop of flexible vine is sewn into the neck – if absent, traces of suturing can be evident	6. No supporting vine at the neck structure
7. Eyelids are tightly drawn into the head and sutured shut	7. Variable, but the eyelids are often carefully sutured to retain their visible form; often with the upper lid positioned over the lower lid
8. Three mouth perforations from chonta pin application – sometimes retained and lashed together with chambira	8. No, or a variable number of perforations mark the mouth. If pins are present, they are not always chonta wood
9. The mouth pins are classically replaced with intricately woven string tassels applied to the mouth at a length equal to the scalp hair. Several horizontal red bands of achiote are painted, but these can fade over time	9. Tassels are often not attached. If present, atypical colourants, materials and knots for securing them may be present
10. Skin browned using carbon staining	10. Skin sometimes remains unstained, presenting as a grey or yellow colour
11. Vellus downy hair removed	11. Vellus downy hair is sometimes maintained, or shaved/trimmed to a stubble
12. Skin is polished	12. Skin can sometimes present a dull, rough texture
13. Skin tends to be dense and of considerable weight	13. Skin can vary; it can sometimes be thin, fragile and very light in weight
14. Typically long scalp hair is present, with no facial hair	14. Scalp hair can vary in length. Facial hair is often maintained
15. One or two perforations mark the crown, with one fitting a vegetable fibre string suspension cord (woven into a five-loop braid) that is secured within the head by a small wooden pin. The cord is long enough for adornment about a person's neck	15. Heads are not always perforated to fit a cord. If cords are fitted, they can be produced from a variety of different materials, woven differently, overly decorated, and of an inappropriate length for personal adornment around someone's neck
16. Piercings that would typically present at the earlobes were not always decorated. Toucan feather ear danglers and/or wooden tubes/pins are however common	16. Headbands, necklaces and any ornamentation comprising beads, seeds, or portions of seeds are atypical to ceremonial *tsantsa*

Table 1: Classic characteristics that distinguish Ceremonial *tsantsa* from Commercial shrunken heads [2-3,5,9,14-17].

2. Materials

Sixty-five shrunken heads were accessed, 44 from Science Museum London (UK), 20 from the Smithsonian Institution (USA), and one from Elgin Museum (UK). In a previous article by Houlton and Wilkinson [17], utilising the same collection, a detailed forensic analysis using existing morphological standards of differentiation [2,3,5,9,14–17] identified 6 ceremonial tsantsa, 36 commercial shrunken heads, and 23 heads of ambiguous origin. Ambiguity is assigned to those that demonstrate a close affiliation to ceremonial tsantsa, but present minor morphological anomalies or have atypical/ethnographically unreported materials attached.

3. Methods

To avoid surface contamination, latex gloves were required to handle each head. To mount heads for image capture, a stand cushioned with white acid-free tissue paper was utilised; metal hairpins prevented any scalp hair from covering the face. Each head underwent basic manual macroscopic inspection and the following:

3.1. Infrared reflectography (IRR)

IRR emphasises deep structural details in the collagen matrix of the desiccated skin [18]. In a dark or artificially lit environment, an infrared light-emitting diode illuminated each head. Image capture used a tripod mounted Fujifilm FinePix IS-1 camera with 28-300 mm Equiv. lens adjusted to 50–55 mm, and an RG780 long pass transmission filter (designed to reflect most visible spectrum light and transmit much of the infrared from the 780-9 nm cut-off). Optimal image capture incorporated a 200 ISO, f-11 aperture, 1 s shutter speed, and 0.5 m head to camera distance [17].

3.2. Ultraviolet fluorescence (UVF)

UVF highlights patterns in superficial skin texture and surface material. A Xenopus Electronix 365 nm Ultraviolet flashlight lit each specimen in a pitch-dark environment. Image capture used a tripod mounted Canon EOSD digital standard lens reflex (SLR) camera, Canon Ultrasonic 28–80 mm zoom lens, with a UV absorbing GG420 nm colour glass filter (to omit excess reflected UV from entering the camera). Optimum image capture incorpo-rated a 200 ISO, f-11 aperture, 1/8 s shutter speed, and 0.5 m head to camera distance [17].

3.3. Multi-detection computerised tomography (MDCT)

Performed on 11 heads (2 ceremonial, 3 ambiguous, 6 commercial); MDCT enabled superficial and cross-sectional observations of each head. A Siemens SOMATOM Emotion CT scanner offered spiral 1 mm slices and a 512 x 512-pixel image size, with generated Digital Imaging and Communications in Medicine (DICOM) DCM files being viewed in OsiriX.

3.4. Microscopic hair analysis

To assess hair preservation, health, and enable the rudimentary assessment of ancestry. A single hair sample per head was cut from the posterior–inferior scalp (where minimal sun damage occurs) using sterile scissors. Longitudinal samples were prepared following Scientific Working Group for Materials Analysis (SWGMAT) protocol [19]. Transverse cross-sections were prepared by embedding samples in liquid cyanoacrylate, within the feeder of a short stem micro-pasteur pipette. Setting periods were 2–3 days, before shaving approximately 0.1 mm slices using a sharp sterile blade under a Leica MZ6 modular stereomicroscope at 4.0 zoom magnification. All prepared hair sections were mounted onto glass slides, with protective glass cover slips, using Styrolite; a semi-permanent mounting medium with a refractive index approxi- mating that of hair (approximately 1.52) [20]. The slides were then viewed under a Leitz Wetlar Orthoplan light microscope, with specimen field illuminated by a low voltage tungsten filament lamp, while using a colour correcting blue filter.

4. Results and discussion

4.1. Facial features

Devoid of ante-mortem photographs with which to compare, the preservation of facial features was discerned according to how they match with characteristics expected in living faces based on facial morphology experience. Fig. 1 summarises the perceived reliability of ceremonial tsantsa and commercial heads for each aspect of the face.

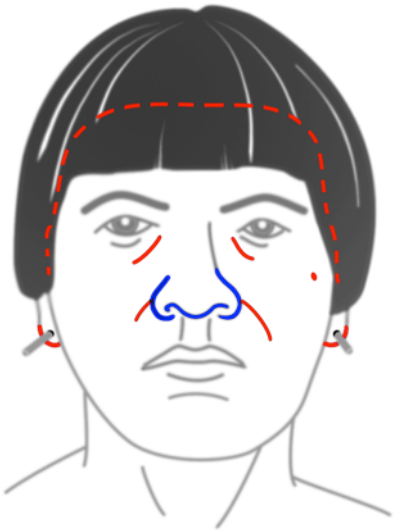
Ceremonial *tsantsa*	Commercial shrunken head
 Ceremonial *tsantsa* example (Smithsonian Institution – E403395-0)	 Commercial shrunken head example (Science Museum London – A642564)
	
Red lines: most reliable features (i.e. hairlines, facial creases, skin defects, adherent/non-adherent earlobe patterns and cartilaginous helical shape of the ears)	
Blue lines: partly reliable features (i.e. cartilaginous area of the nose; specific to most commercial heads is also the eyebrow shape, vermillion border shape, philtrum form, width and distance of the eyelids in relation to the head, and palpebral slit angle)	
Faded lines: clearly distorted features (i.e. cranial shape, cheeks, jawline, neck, nasal root and bridge form, and projection angles of the ears, brows, nose, and mouth)	

Figure 1: Estimation of conceivable ante-mortem facial features maintained in the average ceremonial *tsantsa* and commercial shrunken head. Museum and catalogue numbers of example heads provided.

4.1.1. Craniofacial shape

The craniofacial structure undergoes extreme alterations during shrinkage. Removal of the supportive skull structure invariably results in loss of the original cranial roof, cheeks, jawline, neck, nasal root and bridge form, including brow ridge, ear, mouth, and nose projection. Manual remodelling to reconfigure these features renders them redundant for facial identification purposes.

4.1.2. Facial features

Fig. 2, for reference, demonstrates common craniofacial patterns and differences that exist between ceremonial tsantsa and commercial shrunken heads.

Ceremonial *tsantsa*

Smithsonian Institution – E165119B0

Commercial shrunken head

Smithsonian Institution – P387661-0

Figure 2: MDCT scans demonstrating variations in craniofacial morphology between ceremonial *tsantsa* and commercial shrunken heads. Museum and catalogue numbers of scanned heads provided.

Durable hyaline fibrocartilage defines the complex helical structures of the ears and forms the alae, base and tip of the nose. Cartilage is normally retained in shrunken heads, delivering relevant structural support. Manipulations to the nasal cartilage is, however, common in ceremonial tsantsa, where forcible upturning and spreading of the nose was performed as a common form of mockery, along with extending the mouth [2–4]. The pressure applied when remodelling can be signified by finger nail impressions lining the nasal tip and alae, and deformed nostrils that transform from a rounded to superiorly pointed shape [17].

Shrunken ears maintain their cartilaginous helical shape, but are compressed into a reduced surface area, often obliterating the concha. The globular earlobes retain their relative size and pattern of adherence to the face, but their pre-desiccation pliability promotes often-evident distortions to their projection and general shape. Normal ear placement is often maintained, with the ears roughly occupying the middle third of the face, equal in length to the nose (glabella to subnasale) [21,22]. Removal of a length of posterior scalp, intended to further reduce head size over and above normal shrinkage, however, resulted in 8% commercial heads demonstrating an atypically posterior orientated ear placement.

The eyelids in ceremonial tsantsa, including 91% ambiguous heads, were fully retracted into the head, providing sufficient surface area for the traditionally applied course chambira string sutures; this often transversely compressed the orbital width, foreshortening the upper face, and distorting the eyebrows. In 97% commercial heads, discrete sutures fasten the eyelids, retaining more of the lid and lashes on the superficial face. The face thus appears more upright, retaining the eyebrows form. The endocanthions and exocanthions tend to be visible, enabling discernment of the palpebral slit angle, scale and composition in relation to the face. Without the skull, subcutaneous tissue and eyeballs, the form of the eyelid folds and eyeball protrusion cannot be estimated with any degree of accuracy.

The mouths of ceremonial tsantsa are clearly distorted. The philtrum is obliterated by three mouth pin perforations; skull removal, pinning and evident extending of the mouth creates an unnatural protrusion; string lashings that were traditionally applied to tightly fasten the mouth during shrinkage leave impressions that distort the vermillion [1–5]. The mouths of commercial heads were often discretely sutured [2,3,5,17], better preserving the philtrum and

vermillion shape. In 67% cases, the mouth is preserved open, making it possible to inspect the full vermillion without obstruction to determine relative lip height. Where carbon staining disguises the lips (evident with ceremonial tsantsa [1–5,14–17]), the smooth vermillion can be differentiated from the surrounding skin using UVF or IRR.

4.1.3. Facial creases

Facial crease patterns, consistent with living faces, are retained; infra orbital, alae and nasolabial creases being most readily identified. The manual manipulation and suturing of tissues may however alter the emphasis of creases or conceal them; e.g. in most ceremonial tsantsa, the retraction and suturing of the eyelids consequently hides evidence of the eyelid folds.

Artefact creases do occur (Table 2) and are most apparent when they oppose the natural orientation of the dermis collagen fibres that rest parallel to the underlying muscle (topologically illustrated in Langer lines) [23]. They are a product of manual manipulation or an uncompensated collapse of skin following skull removal, or a possible result of collagen breakdown and alteration in the dermal structure during shrinkage and desiccation [11,12,17]. A rapid, intense and uneven heat application (approximately 46+^{o}C) during desiccation, combined with pronounced manual manipulation, can cause the reticular and papillary layer of the dermis to shrink at different rates to the central dermal junction. This allows moisture to build at the junction, promoting hydrolysis, which turns the connective fibres into gelatin. This introduces a structural weakness that can cause the reticular and papillary layers to separate – described by the leather industry as 'double hiding'; witnessed in 100% ceremonial and 67% ambiguous heads (other- wise subtle, or in 33% of the more carefully remodelled commercial heads, not prevalent). In extreme cases, if the dense reticular layer retracts at a faster rate to the thin papillary layer, the papillary will concertina and form dense randomised facial creases – diagnosed in the leather industry as 'drawn grain' [11,12,17].

Artefact crease	**Possible cause**	**Frequency**
False peri-orbital creases	Collapse in the orbital region from a strong retraction and suturing of the eyelids	100% ceremonial, 87% ambiguous heads
False transverse nasal creases	Collapse in the nasal bridge; sometimes exacerbated by a retraction of the eyelids and forced upturning of the nose (common in ceremonial *tsantsa*)	100% ceremonial, 91% ambiguous, 64% commercial heads
Weak vertical tension lines surrounding the mouth	Formed from a forcible extension of the mouth, often also resulting in a lateral buckling of the mouth	50% ceremonial, 30% ambiguous, 3% commercial heads
Subtle false nasal tip crease	Compressions from pins that fastened the lips – visible pin perforations mark the mouth, if no pins retained	33% ceremonial, 39% ambiguous, 11% commercial heads
Subtle false mental pit crease		67% ceremonial, 43% ambiguous heads
Dense randomised facial creases	Possible case of 'drawn grain'; when the reticular layer separates and retracts at a faster rate to the thin papillary layer of the dermis, making it concertina	16% ambiguous, 8% commercial heads

Table 2: Artefact facial creases identified in the shrunken head collection.

4.1.4. Pathologies and defects

Skin pathology/ defect	**Description**	**Location**	**Prevalence**
Melanocytic naevi	Small flat and uniform black-pigmented macules resembling junctional naevi; and skin- or black-coloured dome shaped papules of varying sizes resembling dermal naevi (intradermal naevi)	Not uniform	67% ceremonial, 31% commercial, 26% ambiguous heads
Hypertrophic scars	Firm and bosselated accumulation of scar tissue that is contained within the original boundary of the injury	Medial forehead	4% ambiguous heads
Keloid scars	Firm and bosselated accumulation of scar tissue that actively spreads into the nearby healthy tissue	Medial forehead	3% commercial heads
Possible seborrheic dermatitis, scalp psoriasis or sebopsoriasis	An inflamed scale-textured scalp	Evident at the central parting of the scalp	3% commercial heads
Possible acne	Multiple small dome papules	Cheeks	3% commercial heads

Table 3: Skin pathologies and defects identified in the shrunken head collection.

Skin pathologies and defects presented in 37% of the total collection (Table 3). The variation in prevalence, shape, pattern and location suggests they are not a consequence of head shrinking, but a preserved ante-mortem feature. Challenges in identifying skin pathologies and defects can occur if shrinkage, tissue distortion and artificial staining impede visibility, or the process of desiccation obliterates symptomatic features used in diagnoses.

Hair conditions can indicate the environmental circumstances a victim to head shrinking once lived in. Pediculosis humanis capitis De Geer, in the form of nit infestations, were profuse in 33% commercial heads and sparse in 9% ambiguous heads. Requiring a living blood supply, lice are only contracted ante-mortem. Victims (certainly of commercial head shrinking) likely existed in over- crowded slum settlements, where aggressive infestation and disease epidemics are common [17,24–26]. An infant-age com-mercial head presents rust-red hair with alternating light and dark bands of colour across the hair shafts, implicit of Kwashiorkor, a critical form of malnutrition associated with prolonged protein deficiency [27]. Hair casts, firm white cylindrical keratinous concretions (2–7 mm long) that encapsulate the hair shaft and are easily dislodged [28], lined the hair in one ambiguous specimen. They are a product of abnormal keratinisation during hair growth following persistent and regular traction of the hair, sometimes even psychological trauma, and can form in conjunc-tion with various fungal skin infections (psoriasis, pityriasis amiantacea, pityriasis capitis and seborrhoeic dermatitis) [29– 32]. Evidence of sun bleaching, fungal infections (e.g. Black piedra, Trichomycosis nodularis), and fractures in the hair shaft (Trichorrhexis nodosa and Central trichoptilosis) were identified, but it is not possible to determine if they occurred ante-mortem or post-mortem [17]. Fig. 3 offers examples of how these hair conditions presented in the studied collection.

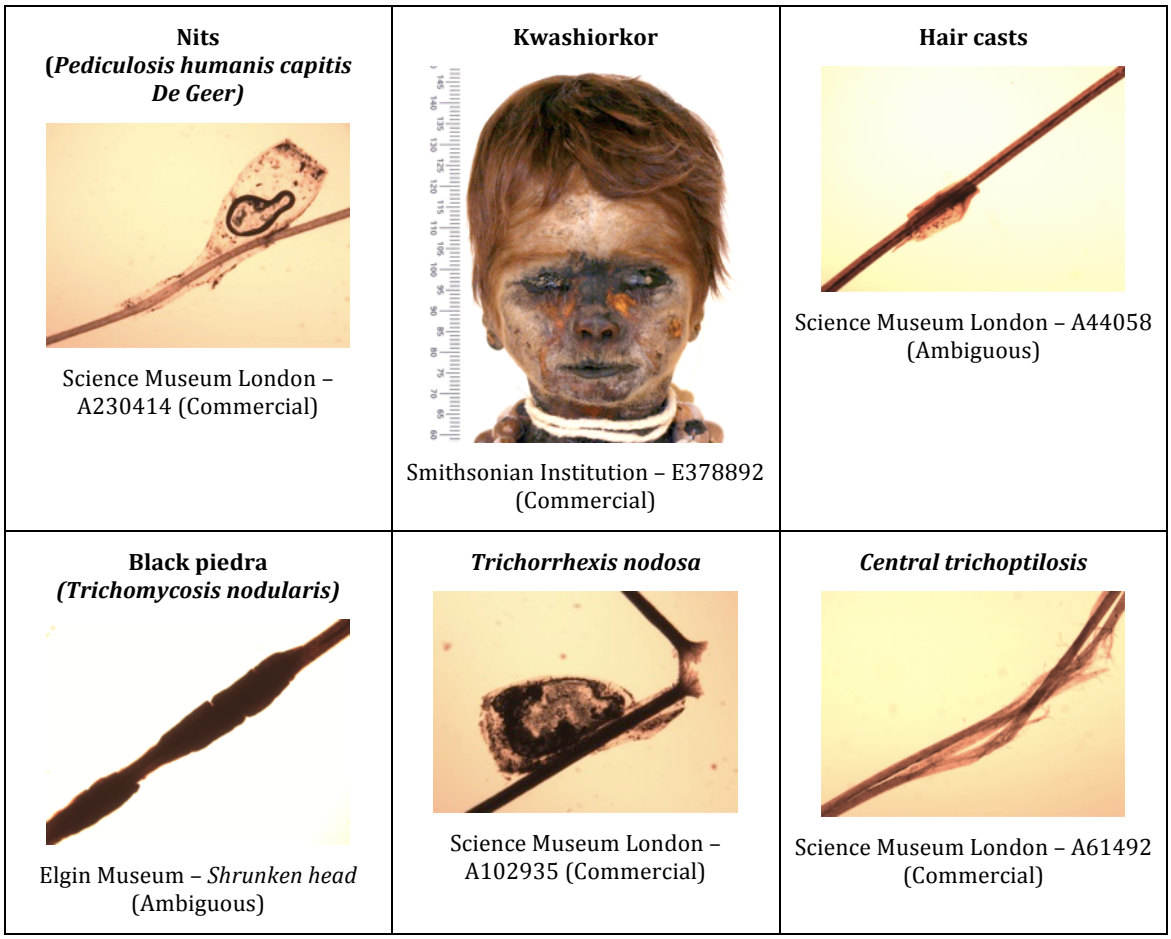


Figure 3: Examples of hair conditions identified within the studied shrunken head collection. Top row images demonstrate conditions only obtainable in life; the bottom row can be obtained both in life and death. All microscopic images are taken using a Leitz Wetlar Orthoplan light microscope and 170/-, 4/0.12 lens. The museum and catalogue numbers of shrunken heads from which hair samples were obtained are provided.

4.1.5. Superficial skin and hair

During shrinkage, the contraction of facial tissues causes all hair follicles to compact into a reduced surface area to produce thicker, denser hair than in life; retraction of the skin and follicles furthermore increases the exposure of once skin-embedded hair shafts, adding to the original visible hair length that already looks exaggerated in relation to the shrunken head [33]. This includes the fine, peach-white hypopigmented vellus hair that covers most of the body and face. Ordinarily, only 2–3 mm of vellus hair is superficially visible [34], but the longest identified vellus hair in the collection was approximately 8 mm. Evident vellus hair was retained in 70% commercial heads; 76% of which trimmed or shaved the hair to leave a felt-like stubble [17]. All ceremonial and ambiguous heads, and 31% commercial, had the vellus hair

singed away, likely by a hot flat pebble or another heat bearing implement, with any surviving hairs designated to less accessible, tightly folded regions of the skin. Using IRR, epidermal degeneration was apparent where the hair was likely obliterated by intensive heat treatments to the superficial skin during desiccation. The heat would have penetrated the tissue, intensifying when contacting the skin's natural oils, which expresses a low melting capacity and promotes thermal damage. The temperature and duration heat was applied, including abrasion from the heat bearing implement used, present variables in the extent of protein denaturation, cell damage, and surface contraction achieved; burning the vellus hair and causing the thin epidermis to blister and flake away [17].

The basal cell layer of the epidermis contains melanin-producing melanocytes, which influences skin complexion. Starved of a living blood supply, melanin is further damaged or denatured by the intensive heat treatment and desiccation of tissues, resulting in a breakdown of chromophore pigment levels and a discolouring of the skin to a grey-white colour [12,17]. If devoid of the epidermis, the exposed dermis exhibits a yellow colour. In all ceremonial, ambiguous and 86% commercial heads, the skins are carbon-stained to a dark brown-mahogany. The depth of colour likely reflects the duration and concentration of carbon applied, with the porous qualities of the epidermis probably being more conducive to staining than the thicker, tougher dermis [5,17].

Hair demonstrates a high resistance to decay, likely due to its low water content, high surface area and keratin structure, which is near absent from pro-degradational lysosomes [35]. Retained scalp, eyebrow and facial hair may maintain some useful information regarding their original ante-mortem appearance. Hairlines appear most reliable; a strong retraction and suturing of the eyelids (prevalent in ceremonial tsantsa designs) can however re-orientate the eyebrows, altering their original angle, alignment and visibility. Some indication to hair colour, approximate length and style is possible; post-mortem UV-sunlight exposure, artificial bleaches and dyes, including the manual cutting and restyling of hair can however alter hair appearance considerably.

4.1.6. Piercings

Prominent (3–6 mm) symmetrical ear lobe piercings marked 83% ceremonial, 70% ambiguous and 6% commercial heads; with small (<3 mm) symmetrical piercings in 17% ceremonial, 17% ambiguous and 13% commercial heads. Colonial fashions were variable, but in Amazon head shrinking cultures, both male and female earlobes were pierced during early infancy [3,36]. The initial piercing was small, but as males matured the piercings were stretched up to approximately 10 mm [2,3,36]. In shrunken heads, fraudulent ear lobe piercing and stretching is possible. Post-desiccation piercings present a disturbed skin texture and colour difference at the perforation [5]; dermestid beetles may furthermore cut 1 mm diameter holes that initially resemble piercings, but they rarely form straight channels. Pre-desiccation post-mortem piercings and stretching, evident with mouth pin perforations, are however indistinguishable from ante-mortem piercings.

4.2. Biological profiling

4.2.1. Species and ancestry

Shrunken heads present distorted facial morphologies that can challenge inexperienced investigators from establishing specie of origin during initial observation. The reduced human ear, however, retains its distinctive helical complex and smooth texture, which differs from other species [5,37]. Orangutans (pongo abelii) may share a similar helical configuration and proximity, but the inner helix extends further anterior than a human ear, with the overall ear presenting as larger and coarser [37,38]. Chimpanzees (pan troglodytes) are also similar, but the inner helix is flatter and broader, and the outer helix less defined [37]. Hair furthermore offers a characteristic pattern, length, colour, shape, root appearance and internal microscopic structure that varies across species, including human ancestry groups (Table 4) [39–41].

The studied collection were all human, with 100% ceremonial, 96% ambiguous, and 58% commercial heads presenting a hair type common in Central East Asian, Native American and Inuit groups (Type 1). Commercial heads varied, demonstrating hair types classified as 6% White European, Middle Eastern or Indian subcontinent (Type 2), 6% Sub-Saharan African (Type 3), 3% mixed types 2/3, and 25% mixed types 1/2 (as with 4% ambiguous heads). However, ancestry determination is tentative; museum preserva- tion concerns limited sample sizes to a single hair; hair variation is also organic, with hair types sometimes crossing between ancestry groups and varying within a single scalp due to differences in chemical and environmental exposure (e.g. hormones, sun bleaching) [39,41]. Black piedra (Trichomycosis nodularis), a superficial fungal infection of the hair shaft caused by piedraia hortae, an ascomycetous fungus forming hard black nodules on the hair, was identified in 17% ceremonial and 13% ambiguous heads. Infections are possible ante-mortem and post-mortem, but it indicates that the heads once existed in a tropical environment, with piedraia hortae being notably prolific in the soils of the Amazon rainforest [17,42–44].

Regarding who were potential victims of head shrinking in the Americas, ceremonial tsantsa would normally comprise of the Shuar, Achuar, Awajún, Wampís, or Candoshi-Shapra (Type 1) [1– 5,10]. Stimulated by the European curio-trades, Shuar attacks against predominantly the Achuar notably intensified during 1850–1915 [3,45,46]. Internal

jealousies over received European trade goods also led to prolific feuds within the Shuar (1920–1960) and Achuar (1940–1970), likely resulting in further tsantsa production [3,46–48].

Commercial heads likely comprised of members from the poor and disenfranchised echelons of society [2,3,24]. This included many indigenous (American Type 1) survivors of European colonisation; unskilled labourers from China (Type 1) and India (Type 2), (up to 125,000 Chinese labourers alone are recorded to have been sent to Cuba during 1847–1874, and their labour was similarly utilised in Peru, Guyana, Trinidad, Jamaica, Panama, Mexico, Brazil, and Costa Rica, among other places in the Americas) [49,50]; and African (Type 3) slaves imported from predominantly West Africa during the transatlantic slave trade. Approximately 9.6–10.8 million survived the 'Middle Passage', where over 90% were taken to the West Indies and South America (predominantly Brazil), the remainder to the United States [50–52]. Amongst the European colonies (Type 2), the Spanish dominated much of Central and South America, with the Portuguese, Dutch, British and French influencing elements of South America [52–55]. North America experienced British, Spanish, German, French and Italian colonies; the West Indies had British, Spanish and French colonies [53,54]. In this multi-layered environment, evident miscegenation included Mestizos (Spanish-indigenous mix, Type 1/2) largely populating the highland countries of South America and Paraguay; Mamelucos (Portuguese-indigenous mix, Type 1/2) in the Brazilian lowlands; 'Mulattos' (European-African mix, Type 2/3) most established in Brazil and the West Indies, where Spanish, Portuguese and French settlements allowed sexual relations with Africans [55]; and African-indigenous (Type 1/3) mixing in highland South American countries, including Mexico, where predominantly male African slaves were brought to work and invariably entered relationships with indigenous women [56].

Feature	Human	Non-human
Colour	Relatively consistent throughout hair	Colour banding is common, where colour varies significantly in relatively short sections of the shaft
Cortex	More than 1/3 the shaft width	Less than 1/3 the medulla width
Medulla	Amorphous. Less than 1/3 the shaft width. Not always present	Continuous with a frequently defined structure. More than 1/3 the shaft width
Pigment granules	Even distribution across the cortex, with slight condensing at cuticle	Centrally condensed close to the medulla
Scales	Subtle and imbricate – rarely coronal. Not always present	Evident imbricate, coronal or spinous pattern – never present in human hair

Ancestry	Diameter	Cross-section	Pigmentation	Cuticle	Undulation	Other
Central East Asian, Native American and Inuit groups (Type 1)	90-120µm. Coarse with little or no variation	Round – nearly circular	Dense auburn, often arranged in large patchy areas or streaks	Thick	None – straight	Prominent medulla – often broad and continuous
White European, Middle Eastern or Indian subcontinent (Type 2)	70-100µm. Moderate with minimal variation	Oval	Sparse to moderately dense with relatively even distribution	Medium	Rare – straight or wavy	-
Sub-Saharan African (Type 3)	60-90µm. Moderate to fine with noticeable variation	Flattened	Dense, unevenly distributed and clumped	Undulated	Prevalent – prominent twist and curl	-

Table 4: Microscopic characteristics used to differentiate non-human and human hair, and distinguish between human ancestry groups [39-41].

4.2.2. Age and sex

The prevalence and intensity of facial creases can indicate the aged appearance of an individual. Hair analysis enables a basic assessment of age at death. Infant scalps typically present short, soft, weakly pigmented, <30 mm diameter vellus hair [39,57]. Intermediate hairs, typically <60 mm diameter, gradually develop 3–7 months succeeding birth, eventually being replaced by thick terminal hair following 2 years [39,57]. Vellus hairs continue to cover 6–25% of the scalp until the age of 3–4 years, where all hair gradually grows to full size by approximately 10 years [39,57–59]. Commencing puberty, males typically develop facial hair that first grows at the corners of the upper lip and spreads medially to form the moustache, before appearing on the cheeks and chin [39,60]. Permanent hair loss from androgenic alopecia is most common in post-pubescent males, affecting up to 50% of all men by age 50 years [61]. Androgens (testosterone androstenedione and dihydrotestosterone, DHT) can cause genetically susceptible hair follicles to undergo miniaturisation and reduction in the anagen (hair growing) phase. In males, hair is typically lost in a well-defined pattern, first receding from the temples, then the crown, often progressing to complete or partial baldness. In females, the hair instead thins evenly across the scalp, rarely leading to total baldness [62].

Hair colour is strongest during youth, where the scalp follicular melanin is only a few cycles old. On average a hair follicle will receive 7–15 melanocyte replacements from the outer root sheath reservoir to the hair bulb before its regenerative capacity of melanin pigmentation is exhausted and canities (grey hair) develop [63]. White Europeans tend to grey in their mid-30's (approximately 34.2 – 8.6 years), Central East Asians in their late 30's, Sub-Saharan Africans in their mid-40's (approximately 43.9 – 10.3 years); with established canities presenting at age 50 + years for White Europeans, 50–55+ years for Central East Asians, and 60+ years for Sub-Saharan Africans [39,64]. Facial hair notably greys before scalp hair [39].

The research collection demonstrated adult hair development, with exception to 6% (2) commercial heads (one infant presenting vellus to intermediate hairs, sampled diameter of 26.4 mm; one possible juvenile with intermediate hairs, sampled diameter of 52.2 mm). These heads were comparatively smaller in scale with markedly thinner skins (c.1.2–1.7 mm depth). One ambiguous head was similarly diminutive but demonstrating tertiary hair growth; this may imply that the individual was over 10 years but still undergoing pre-adult craniofacial development [65–67]. Canities influenced 17% (6) commercial heads; four with <50% coverage, comprising two Type 1 (estimated 35–40 years), one Type 2 (estimated 34.2 – 8.6 years) and one mixed Type 2/3 (estimated 35–45 years); two presented with 50>% coverage, including one Type 2 (estimated 50+ years) and one Type 3 (estimated 60+ years). One commercial head also demonstrated a stage 5 V male pattern androgenic hair loss according to the Norwood-Hamilton scale.

Evident facial hair identifies 28% commercial and 13% ambiguous heads as post-pubescent males. Incorporating UVF and IRR, it is possible to examine follicle size and density across the face in heads where the epidermis is removed (this otherwise appears blistered, impeding root visibility). Dense follicle patterns identified 67% ceremonial, 13% ambiguous and 8% commercial heads as potentially male. Adult males were more likely victims of head shrinking, but women and children were not immune [3,5,46].

4.2.3. Possible developments

Ideally more sophisticated profiling would have been per- formed. The neutral pH environment maintained during head shrinking preserves nuclear DNA, which has before been successfully extracted from shrunken head skins to confirm their specie, ancestral origin, and chromosomal sex [68–70]. Mitochondrial DNA is a more stable alternative for investigating the maternal bloodline, which can be extracted from even aged and degraded hair samples [71,72].

Hair grows approximately 10 mm per month and retains an unaltered microstructure that can undergo stable isotope analysis to determine a subject's chronological dietary intake prior to death; potentially indicating an individual's living circumstances and provenance [18,73]. Combined with mass spectrometry, the metabolic processes within the body may also be identified [74]. Biochemical analysis may furthermore indicate lifestyle, drug consumption (mostly alkaloid), and stress cortisol levels [18,75–78].

4.3. Post-mortem depiction of a shrunken head

To explore the potential of a post-mortem depiction, a commercial head demonstrating minimal tissue contortion and unique facial characteristics (e.g. facial creases, facial hair, skin defects) was selected. The head was from an adult male of Type 1 ancestry. Collected in Ecuador, it was presumably produced from a member of the local indigenous population – possibly Shuar or Achuar, although Quichua speakers of Incan decent predominated the country and co-existed with White Europeans within town regions [79].

To compensate for the irreversible distortions in craniofacial shape, an average-face template was generated using the image-morphing programme Abrosoft FantaMorph 5, with 10 available anterior photographs of indigenous Ecuadorians from the 1930s [2]; when ceremonial and commercial head shrinking was still prevalent [2,3,10,46]. If available, more portraits would have been integrated, but 10 were adequate to regress variables unrelated to facial identity (e.g. light, shadow) to a mean, while preserving consistent facial characteristics [80–82].

The composition of facial features, including recognised facial creases, was then translated from the shrunken head onto the average face using Adobe Photoshop CS3. Superimposing the evenly scaled shrunken head image over the average-face, to demonstrate the closest possible correlation of features while applying different opacity settings to relate the two, facilitated this; the outer face of the shrunken head was also cropped due to its unreliability. The scalp, eyebrow and facial hairstyle was replicated, with subtle modifications made to reduce the hair length and profuseness, which was exaggerated by shrinkage. Devoid of correct colour detail for skin tone, the depiction was presented in grey scale. Due to the possibility of errors in the depiction, an artistic effect was applied to offer a more abstract, rather than literal representation (Fig. 4).

The reliability of the produced depiction cannot be tested due to there being no available ante-mortem images. Distinct facial features and clear facial obliterations have however been objectively discerned. Significant features, like that of apparent facial creases, facial hair and skin defects, help individualise the face; without these qualities however, there is a risk of depictions appearing generic in design due to the dependence of an average-face template.

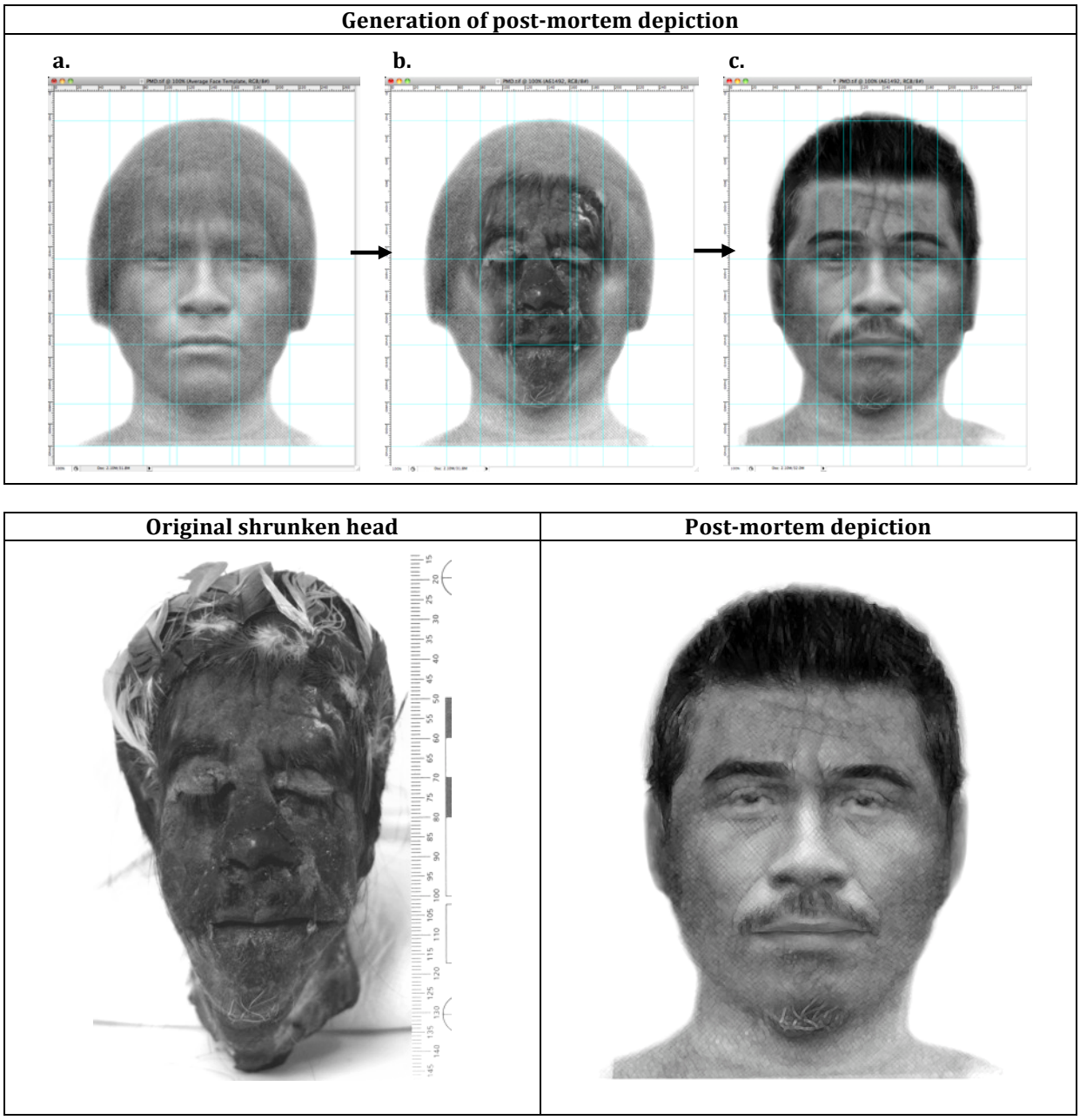


Figure 4: Applied stages used to generate a post-mortem depiction of a commercial shrunken head (taken from Science Museum London – A61492), (a. average-face template, b. superimposition of shrunken head over average-face, c. mapping and merging of features into average-face).

5. Conclusion

The human craniofacial structure undergoes extensive trans-formation in head shrinking. Obliterated features include shape of the outer face, cheeks, nasal root and bridge, including projection of the brow ridge, eyes, ears, mouth, and nose. Normal skin texture and complexion are also disturbed. Papillary and reticular dermis separation often occur in the evidently distorted ceremonial and ambiguous heads. When the papillary concertinas, this can result in artefact creases.

Normal hair structure (cuticle, cortex, medulla) is retained, but post-mortem cutting and restyling can occur. The condensing of follicles into a reduced surface area furthermore causes the hair to appear longer and more profuse. Hair conditions are preserved. Those that accumulate ante-mortem may indicate the environment a victim once lived. Some conditions however, also occur post-mortem.

The most reliable facial features preserved comprise characteristic signifiers such as skin defects, facial creases, hairlines and earlobe form (adherent/non-adherent). Cartilage helps retain morphological information pertaining the helix of the ear, and shape of the nasal base, tip and alae, but distortions from heavy handling during desiccation can occur. Due to the finer resources often used in commercial heads, they tend to furthermore preserve a definable eyebrow shape, vermillion lip shape, lip thickness (if mouth is open), philtrum form, and palpebral slit angle.

Inspection of ear morphology and hair can conclude a head's specie of origin. Microscopic hair analysis can facilitate ancestry and age (juvenile/adult) estimation, with canities roughly indicating age in adult victims. Sex estimation can be achieved via the detection of facial hair or tertiary facial hair follicles using UVF or IRR. Ideally, DNA would have offered a more reliable means of specie, sex and ancestry identification if available. Further elemental analysis may have also helped build a stronger victim profile (e.g. diet, drug use).

A method of post-mortem depiction is proposed, utilising an average face template with the more recognisably proportioned commercial heads. Reliance in the prevalence of signifying facial characteristics to produce a non-generic depiction however exists.

Note on Ethics

Research was conducted in compliance with the ethical standards and requirements of the Science Museum London, Smithsonian Institution and Elgin Museum.

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References

[1] R. Karsten, Blood Revenge, War, and Victory Feasts Among the Jibaro Indians of Eastern Ecuador, Government Printing Office, Washington, 1923.

[2] M.W. Stirling, Historical and Ethnographical Material on the Jivaro Indians. Smithsonian Institution Bureau of American Ethnology: Bulletin 117, Govern- ment Printing Office, Washington, 1938.

[3] M.J. Harner, The Jivaro: People of the Sacred Waterfalls, University of California Press, Berkeley, Los Angeles/London, 1972.

[4] F.W. Up de Graff, Head Hunters of the Amazon: Seven Years of Exploration and Adventure, Garden City Publishing Co. Inc., New York, 1923.

[5] J.L. Castner, Shrunken Heads, Feline Press, Gainesville, FL, USA, 2002.

[6] R.A. Phillippi, Menschenköpfe als Trophäen bei wilden Völkern, Globus Band xxi (1872) 340–343.

[7] K.C. Duncan,1001 Curious Things: Ye Olde Curiosity Shop and Native American Art, University of Washington Press, 2001, pp. 146–147.

[8] C. Morgan, Object of the Month: Shrunken Heads (Real and Fake), Wellcome Trust, 2014 http://blog.wellcomecollection.org/2014/06/27/object-of-the- month-shrunken-heads-real-and-fake/ (accessed 18.09.17).

[9] P. Charlier, I. Huynh-Charlier, L. Brun, C. Hervé, G. Lorin de la Grandmaison, Shrunken head (tsantsa): a complete forensic analysis procedure, Forensic Sci. Int. 222 (2012) 399.e1–399.e5.

[10] L. Cotlow, Amazon Head-Hunters, Henry Holt and Company, New York, 1953.

[11] M. Dempsy, Hide, Skin and Leather Defects: A Guide to their Microscopy, Al Asra Publication, New Zealand Leather and Shoe Research Association, Swift- copy Centre Ltd, 1984.

[12] J.J. Tancous, Skin, Hides and Leather Defects, Leather Industries of America Laboratory, 1992.

[13] N. Sadick, Tissue tightening technologies: fact or fiction, Aesthet. Surg. J. 28 (2) (2008) 180–188.

[14] H.N. Wardle, Description of a tsantsa in the ethnological collection of the academy, with notes on another specimen, Acad. Nat. Sci. 66 (1) (1914) 197– 205.

[15] G.L. Mutter, Jivaro tsantsas, authentic and forged: a study of two shrunken heads in the Mutter Museum, Trans. Stud. College Phys. Phil. 43 (1975) 78–82.

[16] R.W. Mann, B.B. Farmer, J.W. Verano, South American shrunken heads: genuines and fakes, Bioantropologia 2 (1992) 8–13.

[17] T.M.R. Houlton, C.M. Wilkinson, Recently identified features that help to distinguish ceremonial tsantsa from commercial shrunken heads, JCH 20 (2016) 660–670.

[18] N. Lynnerup, Mummies, Yearb. Phys. Anthropol. 50 (2007) 162–190.

[19] Forensic Science Communications (FSC), Forensic human hair examination guidelines: Scientific Working Group on Material Analysis (SWGMAT), Forens. Sci. Comm. 2 (3) (2005) 1–32 (U.S. Department of Justice, Federal Bureau of Investigation).

[20] G.M. Roe, R. Cook, C. North, An evaluation of mounts for use in forensic hair examination, J. Forensic Sci. Soc. 31 (1) (1991) 59–65.

[21] L.G. Farkas, Anthropometry of the Head and Face, 2nd ed., Raven Press, New York, 1994.

[22] F. Vegter, J.J. Hage, Clinical anthropometry and canons of the face in historical perspective, Plast. Reconstr. Surg. 106 (5) (2000) 1090–1096.

[23] M.H.K. Motamedi, S.H. Mortazavi, H. Behnia, M. Yaghmaai, A. Khodayari, F. Akhlaghi, M.G. Shams, R.Z. Marandi, Maxillofacial reconstruction of ballistic injuries, in: M.H.K. Motamedi (Ed.), A Textbook of Advanced Oral and Maxillofacial Surgery, In Tech, Manhattan, 2013, pp. 552 (Chapter 19).

[24] S.M.F.M. De Souza, M. Fátima, K. Reinhard, A. Araújo, The Jivaro shrunken heads from the National Museum, Rio de Janeiro, Brazil: authentic of counterfeits? V World Congress on Mummy Studies, Turin, J. Biol. Res. (2005) 129–131 Turin: Societa Italianadi Biologia Experimentale LXXX.

[25] D. Carrion, J. Vasconez, N. Bermudez, The case of Quito, Ecuador, Centro de Investigaciones de Ciudad, Fernando Meneses #265 y Av. la Gasca, Quito, Ecuador 1708–8311 (2005) 1–24.

[26] A. Kern, J. Ritzen, Dying for change: poor people's experience of health and ill health, Sustain. Dev. Healthy Environ. (2005) World Health Organisa-tion, http://www.who.int/hdp/publications/dying change.pdf (accessed 18.09.17).

[27] A. Finner, Nutrition and hair: deficiencies and supplements, Dermatol. Clin. 31 (1) (2016) 167–172.

[28] K. França, R.T. Villa, V. Bedin, Hair casts or pseudonits, Int. J. Trichol. 3 (2) (2011) 121–122.

[29] R.P. Dawber, Hair casts, Br. J. Dermatol. 100 (1979) 417–421.

[30] J.L. Held, R.M. Bernstein, Hair casts or pseudonits acquired following psychological trauma, Cutis 43 (1989) 380–381.

[31] W. Zhang, Epidemiological and etiological studies on hair casts, Clin. Exp. Dermatol. 20 (1995) 202–207.

[32] P.H. Itin, S.K. Fistarol, Hair shaft abnormalities – clues to diagnosis and treatment, Dermatology 211 (2005) 63–71.

[33] R.C. Vreeman, A.E. Carroll, Medical myths, BMJ 335 (2007) 128.

[34] L. Rudnicka, A. Rakowsk, M. Olszewska, M. Slowinska, J. Czuwara, M. Rusek, A. M.C. Pinheiro, Atlas of trichoscopy, dermoscopy in hair and scalp disease, Springer-Verlag, London, 2012, pp. 11–46.

[35] A.C. Aufderheide, The Scientific Study of Mummies, Cambridge University Press, Cambridge, UK, 2003, pp. 314–315.

[36] R. Karsten, The Headhunters of Western Amazonas, Societas Scientiarum Fennica. Commentations Humanarum Litterarum. VII. 1. Helsingfors – Centraltryckeriet, (1935).

[37] J.R. Grehan, Buffalo Museum of Science: External Ear Morphology, (2010) http://www.sciencebuff.org/research/current-research-activities/john-gre- han/human-origins/humans-and-orangutan/orangutan-relationship/exter- nal-ear/ (accessed 28.08.17).

[38] C. Violette, External Ear Morphology, (2010) http://www.sciencebuff.org/ research/current-research-activities/john-grehan/human-origins/humans- and-orangutan/orangutan-relationship/external-ear/ (accessed 28.08.17).

[39] J. Robertson, Forensic Examination of Hair, Taylor and Francis Forensic Science Series, Australia, 1999.

[40] R.E. Bisbing, Forensic identification and association of human hair, 2nd ed., in: R. Saferstein (Ed.), Forensic Science Handbook, vol.1, Pearson Education, Upper Saddle River, NJ, 2002, pp. 390–428.

[41] D.W. Deedrick, S.L. Koch, Microscopy of Hair Part 1: A Practical Guide and Manual for Human Hairs. Forensic Science Communications, vol. 6(1, U.S. Department of Justice, Federal Bureau of Investigation, 2004.

[42] B. Adam, A.T. Soo-Hoo, K.C. Chong, Black piedra in West Malaysia, Australas. J. Dermatol. 18 (18) (1977) 45–47.

[43] G.S. De Hoog, J. Guarro, J. Gené, M.J. Figueras, Atlas of Clinical Fungi, CBS, Universitat Rovira i Virgili, 2005.

[44] D. Larone, Medically Important Fungi, ASM Press, Washington, DC, 1995.

[45] J. Bottasso, Les Missions salésiennes et le peuple shuar: Bilan d'une expérience, Recherches amérindiennes au Québec 21 (1991) 77–91.

[46] D. Steel, Trade goods and Jivaro Warfare: the Shuar 1850-1957, and the Achuar, 1940–1978. Warfare and violence in ethnohistorical perspective, Ethnohistory 46 (4) (1999) 753–759.

[47] M. Allioni, The Shuara, An Indian Savage Tribe of Ecuador. Vol. 1, 132 leaves, New York Public Library, New York, 1911 (Archived material).

[48] J. Bennett-Ross, Effects of contact on revenge hostilities among the Achuara Jivaro, in: R.B. Ferguson (Ed.), Warfare Culture, and Environment, Academic Press, Orlando, FL, 1984, pp. 83–124.

[49] E. Hu-Dehart, Chinese Coolie Labor in Cuba in the Nineteenth Century: Free Labor of Neoslavery. Contributions in Black Studies, vol. 12 (1994) Article 5, http://scholarworks.umass.edu/cibs/vol12/ iss1/5.

[50] L. Yun, R.R. Laremont, Chinese Coolies and African Slaves in Cuba, 1847-74, JAAS 4 (2) (2001) 99–122.

[51] The Gilder Lehrman Institute of American History, Facts about the Slave Trade and Slavery, (2009) http://www.gilderlehrman.org/history-by-era/slavery- and-anti-slavery/resources/facts-about-slavetrade-and-slavery (accessed 28.08.17).

[52] A. Reed, Pilgrimage Tourism of Diaspora Africans to Ghana, Routledge, New York, 2014, pp. 56.

[53] N. Moss, The Hutchinson Paperback Guide to the World, Helicon Publishing Ltd, Oxford, 1990.

[54] M. Van Groesen, The Legacy of Dutch Brazil, Cambridge University Press, 2014.

[55] C. Wagley, The Latin American Tradition, Columbia University Press, New York, 1968.

[56] L.S. Hoberman, S.M. Socolow, Cities and Society in Colonial Latin America, University of Mexico Press, Albuquerque, 1986.

[57] L.C. Sperling, S.E. Cowper, E.A. Knopp, An Atlas of Hair Pathology with Clinical Correlations, 2nd ed., CRC Press/Taylor and Francis Group, Florida, 2012.

[58] O.H. Duggins, M. Trotter, Changes in morphology of hair during childhood, Ann. N. Y. Acad. Sci. 53 (1951) 569–575.

[59] S.A. Furdon, D.A. Clark, Scalp hair characteristics in the newborn infant, Adv. Neonatal Care 3 (2003) 286–296.

[60] F.J. Ebling, The biology of hair, Dermatol. Clin. 5 (3) (1987) 467–481.

[61] A.S. Tully, J. Schwartzenberger, J. Studdiford, Androgenic Alopecia, J. Men's Health 7 (3) (2013) 177–178.

[62] Genetics Home Reference, Androgenetic Alopecia, US National Library of Medicine, 2006 http://ghr.nlm.nih.gov/condition/androgenetic-alopecia (accessed 09.09.17).

[63] D. Pandhi, D. Khanna, Premature graying of hair, IJDVL 79 (5) (2013) 641–653.

[64] A. Rook, R. Dawber (Eds.), Diseases of the Hair and Scalp, Blackwell Scientific, Oxford, 1982.

[65] N. Otberg, H. Richter, H. Schaefer, U. Blume-Peytavi, W. Sterry, J. Lademann, Variations of hair follicle size and distribution in different body sites, J. Invest. Dermatol. 122 (2004) 14–19.

[66] A. Pagnoni, A.M. Kligman, S. El Gamma, T. Stoudemayer, Determination of density of follicles on various regions of the face by cyanoacrylate biopsy: correlation with sebum output, Br. J. Dermatol. 131 (6) (1994) 862–865.

[67] L. Rudnicka, A. Rakowsk, M. Olszewska, M. Slowinska, J. Czuwara, M. Rusek, A. M.C. Pinheiro, Atlas of Trichoscopy, Dermoscopy in Hair and Scalp Disease, Springer-Verlag, London, 2012, pp. 11–46.

[68] A. Vuissoz, M. Worobey, N. Odegaard, M. Bunce, C.A. Machado, N. Lynnerup, E. E. Peacock, M.T.P. Gilbert, The survival of PCR-amplifiable DNA in cow leather, J. Archaeol. Sci. 34 (5) (2006) 823–829.

[69] A. Sauvageau, C. Kremer, V. Brochu, F. Julien, S. Racette, Jivaro tsantsas or shrunken head. An expertise of authenticity evaluation, Am. J. Forensic Med. Pathol. 30 (1) (2009) 72–74.

[70] D. Hermon, R. Gafny, A. Zamir, L. Hadas, M. Faerman, G. Kahila Bargal, The genetic signature of a shrunken head, Archaeol. Anthropol. Sci. 3 (2011) 223– 228.

[71] M.T. Gilbert, A.S. Wilson, M. Bunce, A.J. Hansen, E. Willersley, B. Shapiro, T.F. Higham, M.P. Richards, T.C. O'Connell, D.J. Tobin, R.C. Janaway, A. Cooper, Ancient mitochondrial DNA from hair, Curr. Biol. 14 (2004) 463–464.

[72] M.M. Houck, Forensic Human Hair Examination and Comparison in the 21st Century, Central Police University Press, 2005, pp. 51–66.

[73] A.S. Wilson, Hair as a bioresource in archaeological study, in: D.J. Tobin (Ed.), Hair in Toxicology—An Important Biomonitor, Royal Society of Chemistry, Cambridge, 2005, pp. 321–345.

[74] H. Schierbeek, C.H. van den Akker, L.B. Fay, J.B. van Goudoever, High-precision mass spectrometric analysis using stable isotopes in studies of children, Mass Spectrom. Rev. 31 (2) (2012) 312–330.

[75] L. Cartmell, A.C. Aufderheide, D. Caprara, J. Klein, G. Koren, What were they drinking? A preliminary study of alcohol metabolites in Andean mummy hair, J. Biol. Res. 80 (2005) 114–116.

[76] A.J. Nelson, C.D. White, S. Thomson, G. Koren, S. van Uum, The recovery of corticosteroids from hair in archaeological contexts, in: P. Atoche, R. Ramirez (Eds.), Program and Abstracts. VI World Congress on Mummy Studies, Teguise, Canary Islands, Spain, 2007, pp. p166.

[77] E. Russel, G. Koren, M. Rieder, S.T. van Uum, Hair cortisol as a biological marker of chronic stress: current status, future directions and unanswered questions, Psychoneuroendocrinology 37 (2012) 589–601.

[78] M. Barroso, E. Gallardo, D.N. Vieira, M. Lopez-Rivadulla, J.A. Queiroz, Hair: a complementary source of bioanalytical information in forensic toxicology, Bioanalysis 3 (1) (2011) 67–79.

[79] G.M. Lauderbaugh, The History of Ecuador, ABC-CLIO, 2012.

[80] R. Jenkins, A.M. Burton, D. White, Face recognition from unconstrained images: progress with prototypes, Proc. 7th IEEE Int. Conf. on Automatic Face and Gesture Recognition, Southampton, UK, 2–6 April 2006 (2006) 25–30.

[81] R. Jenkins, A.M. Burton, 100% accuracy in automatic face recognition, Science 319 (2008) 435.

[82] R. Jenkins, A.M. Burton, Stable face representations, Philos. Trans. R. Soc. Biol. Sci. 366 (1571) (2011) 1671–1683.