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journal homepage: [www.elsevier.com/locate/jhevol](http://www.elsevier.com/locate/jhevol)LB1 and LB6 *Homo floresiensis* are not modern human (*Homo sapiens*) cretins

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## ABSTRACT

Excavations in the late Pleistocene deposits at Liang Bua cave, Flores, have uncovered the skeletal remains of several small-bodied and small-brained hominins in association with stone artefacts and the bones of *Stegodon*. Due to their combination of plesiomorphic, unique and derived traits, they were ascribed to a new species, *Homo floresiensis*, which, along with *Stegodon*, appears to have become extinct ~17 ka (thousand years ago). However, recently it has been argued that several characteristics of *H. floresiensis* were consistent with dwarfism and evidence of delayed development in modern human (*Homo sapiens*) myxoedematous endemic (ME) cretins. This research compares the skeletal and dental morphology in *H. floresiensis* with the clinical and osteological indicators of cretinism, and the traits that have been argued to be associated with ME cretinism in LB1 and LB6. Contrary to published claims, morphological and statistical comparisons did not identify the distinctive skeletal and dental indicators of cretinism in LB1 or LB6 *H. floresiensis*. Brain mass, skeletal proportions, epiphyseal union, orofacial morphology, dental development, size of the pituitary fossa and development of the paranasal sinuses, vault bone thickness and dimensions of the hands and feet all distinguish *H. floresiensis* from modern humans with ME cretinism. The research team responsible for the diagnosis of ME cretinism had not examined the original *H. floresiensis* skeletal materials, and perhaps, as a result, their research confused taphonomic damage with evidence of disease, and thus contained critical errors of fact and interpretation. Behavioural scenarios attempting to explain the presence of cretinous *H. sapiens* in the Liang Bua Pleistocene deposits, but not unaffected *H. sapiens*, are both unnecessary and not supported by the available archaeological and geochronological evidence from Flores.

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## Introduction

Excavations in the Pleistocene layers at Liang Bua, western Flores, in August 2003, uncovered the partial skeletal remains of a small-bodied and small-brained hominin, as well as a large number of stone artefacts and the bones of extinct fauna, including *Stegodon* (Morwood et al., 2004). The combination of unique, derived and primitive traits in the LB1 skeleton resulted in its allocation to a new species, *Homo floresiensis* (Brown et al., 2004). In the following year, these discoveries were further enhanced with the excavation of additional skeletal components from as many as nine individuals (Morwood et al., 2005), and most of the hominin fossils, as well as their geochronological and cultural contexts, have now been published in detail (Falk et al., 2005b, 2009b; Tocheri et al., 2007; Brown and Maeda, 2009; Larson et al., 2009; Moore et al., 2009; Morwood and Jungers, 2009; Roberts et al., 2009; Jungers et al., 2009a, b; Westaway et al., 2009a, b). However, the allocation of these fossils to a new species has not gone

unchallenged, with several independent teams arguing that morphologically and metrically the LB1 skeleton falls within the range of modern humans with particular developmental disorders or syndromes (Weber et al., 2005; Jacob et al., 2006; Martin et al., 2006a, b; Richards, 2006; Hershkovitz et al., 2007, 2008; Eckhardt and Henneberg, 2010; Vannuccia et al., 2011). In turn, many of these claims for pathology have been reviewed and found to be insubstantial, with the critics unable to present a modern human skeleton with the attributes of *H. floresiensis* (Falk et al., 2007, 2009a, 2010; Brown and Maeda, 2009; Jungers et al., 2009b; Aiello, 2010; Kaifu et al., 2010; McNulty and Baab, 2010).

Stated concerns for those favouring a pathological interpretation of *H. floresiensis* include the association between the cultural remains and hominin fossils, the intellectual capabilities of a hominin with a brain the size of a chimpanzee, and a belief that *Homo sapiens* may have been contemporaneous with LB1 on Flores. The latter presumably driven by the archaeological evidence for modern humans on the Sahul Shelf and Bismark Archipelago by 45–46 ka (thousands of years ago) (O'Connell et al., 2010) and Timor at >42 cal BP (calibrated years before present) (O'Connor, 2007), suggesting to some that *H. sapiens* were the tool makers at

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Liang Bua and *H. floresiensis* was most probably a pathological member of that population. However, there is currently no archaeological or skeletal evidence indicating that *H. sapiens* was present on the Lesser Sunda Islands, and Flores in particular, in the Pleistocene and the early Holocene human skeletons from Flores are distinctively modern (Verhoven, 1958; Jacob, 1967; Heekeren, 1967, 1972; Storm, 1995; Brumm et al., 2006; van der Plas, 2007). While this certainly complicates the southern-route, island-hopping scenario for the initial colonization of the Sahul Shelf (O'Connor, 2007), the available evidence indicates that *H. sapiens* were only present on Flores in the Holocene. It is also clear that tools of the types found in the Pleistocene layers at Liang Bua were also present at Mata Menge in western Flores at 880–800 ka (Morwood et al., 1998; Brumm et al., 2006, 2010; Moore and Brumm, 2007; Moore et al., 2009), pre-dating all of the available evidence for the evolution and dispersion of *H. sapiens* by >0.6 Ma (millions of years ago) (Klein, 2008). Based on chronology and the geographic proximity of Java, the potential candidates for the tool manufacturers at Mata Menge include *Homo erectus* (Anton, 2003; Kaifu et al., 2008) and *H. floresiensis* (LB2 left P<sub>3</sub>, ~74<sup>+14</sup>/<sub>-12</sub> ka) (Brown and Maeda, 2009; Morwood and Jungers, 2009), but not *H. sapiens*.

Most recently, it has been suggested by Obendorf and colleagues that the “New evidence of modern humans in East Timor, with similar stone tools to those found at LB (Liang Bua) at 42 ka BP (O'Connor, 2007) strongly indicates modern human presence on Timor, and therefore on neighbouring Flores, well before these key fossils. Thus, hypotheses of the form that LB1 is a pathological human (species *H. sapiens*) should be tested” (Obendorf et al., 2008: 1287). As O'Connor (2007) points out, as similar tools are present at Mata Menge (Brumm et al., 2006), the Pleistocene layers at Liang Bua and Jerimalai in East Timor, then it appears that the complexity of stone artefact manufacture does not provide information on behavioural modernity or hominin phylogeny in the southeast Asian region. It is also not certain if *H. sapiens* manufactured the Late Pleistocene artefacts at Jerimalai as hominin bones and teeth have not been recovered (O'Connor, 2007).

As Obendorf et al. (2008) believe that modern humans were the most probable tool makers at Liang Bua, they considered that it is important to test the possibility that LB1 and LB6 *H. floresiensis* are actually pathological humans (*H. sapiens*). Based on their assessment of the significance of dwarfism and reduced brain size in LB1, and criticisms of previous attempts to connect specific genetic pathologies to LB1 (Weber et al., 2005; Jacob et al., 2006; Martin et al., 2006b; Hershkovitz et al., 2007), they hypothesize that LB1 and LB6 are myxoedematous endemic cretins, “within part of an inland population of (mostly unaffected) modern humans” (Obendorf et al., 2008: 1287). However, the justification for their working hypothesis is at odds with the clinical literature on cretinism, where significantly reduced brain size is not listed as one of the attributes of myxoedematous, hypothyroid or hyperthyroid cretinism. Indeed, case studies and clinical descriptions, supported by photographs of patients, highlight that heads are of normal size (although not necessarily of normal shape), or large in relation to body size, and where brain weights and endocranial volumes are provided they are in the normal human range of variation (Pearl, 1905; Finkbeiner, 1923; von Bonin, 1934; Hill, 1936; Quervain and Wegelin, 1936; Jackson, 1952b; Blinkov and Glezer, 1968; Obendorf et al., 2008), and MRI and CT scans show remarkably normal appearance (Ma et al., 1988; Delong, 1993). On this point alone, LB1 would be a very unlikely candidate for any modern human form of cretinism.

There are two main types of cretinism, neurological (euthyroid) and myxoedematous (hypothyroid), with both phenotypes having a common pathogenesis, but occurring at different times during

foetal and postnatal development (Halpern et al., 1991; Bruyn and Poser, 2003; Chen and Hetzel, 2010). Both types of cretinism, neurological and myxoedematous, can also be described as endemic or sporadic depending upon the frequency of occurrence within the local population. Neurological cretins are the offspring of severely iodine-deficient mothers who could not provide sufficient thyroxine to the foetus during the first seven months of pregnancy. Prior to medical intervention, this form of cretinism was most common in mountainous regions, with iodine-depleted soils and at some distance from marine resources, for instance Switzerland, Papua New Guinea and in South America (Kevany et al., 1969; Heywood et al., 1986; Burgi et al., 1990; Pharoah and Heywood, 1994). Myxoedematous cretins suffer from foetal rather than maternal thyroid deficiency in the last trimester of gestation, or in the neonatal period, that persists for an extended period and may result in thyroid atrophy. This form of cretinism also has geographic centres, and until recently was common in Zaire and Western China (Thilly et al., 1977; Boyages et al., 1988b; Vanderpas et al., 1990; Boyages and Medeiros-Neto, 1996). However, some populations have evidence of both neurological and myxoedematous cretinism (Boyages and Halpern, 1993), and dietary goitrogens, hereditary predisposition, the presence of gastrointestinal diseases, and a greater susceptibility of females may also contribute to the complex causation and expression of the disease (Ermans et al., 1972; Eastman and Phillips, 1988; Thilly et al., 1993; Vanderpas, 2006).

Clinically, neurological cretins are usually distinguished by the presence of goitre, extreme mental retardation, deaf-mutism, squint and motor spasticity, and myxoedematous cretins by extreme growth retardation, facial dysmorphism, myxedema and less severe mental retardation (Collins et al., 1987; Eastman and Phillips, 1988; Boyages and Halpern, 1993). However, with the exception of extreme dwarfism, the literature is unclear over whether the two forms of the disease can be separated by the development of particular sets of skeletal and dental traits (Finkbeiner, 1923; Nager, 1933; Hill, 1936; Quervain and Wegelin, 1936; Wilkins, 1941; Dreyfus et al., 1950; Bellini and Neves, 1956; Middlemass, 1959; Tumay et al., 1962; Borg et al., 1975; Israel et al., 1983; Ortner and Hotz, 2005). The crucial factor in the development of the skeletal manifestations of cretinism, both in the euthyroid and hypothyroid forms, is that the thyroid deficiency is present during growth. With the possible exception of the abnormal development of the inner ear and temporal region in euthyroid cretins (Nager, 1933; Koenig and Neiger, 1972), both euthyroid and hypothyroid forms may have similar skeletal and dental indicators of the disease. Diagnosis is further complicated by the number of unrelated syndromes that can have an impact on growth (Stevenson and Hall, 2006), as well as the skeletally heterogeneous expression of the disease in cretins.

Clinical studies of adult cretins have identified skeletal and dental indicators of retarded linear growth and development, that may persist into middle-age and be useful in the identification of adult cretinism in isolated human skeletons (Knaggs, 1928; Hill, 1936; Wilkins, 1941; Mahmoud, 1954; Tenchov et al., 1957; Tumay et al., 1962; Wrinch and Lewall, 1969; Israel et al., 1969, 1976, 1983; Borg et al., 1975; Crawford et al., 1977; Ortner and Hotz, 2005; Iqbal et al., 2009) (Table 1). Stature is often reported as dwarfed, but the range extends from ~82–161 cm (Ibbertson et al., 1972; Delange et al., 1972b; Fierro-Benitez et al., 1974) and is not usually adjusted for kyphosis. In adults, the skeletal changes may comprise unfused epiphyses, under-development or absence of air sinuses, including acellular mastoids, narrow diploic space, an open anterior fontanelle, reduction of the vertical height and wedging of lumbar vertebrae, spinal kyphosis, and dysgenesis and fragmentation of the femoral heads. There is also evidence of abnormal bone development in the middle ear, including bony

**Table 1**

Skeletal and dental traits that the clinical literature associates with hypothyroid and euthyroid cretinism (x), indicators of cretinism that Obendorf et al. (2008) claim are present in either LB1 or LB6 *H. floresiensis*, and indicators of cretinism that direct observation demonstrate are present in the LB1 and LB6 skeletal materials.

	Myxoedematous cretin (hypothyroid)	Endemic cretin (euthyroid)	Obendorf et al. (2008) LB1 and LB6 claimed similarities to cretins	<i>H. floresiensis</i> LB1 and LB6
Stature	Often severe growth retardation	Normal or mildly subnormal	Yes	108 cm
Mental retardation	'Present, less severe'	Often severe		No evidence
Deafness	Absent	Usually present		No evidence
Sexual maturity	Often delayed	Often delayed		Adult skeleton and dentition
Protuberant abdomen	x	x		Unknown
<b>Cranium</b>				
Endocranial volume	Normal range	Normal range	Claimed reduction in cretins	380–420 cc
Narrow diploic space	x		Thick vault (not defined)	<i>H. sapiens/H. erectus</i> range
Anterior fontanelle open or paper-thin		x	Suggested open fontanelle	No
Enlarged sella turcica	x		Enlarged, claimed length 12.9 mm	No, length ~8.5 mm
Petro-mastoid hypoplasia		x		Robust mastoid process
Mastoid pneumatization reduced or absent		x		Pneumatized mastoid
Hyperostosis of basicranium	x			No
Hypoplastic paranasal sinuses	x		Frontal sinuses not present	No, all sinuses present
Some retained deciduous teeth	x	x	Retained mandibular deciduous molars	No deciduous teeth
Reduced facial height	x	x	Suggested	No
Flat mid-face	x	x		No
Broad interorbital space	x	x		Insufficient evidence
Subnasal prognathism	x		Suggested	No, full facial prognathism
Hypoplastic nasal bones	x		Suggested	Not preserved
Auditory ossicles enlarged and distorted, especially the stapes		x		Insufficient resolution
Round and oval windows distorted		x		No
<b>Mandible</b>				
Unfused symphysis	x			No
Hypoplastic	x			No
Increased mandibular angle	x			No (116–110)
Retained deciduous premolars	x	x	Claimed for LB1 and LB6	No
<b>Vertebral column, ribs, and scapula</b>				
Lumbar kyphosis	x	x		Insufficient evidence
Persistent canals of Hahn	x			Insufficient evidence
Shortened 'bullet-shaped' vertebral bodies	x	x		Insufficient evidence
Wide disk spaces	x	x		Insufficient evidence
Unfused apophyses	x	x	Claimed for LB1	No
Delayed ossification of sternum	x			No
Disproportionate development of rib cage	x			Insufficient evidence
Clavicle with incomplete ossification			Claimed for acromial and sternal ends of LB1	No
Delayed fusion of scapula			Claimed for LB6	No
<b>Pelvis</b>				
Unfused iliac apophyses	x	x		No
Hypoplastic ilia	x	x		No
<b>Limbs</b>				
Short metacarpals and metatarsals	x	x		Not for body size
Epiphyseal dysgenesis of humeral, femoral, tibial epiphyses and patellae	x	x		No
Coxa vara, magna, and plana	x	x		No
Delayed carpal ossification	x			No
Carpal bones reduced in size	x			Not for body size
Hands and feet broad and short	x	x		No
Severe flexion deformities (knees and ankles)		x		No
Rigidity	x	x		Unknown, unlikely
Abnormal gait	x	x		Probably distinct from <i>H. sapiens</i>
Bradykinesia	x	x		Unknown, unlikely

(continued on next page)

Table 1 (continued)

	Myxoedematous cretin (hypothyroid)	Endemic cretin (euthyroid)	Obendorf et al. (2008) LB1 and LB6 claimed similarities to cretins	<i>H. floresiensis</i> LB1 and LB6
Increased robusticity	Femur robusticity mean 19.4		Claimed for experimental dog cretins	Robust, femur 23.4
Humerofemoral index	Mean 71.9		Claimed high for human cretins	Extremely high, 86.4
Humeral torsion	Mean 145.0		Claimed reduced in Swiss cretins	Extremely low, 110–121

The clinical and anthropological literature does not always distinguish between the different forms of cretinism, etiologies are complex and distributions overlap. As a result, there is uncertainty over whether some traits are only found in hypothyroid or euthyroid cretins.

hypertrophy, deformation of the ossicles and fixation of the stapes and distortion of the round and oval windows (Nager, 1933; Koenig and Neiger, 1972). In the mandible, there can be hypotrophy, an increased mandibular angle, unfused symphysis and retention of infantile symphyseal morphology. Hands and feet are usually described as infantile, short and broad, and the carpals reduced in size (Hill, 1936; Quervain and Wegelin, 1936; Benda, 1947; Middlemass, 1959; Borg et al., 1975). However, Middlemass's (1959) radiographic study of bony changes in 32 adult cretins, aged 16–56 years, highlighted the great degree of variation in the presentation of these traits, which is not surprising in a disease with such a complex etiology. For instance, only 6/32 in Benda's sample had an enlarged sella turcica, 15/32 were without frontal sinuses and 25/32 had normal mastoids. Some of these developmental abnormalities are also associated with a variety of other metabolic disorders and syndromes (Stevenson and Hall, 2006). However, they are all less common than the iodine deficiency disorders used to be, and therefore less likely to be encountered archaeologically. In developing their argument for ME cretinism in LB1 and LB6, Obendorf et al. (2008) focus on a small suite of developmental features that they believe are diagnostic, and which are present in two cretins described by Dolega (1891; Knaggs, 1928) and Hill (1936), and also in LB1 and LB6 *H. floresiensis*. As several of the features they describe are actually not preserved in LB1, but are crucial to their diagnosis, it is worthwhile examining the extent to which their claims are supported by the anatomy of the original skeletons. Rather than selecting traits that might suit a particular argument, it is also possible to extend their comparison to the larger group of traits that have been associated with the skeletons of adult cretins by clinicians and osteologists (Table 1). This will provide a test of the accuracy of Obendorf et al.'s (2008) observations and conclusions, and the likelihood that *H. floresiensis* was a modern human with ME cretinism. As previous publications have focused on describing the combination of unique, derived and symplesiomorphic features in the skeleton and dentition of *H. floresiensis*, with consideration of its cultural behaviour, locomotor adaptations, evolutionary history and phylogenetic relationships, the morphological support for these will not be re-examined here. The focus is purely on the skeletal and dental evidence for cretinism in LB1 and LB6 and not a critique of either unrelated claims of pathology (Jacob et al., 2006; Richards, 2006; Martin et al., 2006b; Hershkovitz et al., 2007; Kaifu et al., 2009), evidence of insular dwarfing (Brown et al., 2004; Weston and Lister, 2009), or possible phylogenetic relationships with either *H. erectus* or earlier African Pliocene hominins (Argue et al., 2006; Baab et al., 2007; Collard and Wood, 2007; Tocheri et al., 2007; Brown and Maeda, 2009). However, if the evidence indicates that LB1 and LB6 were actually modern humans (*H. sapiens*) with cretinism as claimed by Obendorf et al. (2008), there are obviously implications for the specific status of *H. floresiensis* and the cultural and evolutionary scenarios that have been constructed around the survival of a small-bodied and small-brained hominin on Flores into the terminal Pleistocene.

## Materials and methods

The author examined the Liang Bua *H. floresiensis* skeletal and dental materials using previously published procedures (Brown et al., 2004; Morwood et al., 2005; Brown and Maeda, 2009). Where possible, measurements and morphological observations were compared with those obtained from the original specimens by other investigators (Falk et al., 2005a; Tocheri et al., 2007; Kaifu et al., 2009; Larson et al., 2009; Jungers et al., 2009a, b). Where multiple, independent observations were available, there were only minor differences in measurement that were within the range expected of inter-observer error (Hunter and Priest, 1960; Utermohle and Zegura, 1982). More importantly, none of the reported differences in measurement, for instance an endocranial volume range of 380–417 cm<sup>3</sup> (Brown et al., 2004; Falk et al., 2005b) or estimated humeral torsion angle range of 110–115° (Morwood et al., 2005; Larson et al., 2009), have implications for the assessment of cretinism in LB1 and LB6.

A large modern human skeletal sample ( $n = 2063$ ), with a broad temporal and geographic distribution, was used for comparison of craniofacial dimensions, relative limb lengths and skeletal robusticity in cretins, normal *H. sapiens* and *H. floresiensis* (Brown et al., 2004; Morwood et al., 2005; Brown and Maeda, 2009). The *H. sapiens* sample was weighted towards the Australia-Melanesian region ( $n = 378$ ) and includes small-bodied modern humans (African Pygmies  $n = 10$  and Andaman Islanders  $n = 15$ ). Preservation and changes in research emphasis between 1980 and 2008 has resulted in unequal sample sizes for some skeletal elements. Even though LB1 and LB6 are probably female (Brown et al., 2004; Morwood et al., 2005; Brown and Maeda, 2009; Jungers et al., 2009b), pooled sex data were used because without genetic information the sex of any hominin skeleton will never be beyond dispute. Data were recorded using standardised measurement procedures (Martin, 1914; Martin and Saller, 1957), which were also followed by the most comprehensive source of published cretin skeletal information (Finkbeiner, 1923). Data on morphological and metrical variation in cretin skeletons and dentitions were obtained from the published clinical and anthropological literature (Dolega, 1891; Finkbeiner, 1923; Knaggs, 1928; Nager, 1933; Hill, 1936; Quervain and Wegelin, 1936; Wilkins, 1941; Benda, 1947; Jackson, 1952b; Middlemass, 1959; Vandendorp et al., 1959; Tumay et al., 1962; Koenig and Neiger, 1972; Borg et al., 1975; Israel et al., 1983; Stanbury, 1984; Ortner and Hotz, 2005).

CT scans of LB1 and LB6 were performed using a Siemens Emotion CT scanner (Siemens Medical Systems, Inc., Erlangen, Germany) in Jakarta Selatan, Indonesia. Parameters included a 512 × 512 matrix, 2 mm collimation, 1 mm reconstruction interval, and a H70s reconstruction kernel. These CT scans were of low resolution and adjusting threshold values would not reveal the details of some delicate structures that visual inspection demonstrated were present on the original specimens. Where possible, dimensions recorded from individual CT slices, for instance with cranial vault thickness or the size of the sella turcica, were

compared with measurements from the original skeleton, or stereolithographic models. The OsiriX imaging software 3.9 was used for 2D and 3D examination of DICOM data.

A variety of exploratory procedures were employed to examine sample-based differences in the distribution of data used in this analysis. The distribution of all data sets were examined graphically using normal probability, stem and leaf, and box plots, and distributions tested for univariate normality with the Shapiro–Wilk and Kolmogorov–Smirnov tests ( $p < 0.01$ ). Bivariate associations in postcranial dimensions were examined using scatter plots, conventional least squares regression and plots of residuals, with ANCOVA to test for differences in regression slopes and y-intercepts. Results were considered statistically significant at  $p < 0.05$ . The indices used to define proportional differences in postcranial dimensions are defined in Table 2.

The extent and pattern of multivariate differentiation between the postcranial skeletons of cretins and unaffected *H. sapiens*, and the influence of individual variables on distributions, were explored using principal component analysis (PCA). PCA uses a single set of variables to discover if any of the variables form subsets (groups) that are relatively independent of each other. The factors generated by the PCA are based on correlated, as well as inversely correlated, subsets of variables, which may reflect underlying biological processes (Brown, 2010). Statistical and graphical procedures were performed using SYSTAT 13 (Systat, 2002) and SPSS 18 (SPSS, 1990).

### Taphonomy, developmental age and disease

A critical issue for the interpretation of any evidence of pathology in the Liang Bua hominins concerns their taphonomic history, from burial to excavation and analysis (Falk et al., 2010). To some extent, preservation of the Liang Bua fossils, both in relation to damage sustained during transport and an inappropriate attempt to cast some of the hominin fossils in 2005 (Dalton, 2005a, b; Brown and Maeda, 2009), and in descriptions of individual skeletal elements (Brown et al., 2004; Morwood et al., 2005; Falk et al., 2005a, 2010; Brown and Maeda, 2009; Larson et al., 2009; Jungers et al., 2009a, b), has been discussed previously. However, with respect to the cretinism hypothesis, it is necessary to clarify some of the relevant taphonomic issues and evidence of developmental age.

Most of the LB1 skeleton was excavated in August 2003 from Spit 59, Sector VII, at Liang Bua, at a depth of approximately 5.9 m. Other parts of the skeleton were recovered in 2004, as well as skeletal elements from other individuals (Brown et al., 2004; Morwood et al., 2004, 2005). The bones were recovered from layers of damp, dark brown silty clay and were extremely soft and unmineralized, as were contemporaneous bones of *Stegodon*. When

dried, the bones were chalky and fragile. Freshly broken sections of bone were white in color, as was exposed dentine. The LB1 skeleton was discovered when a member of the excavation team inadvertently removed part of the facial skeleton and a section of the superior vault (Figs. 1 and 2). After initial cleaning, while still positioned in a block of sediment, it was apparent that the posterior frontal, left side of the supraorbital, fronto-nasal region and sub-nasal region were damaged, removing glabella, the left frontal sinus and nasal bones (Fig. 2), and there was some post-mortem distortion on the right side of the vault (Falk et al., 2010). Preservation of the left mastoid region is not as complete as the right and the basi-occipital also has some damage. The associated mandible had been broken and distorted post-mortem, and would not occlude or articulate properly with the cranium and maxillary dentition (Brown and Maeda, 2009). The overall affect, when combined with excavation damage and positional plagiocephaly (Kaifu et al., 2009, 2010), increased perceptions of asymmetry, although this remains within the limits of a normal population (Baab and McNulty, 2009; McNulty and Baab, 2010).

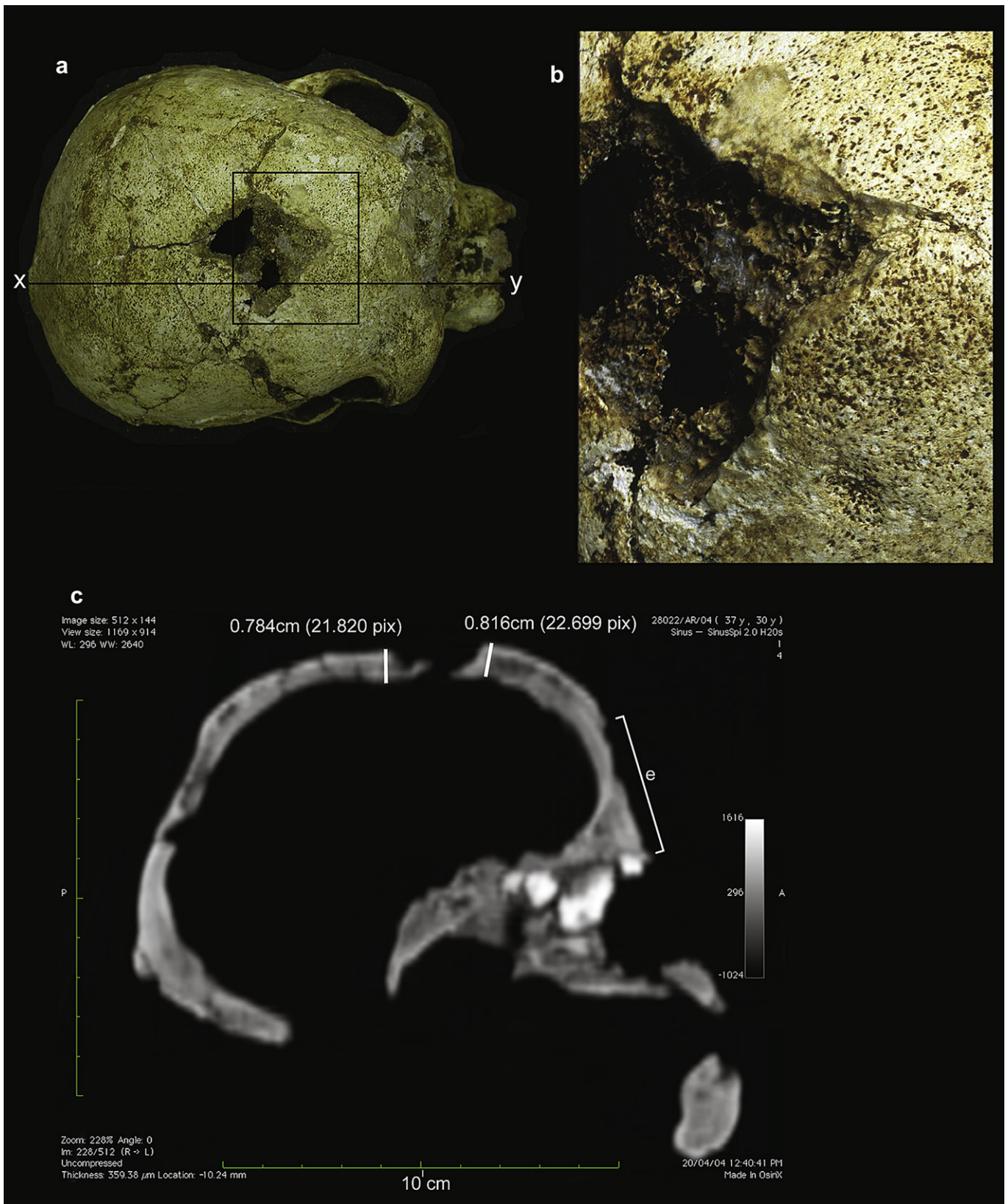
Apart from some of the smaller and denser bones of the wrists, hands and feet (Tocheri et al., 2007; Jungers et al., 2009a), most of the postcranial elements from LB1, LB6 and other individuals from the late Pleistocene deposits display evidence of post-mortem damage. There is little plastic distortion but the shafts of most limb bones are broken (tibia LB1/13, LB1/12 and LB8/1, femora LB1/8 and LB1/9, humerus LB1/50, and others), articular surfaces are poorly preserved (LB1/5 right clavicle, tibia LB1/13, LB1/12 and LB8/1, femora LB1/8 and LB1/9, humerus LB1/50) and there is some slight compression crushing (LB6/3 left ulna, LB1/51 left ulna, LB1/5 right clavicle). The relatively fragile bones of the vertebral column, and thorax are only represented by fragments. Fortunately, for LB1 and LB6, there is adequate preservation of dental, cranial and postcranial elements to be certain of adult status and completion of growth (LB1 cranium with fully fused sphenoccipital synchondrosis, worn adult dentition and complete epiphyseal union in LB1/50 humerus, LB1/52 right ulna, LB1/13 right tibia, LB1/9 left femora and LB1/7 left os coxae, LB6 worn adult dentition, and complete epiphyseal union in LB6/2 right radius, LB6/3 left ulna, LB6/4 scapula) (Brown et al., 2004; Morwood et al., 2005; Brown and Maeda, 2009; Larson et al., 2009; Jungers et al., 2009a, b). Currently, the only bones recovered with unfused or incompletely fused epiphyses from the Pleistocene deposits are the extremely small LB4/1 left radius and LB4/2 right tibia (Jungers et al., 2009b; Larson et al., 2009; PB personal observation).

As discussed below, Obendorf et al. (2008) discuss the presence of open anterior fontanels in some adult cretins and speculate that this is “possibly replicated in the damaged LB1” (1288). They also suggest that the right clavicle of LB1 (LB1/5) and right scapula of LB6 (LB6/4) also provide evidence of the “characteristic delayed

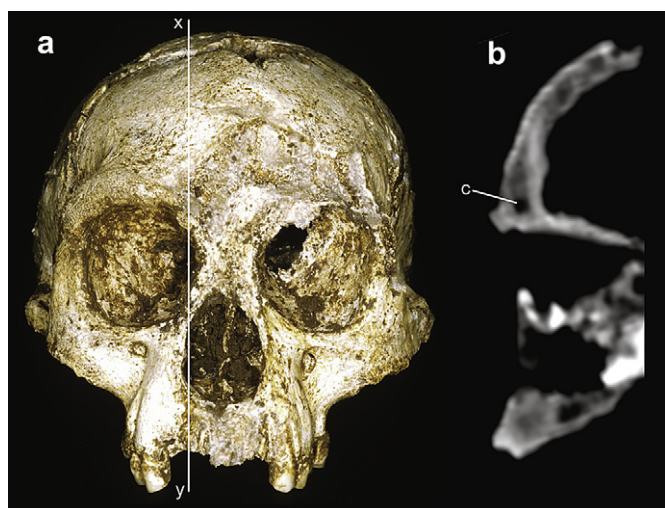
**Table 2**

Indices used to compare relative limb proportions, shape and robusticity in the normal *H. sapiens*, cretins, and LB1 and LB6 *H. floresiensis*, with the identification of the individual skeletal dimensions from Martin (1928).

Index	Formula	Martin (1928)
Intermembral index	$[(\text{Humerus length} + \text{radius length}) * 100] / (\text{femur length} + \text{tibia length})$	1a, 1, 1, 1a
Humerofemoral index	$(\text{Humerus length} * 100) / \text{femur length}$	1a, 1
Brachial index	$(\text{Radius length} * 100) / \text{humerus length}$	1, 1a
Crural index	$(\text{Tibia length} * 100) / \text{femur length}$	1a, 1
Radiofemoral index	$(\text{Radius length} * 100) / \text{femur length}$	1, 1
Ulna intermembral index	$[(\text{Humerus length} + \text{ulna length}) * 100] / (\text{femur length} + \text{tibia length})$	1a, 1, 1, 1a
Ulnahumeral index	$(\text{Ulna length} * 100) / \text{humerus length}$	1, 1a
Ulnafemoral index	$(\text{Ulna length} * 100) / \text{femur length}$	1, 1
Pilaster index	$\text{Femur a-p midshaft breadth} * 100 / \text{femur midshaft m-l breadth}$	6, 7
Femoral robusticity index	$(\text{Femur midshaft circumference} * 100) / \text{femur length}$	8, 1
Femoral breadth index	$(\text{Transverse breadth of femur midshaft} * 100) / \text{femur length}$	7, 1
Humeral robusticity index	$(\text{Humerus midshaft circumference} * 100) / \text{humerus length}$	7a, 1a



**Figure 1.** Post-mortem damage to the LB1 cranium that occurred during initial discovery. (a) Superior view showing damage to posterior frontal and anterior parietals, and left anterior frontal and supraorbital region. (b) Detail of damage to the frontal, with sharp fracture lines in the external table and perforated diploë. The brown discoloration is sediment that accumulated in the diploë and textured bone surfaces during cleaning. (c) Antero-posterior CT slice running in the plane x–y in (a). Note indicated cranial vault thickness. There was still sediment in the maxillary sinuses and posterior nasal cavity when this CT was recorded, which appear as 'white' radio-opaque blobs. (e) Area of post-mortem damage extending down the mid-face that removed glabella and the nasal bones. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)



**Figure 2.** Facial views of LB1. (a) Damage to the fronto-nasal, and left supraorbital and subnasal regions. (b) Antero-posterior CT slice through the fronto-facial region orientated in the plane x–y indicated in (a). (c) Preserved section of right frontal sinus.

fusion” (Obendorf et al., 2008: 1289) evident in adult cretins. More unusually, in attempting to explain an endocranial volume (EV) in LB1 that is approximately 35–40% of the cretin average (discussed further below) they speculate that the EV of LB1 “may have been reduced by post-mortem deformation” (Obendorf et al., 2008: 1292). This was apparently the result of the cartilage present in unfused and widely separated synchondroses in the basicranium of LB1 not being preserved post-mortem, with the ‘soft and deformable’ bones of the cranial base then closing and reducing EV from what it was during life. How this deformation of the cranial base, without corresponding distortion of the rest of the neurocranium, could result in 60% reduction in EV from the cretin average is not explained. It is true that in some cretins, the basi-occipital, lateral occipitals and squamous occipital, that usually unite to form a single occipital bone by five to seven years of age (Scheuer and Black, 2000), remain as separate bones into adulthood (Fig. 3). For instance, Knaggs (1928) discusses the 28 year-old sporadic cretin described by Dolega (1891), in which the anterior and posterior intra-occipital sutures, as well as the sphenoccipital synchondrosis, remain open. However, while there is some post-mortem damage to the LB1 basicranium and occipital bone, comparison of cracks and missing bone on the left and right sides does not provide room for ambiguity. The occipital bone was a normal, fully fused, single bone and the sphenoccipital synchondrosis completely closed (Fig. 3).

Similarly, direct examination of the asymmetrical hole in the posterior frontal of LB1, supported by CT scans, clearly indicates that this is the result of post-mortem excavation damage and is definitely not an unfused anterior fontanelle (Fig. 1). A large part of the removed section of frontal, consisting of outer table and some diploë, is also in the Liang Bua collection, ARKANAS, Jakarta (PB personal observation, 2005). Cranial vault bone surrounding the broken section is ~8 mm thick, there are fresh, sharp broken edges in the bone of the outer table, the damage extends into the parietals, and the profile of the damaged edges demonstrates that a thick piece of bone had been excised from this position (Fig. 1).

The LB1 right clavicle (LB1/5) and LB6 right scapula (LB6/4) that Obendorf et al. (2008) believe show evidence of the delayed ossification seen in some adult cretins have been described in detail by Larson et al. (2007, 2009). The clavicle is incomplete, with an eroded lateral end and the medial end is broken and partially crushed (Larson et al., 2009: Fig. 1; PB personal observation). Using modern

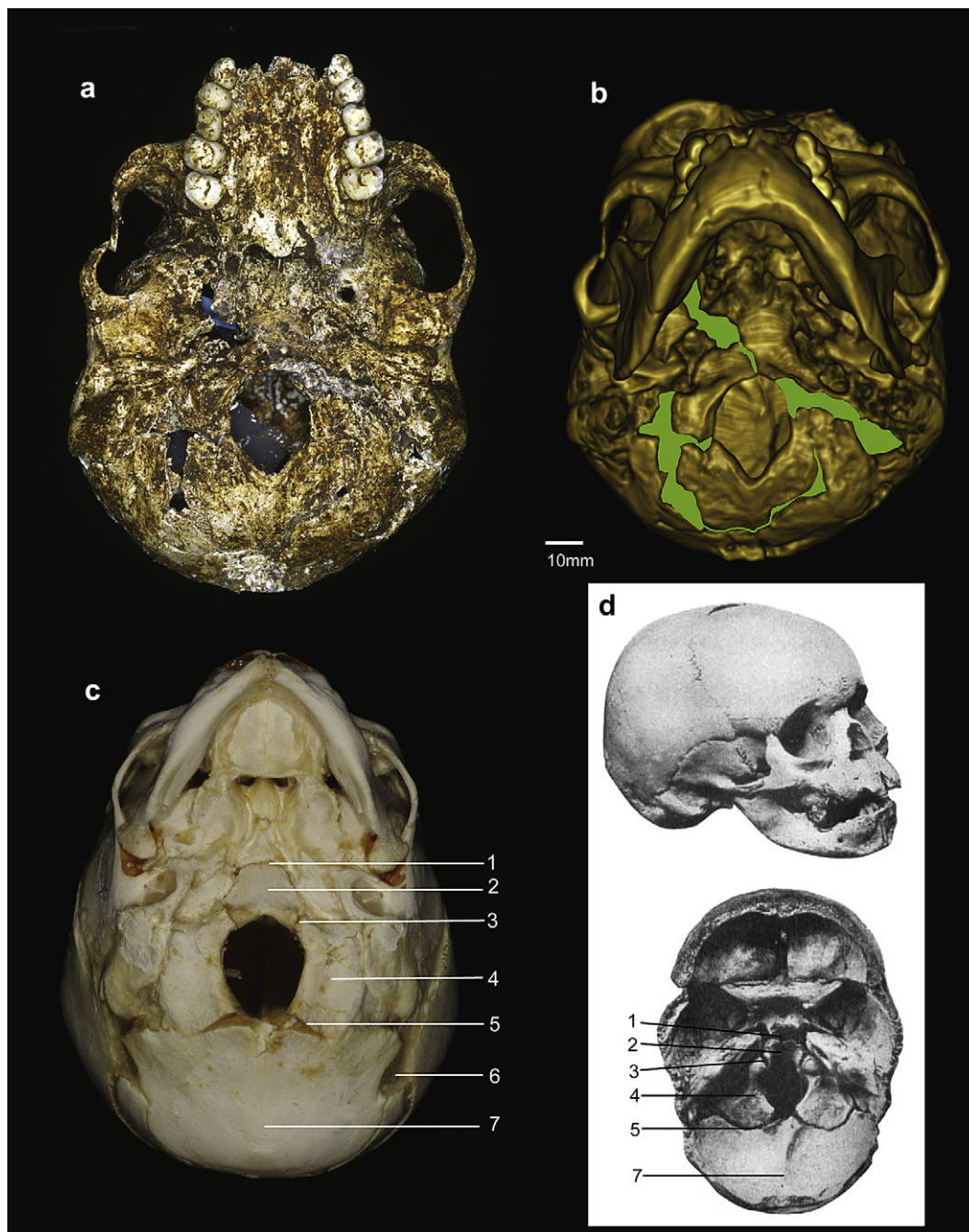
human standards, as the medial epiphysis is not preserved, it is not possible to determine if the ossification of the clavicle is complete (Webb and Suchey, 1985; Black and Scheuer, 1996). The remarkably complete and delicate scapula (LB6/4) assigned to LB6 is missing only the medial part of the spine and the supraspinous fossa (Larson et al., 2009: Fig. 13). However, there is some post-mortem distortion, with the blade divided into two pieces, and the inferior border is eroded and incomplete (Larson et al., 2009; PB personal observation). Nevertheless, the glenoid and coracoid epiphyses are fully fused, so the available evidence supports adult status (Rissech and Black, 2007). This is consistent with the other skeletal elements assigned to LB6, which are all clearly from an adult.

Additional evidence of normal growth in LB1 is provided by the os coxae (Fig. 4). Delayed epiphyseal union and hypoplastic ilia are a commonly recorded clinical feature in juvenile and adult cretin pelvis (Wilkins, 1941; Middlemass, 1959; Stanbury, 1984). An ununited acetabulum, iliac crest and ischial ramus may persist even into middle-age (Jackson, 1952a; Borg et al., 1975), and the acetabulum can show the remodelling associated with any dysgenesis and malformation of the associated femoral head (Jackson, 1952a; Borg et al., 1975; Ortner and Hotz, 2005). However, like all of the skeletal traits clinically and anthropologically associated with cretinism their presentation is heterogeneous, with no single trait being diagnostic. For instance, 4/12 of a Swiss cretin sample were without severe osteoarthritic remodelling of the hips and only 1/12 had evidence of delayed epiphyseal union (Ortner and Hotz, 2005). The best preserved of the LB1 os coxae (LB1/7) has complete union of the acetabular and tri-radiate epiphyses, the preserved anterior section of iliac crest and ischial epiphyses, and the ilium is clearly not hypoplastic. Using modern human standards, which are probably not appropriate for small-bodied *H. floresiensis* (Migliano et al., 2007), the LB1 pelvic girdle is clearly from an adult who has completed her skeletal growth (Webb and Suchey, 1985; Cardoso, 2008). There is no evidence of retarded growth with delayed epiphyseal union into adult age comparable to human cretins (*H. sapiens*) in either LB1 or LB6 (Brown et al., 2004; Morwood et al., 2005).

### Stature

One of the most distinctive outcomes of the retarded linear growth in the majority of adult hypothyroid cretins is extremely short stature, relative to their normal siblings, unaffected parents and population averages [Swiss cretins: n23, X 131.4 cm, range 105–147, sd 11.097 (Finkbeiner, 1923; Ortner and Hotz, 2005); Uele cretins: n16, X 104.3, range 82–124, sd 11.17 (Bastenie et al., 1962)]. Obendorf et al. (2008) believe that the similarity in stature between LB1 *H. floresiensis* and ME cretins from Uele (Dumont et al., 1963), Idjwi (Delange, 1974) and Xinjiang (Ma et al., 1982) is an important indicator of the pathological status of LB1. Although endemic goitre is common in Flores (WHO et al., 2000), unlike Java (Goslings et al., 1977), endemic cretinism does not appear to have been present, or at least not recorded in World Health Organization surveys. Even if endemic cretinism had been recorded in Flores in the historic period, it would not necessarily be indicative of the frequency of this disease amongst late Pleistocene hominins with a different mode of subsistence or physiological response to environmental iodine levels (Cooper et al., 1993).

The LB1 *H. floresiensis* adult female skeleton has an estimated stature of 106 cm (Brown et al., 2004). Although diminutive, comparisons with the recovered isolated postcrania (LB6/3 left ulna, LB8/1 right tibia) suggest that LB1 was not the smallest adult hominin living at Liang Bua (Morwood et al., 2005; Larson et al., 2009; Jungers et al., 2009b). In the 1940s, before the distribution of thyroxine to treat the potential effects of low iodine levels on



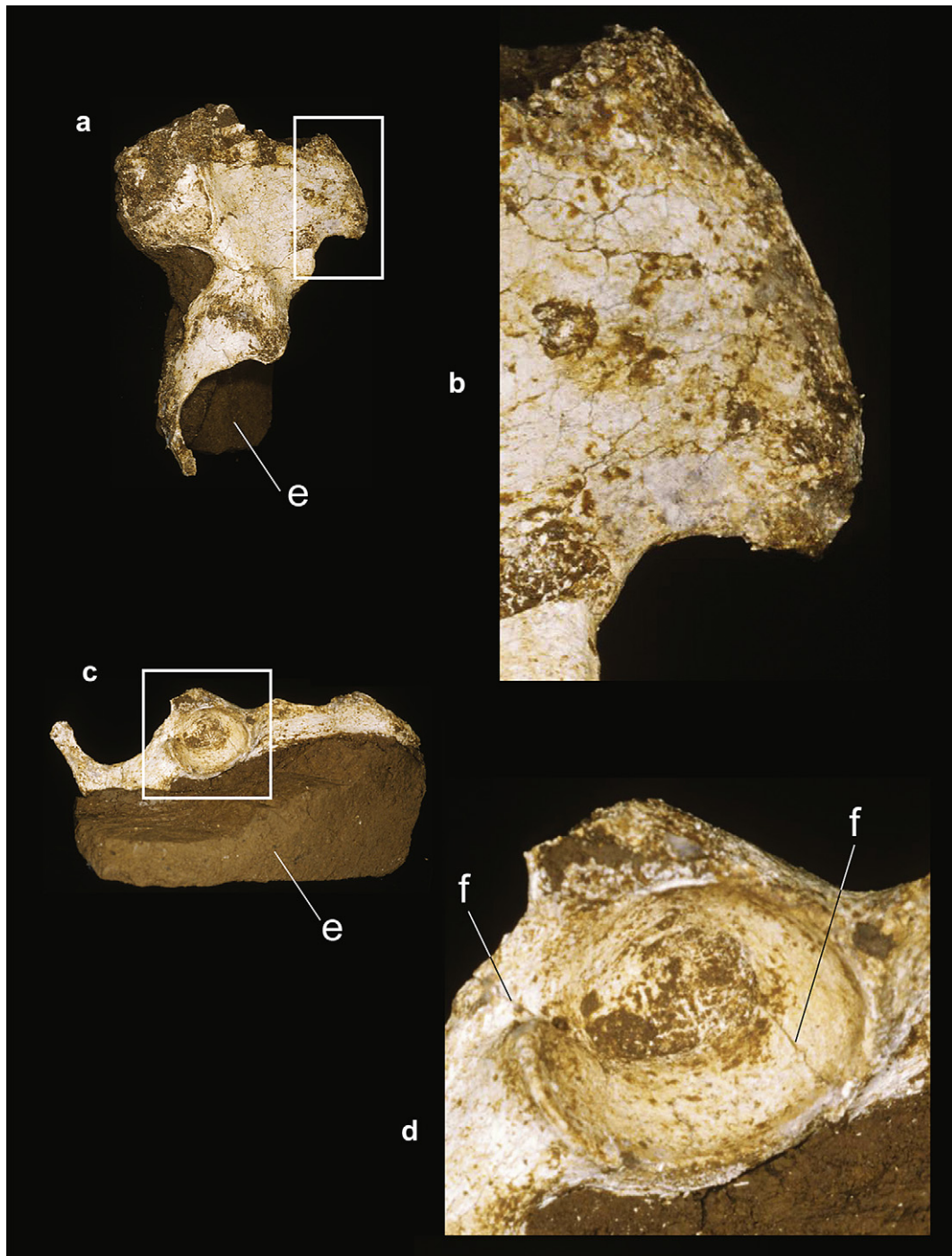
**Figure 3.** Comparison of *H. floresiensis* and *H. sapiens* crania. (a) Basal view of LB1, (b) 3D reconstruction of LB1 from CT data, with areas of post-mortem damage highlighted in green, (c) basal view of *H. sapiens* infant cranium enlarged to the same size as LB1, (d) external and internal views of the adult cretin cranium and mandible described by (Dolega, 1891), with identification of unfused occipital components, reproduced from Knaggs (1928). Note morphology of the mandibular symphysis, with unfused symphysis menti. (1 spheno-occipital synchondrosis, 2 basi-occipital, 3 anterior intra-occipital suture, 4 lateral occipital, 5 posterior intra-occipital suture, 6 posterolateral fontanelle, 7 squamous occipital). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

intellectual development and growth in the Lesser Sunda Islands, Keers (1948) completed an anthropometric survey of Flores that included Manggerai Province, the area surrounding Liang Bua. Keers survey of ten Manggerai villages recorded an average adult male height of 158 cm, with 89–95%  $\geq 150$  cm tall, and no record of anyone shorter than 130 cm. The early Holocene-Mesolithic skeletons from Liang Bua, Liang Toge, Liang Panas and Liang Momer on Flores also have skeletal dimensions and morphology within the normal human range of variation for this region (Verhoven, 1958; Heekeren, 1967, 1972; Jacob, 1967; Storm, 1995; van der Plas, 2007; PB Personal observation). For instance, the Liang Toge left

femora has a maximum length of 380 mm and Liang Momer 445 mm (Jacob, 1967), compared with 280 mm for LB1 (Brown et al., 2004; Jungers et al., 2009b). Contrary to the suggestions of Obendorf et al. (2008), there is currently no evidence of significantly retarded linear growth on Flores as a result of low iodine levels, or endemic cretinism.

#### Cranial and mandibular features

Radiographic and direct examination of cretin adult crania have highlighted a number of traits that may distinguish them from



**Figure 4.** The left os coxa of LB1/7 during removal from a block of sediment (e) in 2003. (a) Internal view, (b) detail of preserved section of anterior iliac crest, (c) anterior view, (d) detail of the acetabulum with (f) post-mortem cracks. This os coxa was subsequently badly damaged during transport to Gaja Mada University in 2004–2005, with the ilium and acetabulum broken into several fragments (Jungers et al., 2009b).

members of the same population who have been unaffected by iodine deficiency during growth (thyroid hypertrophy or hypotrophy) (Table 1). These include hypoplastic sinuses, very small mastoids, hypoplastic nasal bones, short but prognathic facial skeleton, open anterior fontanelle, abnormal bone development in the middle ear, and cranial vault bone that is described as either 'thick' or 'thin'. Some of these traits have been discussed by Obendorf et al. (2008), who claim that the formation of the nasal region, thickness of the cranial vault bone, a cranial index  $\geq 73$ , facial prognathism, absence of frontal sinuses, an open anterior

fontanelle, anatomy of the temporal region and size of the foramen magnum in LB1 are indicative of cretinism.

As noted, the LB1 cranium provides no support for their claim of a 'possibly' open anterior fontanelle. The opening observable in photographs is the result of post-mortem damage during excavation. As shown by detailed photographs of the face of LB1, including mid-sagittal CT sections, that have been available since 2004 (Brown et al., 2004), there is no support for the conjecture that "reduced cartilaginous skull growth produces depressed nasal bridge...and seems to be present in LB1" (Obendorf et al., 2008:

1288). The entire nasal region of LB1, to a depth of ~10 mm at glabella, was accidentally removed by an excavation trowel (Figs. 1 and 2), with the damaged area extending downwards to the alveoli of the maxillary incisors, which were subsequently not recovered from the excavation. The 'nasal bridge' is not preserved and it is not possible to accurately reconstruct the morphology of glabella, depth of the nasal root, or shape of the nasal bones from what remains (Figs. 1 and 2). The available evidence provides no support for Obendorf's et al. (2008) conjecture about nasal anatomy in LB1 *H. floresiensis*.

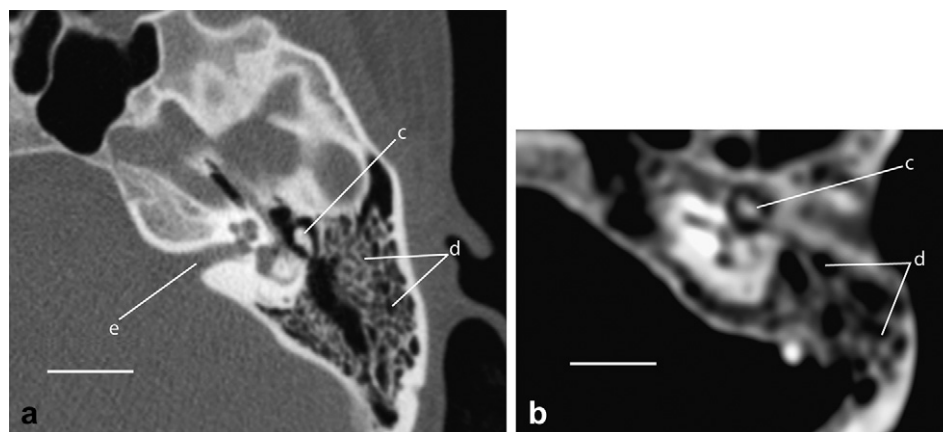
Hypoplastic frontal sinuses have been recorded in lateral radiographs of some cretins (Jackson, 1952b) and all of the paranasal sinuses (frontal, sphenoid and maxillary) may also fail to develop (Middlemass, 1959; Bateson and Chandler, 1965; Delange, 1974; Borg et al., 1975). Without citing the source of their information for LB1, Obendorf et al. (2008) state that "frontal sinuses are absent in European sporadic cretins ..., African ME cretins...DC and LB1" (:1288). This statement, while apparently true for some cretins, is not true for LB1. The same accident that removed the LB1 nasal region also removed the left supraorbital and left frontal sinus. However, the right frontal sinus is preserved and is visible in CT scans and radiographs, as are the sphenoid and maxillary sinuses (Figs. 1 and 2). Therefore, Obendorf et al. (2008) claim that LB1 lacked frontal sinuses is incorrect. In addition to hypoplastic sinuses, cretin crania are often distinguished by hypoplastic mastoids, which are acellular (Middlemass, 1959; Delange, 1974; Borg et al., 1975). The right mastoid process of LB1 is well preserved, and is structurally robust with a prominent mastoid crest (Brown et al., 2004). The left mastoid process was damaged post-mortem, however, CT scans of both mastoid regions indicate that they are highly pneumatized (Fig. 5).

More contentiously, Koenig and Neiger (1972) and Nager (1933) associate the hearing deficits in neurological cretins, at least in part, with abnormal development of the petro-tympanic region, while others have suggested that the sensorineuronal deafness found in many neurological cretins is of primarily neural origin (Comer and McConnell, 2010). The auditory canals and auditory ossicles are preserved in LB1 but the ossicles have not been removed, as they are held in place by sediment and hardened preservative. Unfortunately, CT resolution is too low to provide evidence of any deformation of the ossicles, or fixation of the stapes and distortion of the round and oval windows described by Koenig and Neiger (1972) and Nager (1933) (Fig. 5).

For the most part, clinical descriptions of skeletal and dental attributes of cretins are consistent, with minimal disagreement. An

exception is the thickness of cranial vault bone displayed in lateral radiographs of the living, or sectioned crania after autopsy (Benda, 1947; Jackson, 1952b; Middlemass, 1959; Borg et al., 1975). Benda (1947) describing cretin crania as thick and heavily ossified, but Middlemass (1959) found that only 2/32 of the cretin crania in his study were thicker than normal. To some extent this may be a reflection of observer experience, combined with the fact that cranial vault thickness in cretins has never been quantified. In modern humans, there is a regional, sex and age-based variation in cranial vault bone thickness (Brown, 1987, 1994; Gauld, 1996), haemopoetic disorders can influence cranial vault thickness (CVT) due to the role of the diploë in haematopoiesis (Patel et al., 2010), and CVT also appears to have some taxonomic valence within the hominins, particularly in relation to the basi-cranial and frontal reinforcement in *H. erectus* (Weidenreich, 1939; Brown, 1994; Lieberman, 1996; Strait et al., 2010). Apart from the anterior fontanelle, which may have extremely thin bone in adults, CVT in cretins may display the wide range of variation evident in normal *H. sapiens* (Adeloye et al., 1975; Brown, 1994; Lieberman, 1996). Without providing supporting evidence, or defining 'thick', Obendorf et al. (2008: 1288) state that "[t]he vault is thick in DC (Dolega's cretin (Dolega, 1891)) and LB1". CVT dimensions for LB1 have not previously been published and it would have been more relevant for claims of cretinism if LB1 had thin cranial vault bone in the area once occupied by the anterior fontanel or thin diploë throughout the vault, but it does not (Fig. 1). Direct measurement of CVT in LB1 using the procedures outlined in Brown (1994) indicates dimensions in the range of *H. sapiens* and *H. erectus* (Table 3). The frontal bone of LB1 is slightly thicker than the modern human (*H. sapiens*) average, but this has never been reported as being diagnostic of cretins. CVT in LB1 may be thick in relation to the size of the vault, but this is not an issue for a diagnosis of cretinism and may prove to be a species characteristic.

Obendorf et al. (2008) assert that "forward projecting jaws and teeth are evident in DC (Dolega's cretin (Dolega, 1891)) and HC (Hill's cretin (Hill, 1936)), as well as in ME cretins...sporadic cretins and LB1 and LB6" (:1288) (Fig. 7). The teeth and pattern of dental malocclusion common in many cretins is indeed distinctive, but not in the manner inferred by Obendorf et al. (2008), and it would be difficult to find a greater contrast with LB1 and LB6. Cretins may retain a mixed, or largely deciduous dentition into adulthood, have an infantile orofacial skeleton, often with marked subnasal prognathism, an open anterior bite and undershot jaw, anteriorly inclined and maloccluded maxillary incisor teeth, and a hypoplastic mandible (Figs. 5 and 6). To a great extent, malocclusion and



**Figure 5.** Transverse CT scan slices through the mastoid and auditory regions of *H. sapiens* and *H. floresiensis*. (a) Adult *H. sapiens* unaffected by iodine deficiency disease, (b) LB1 *H. floresiensis*, (c) auditory ossicles, (d) mastoid air cells, (e) acoustic meatus.

**Table 3**  
Cranial vault thickness in *H. sapiens*, *H. erectus* and LB1 *H. floresiensis*.

Population	Measurement locations						
		1	2	3	4	5	6
Holocene Australian <sup>b</sup>	n	84	86	77	77	86	86
	X	7.9	7.7	8.2 <sup>a</sup>	6.5 <sup>a</sup>	7.4 <sup>a</sup>	13.4 <sup>a</sup>
	sd	1.48	1.61	1.42	1.45	1.91	2.96
<i>Homo erectus</i> <sup>b</sup>	n	10	9	5	4	9	8
	X	8.5	8.3	11.1	13.3	11.3	16.4
	sd	2.38	1.22	1.87	1.44	2.89	3.23
LB1		~9.3	~8.0	7.5	5.8	9.6	13.8

1. mid-frontal squama, 2. bregma, 3. vertex, 4. parietal eminence, 5. asterion, 6. external occipital protuberance.

<sup>a</sup> Mean value significantly less than *H. erectus* mean,  $p < 0.05$ .

<sup>b</sup> Data from Brown (1994).

forward projection of the maxillary incisors results from pressure (thrusting) from typically large, broad and often protruding tongues, which are under more limited neural control than in unaffected members of the population (Gershater, 1972). The LB1 facial skeleton was damaged during excavation and the maxillary incisors were lost. However, the lingual margins of some of the maxillary incisor alveoli remain and together with the occluded mandible, maxillary canines and inferior nasal margin, allow for the reconstruction of the subnasal region (Fig. 6). The edge-to-edge wear on the LB1 and LB6 mandibular incisors clearly indicates that there was not an overbite or any substantial anterior malocclusion in either hominin (Brown et al., 2004; Morwood et al., 2005; Brown and Maeda, 2009). LB1 had the full facial prognathism, not just subnasal prognathism, consistent with its relatively large teeth and palate, and a deep maxillary alveolar segment to accommodate the large and robust anterior tooth roots. This morphology is inconsistent with the flattened mid-face and subnasal prognathism in cretins (Figs. 4 and 5).

Both radiographic and direct examination of cretin mandibles indicate that they are often infantile in development, hypoplastic, with unfused symphyses, minimal chin projection, high mandibular angles and with reduced ramus height (Figs. 3 and 6). Anterior symphyseal morphology is most similar to human infants prior to the eruption of the permanent dentition. Viewed laterally, the symphysis is relatively vertical with minimal height, little incurvature and the mental tuberosity, while present, is not always particularly prominent. However, the distinctive anterior and posterior symphyseal morphology of *H. sapiens*, including a midline keel, mental tuberosity and lateral tubercles, incurvature and fossa, and posterior symphysis without continuous superior and inferior tori and deep genioglossal fossa (Schwartz and Tattersall, 2000; Brown and Maeda, 2009), are present in human cretins (Dolega, 1891; Knaggs, 1928; Hill, 1936; Middlemass, 1959; Borg et al., 1975; Israel et al., 1983; Ortner and Hotz, 2005). For instance, Knaggs (1928: 379) provides a photograph of the 28 year-old cretin described by Dolega (1891), which has, contrary to claims by Obendorf et al. (2008), all of the morphological attributes of a modern *H. sapiens* mandibular symphysis combined with the incompletely fused symphysis menti common in cretins (Fig. 3d).

The LB1 and LB6 *H. floresiensis* mandibles have been described in detail, with metric and morphological comparisons distinguishing them from large and small-bodied *H. sapiens* and highlighting symplesiomorphic characters shared with *Australopithecus* and early *Homo* (Brown and Maeda, 2009). Both mandibles have a posteriorly inclined symphyseal axis, no mental tuberosity, lateral tubercles, midline keel, or incurvature, and with continuous superior and inferior transverse tori on the posterior symphyseal surface. Rather than having the small and infantile chin evident in

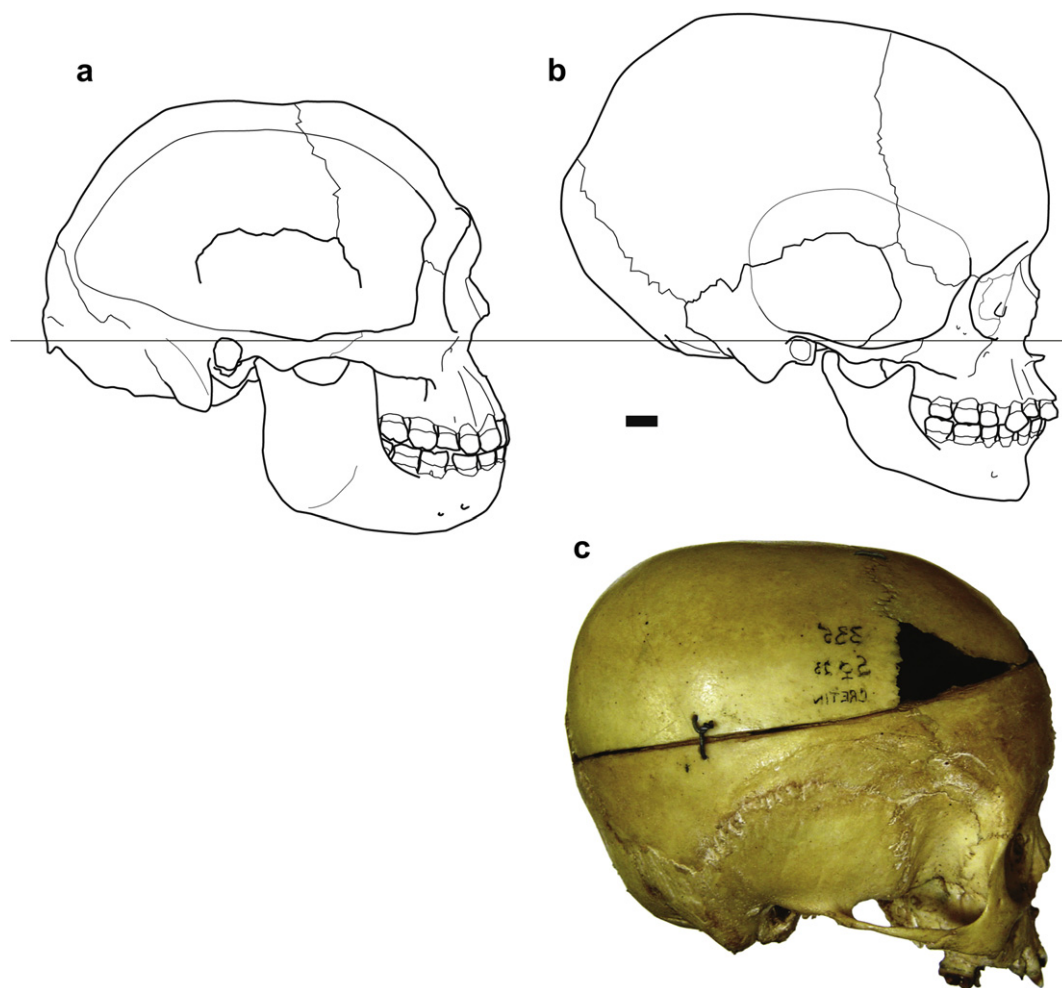
some cretins, LB1 and LB6 do not have a chin. Corpus and symphyseal dimensions are robust relative to estimated body mass, the mandibles are certainly not hypoplastic, and in marked contrast to cretins, the rami are robust, broad and vertical, with a large area of attachment for the masticatory muscles (Brown and Maeda, 2009) (Fig. 6). Multivariate comparisons of symphyseal shape have also emphasized morphological similarities with *Australopithecus afarensis* and separated the Liang Bua mandibles from *H. erectus* and *H. sapiens*, including modern humans from the same geographic region (Brown and Maeda, 2009).

Obendorf et al. (2008), support the claims of Jacob et al. (2006) (see also Richards, 2006), who argued, based on photographs of living people, that modern humans on Flores have a receding mandibular symphysis and that 'racial factors' might contribute to the observable morphology in LB1 and LB6. As discussed by Brown and Maeda (2009), external soft-tissue contours of the lower face, particularly of people who have prognathic faces and prominent lips, do not provide an accurate assessment of underlying skeletal morphology. Both skeletal remains and lateral radiographs of humans living in the Southeast Asian and Australasian regions indicate that while the mental tuberosity is sometimes not pronounced and the symphysis more vertical relative to the occlusal plane, that the characteristic symphyseal traits of *H. sapiens* are always present (Dubois, 1920; Murphy, 1957; Jacob, 1964, 1967; Larnach and Macintosh, 1971; Macintosh, 1978; Brown, 1989; Storm, 1995; Bullbeck, 2005; Brown and Maeda, 2009; PB Personal observation). The size, morphology and robusticity of the LB1 and LB6 mandibles are outside the range of variation in *H. sapiens* and have nothing in common with the mandibular morphology in human cretins, contrary to Obendorf et al. (2008).

#### Mandibular premolar morphology and dental development

A common feature of the delayed development in neurological and myxedematous cretins is that adults often retain deciduous teeth with some permanent teeth failing to erupt or develop fully (Garn et al., 1965; Israel et al., 1969; Borg et al., 1975; Hirayama et al., 2003; Reuland-Bosma et al., 2010). Obendorf et al. (2008) discuss this in relation to the crown and root morphology of the P<sub>3s</sub> of LB1 and LB6 and conclude that rather than permanent teeth, they are deciduous molars (dm<sub>1s</sub>) that have been retained due to the absence of the permanent premolars that would normally displace them. This conclusion was based on the author's assessment that "captured images from X-ray scans presented in *The Mystery of the Human Hobbit* (BBC Horizon, 2005) clearly show a buccogingival ridge sloping to the buccal surface of the mesial root, as in human lower first deciduous molars (dm<sub>1s</sub>) and unlike P<sub>3s</sub> that are symmetrical" (Obendorf et al., 2008: 1289), as well as their understanding of the significance of other anatomical features. As detailed below, the original radiographs that I used in the BBC Horizon documentary do not display the feature described by Obendorf et al. (2008) in the LB1 premolars.

The Liang Bua *H. floresiensis* mandibular dentitions, including the P<sub>3s</sub> from LB1, LB2 and LB6 have been described in detail (Brown et al., 2004; Brown and Maeda, 2009). Computed tomography, radiography and direct examination of the mandibles and maxillae of LB1 indicate that all of the permanent teeth had erupted, with the right P<sub>4</sub> of LB1 lost during life and the right maxillary M<sup>3</sup> possibly represented by a tiny odontome within the alveolar bone. The P<sub>3s</sub> of LB1 and LB6 share asymmetrical and mesiodistally elongated crowns with a broad distal talonid and dominant buccal cusp (paracone) (Fig. 8). In occlusal view, the crowns have a triangular outline and slightly oblique orientation relative to the P<sub>4</sub>-M<sub>3</sub> axis. The P<sub>3s</sub> had a small metacone and distinct anterior and



**Figure 6.** Lateral views of *H. floresiensis* and *H. sapiens* crania. (a) LB1 *H. floresiensis*, (b) Swiss *H. sapiens* cretin, (c) Sri Lankan *H. sapiens* cretin described by (Hill, 1936). (a) This is a reconstruction based on the best-preserved remaining anatomy from the left and right sides of LB1. The morphology of the subnasal region and position of the maxillary incisors is inferred from remaining sections of incisor alveolus, and the edge-to-edge wear on the occluded mandibular incisor teeth. The morphology of glabella and fronto-nasal region is more problematic. (b) Redrawn and reversed from (Ortner and Hotz, 2005), with the mandible occluded. (c) Left side reversed.

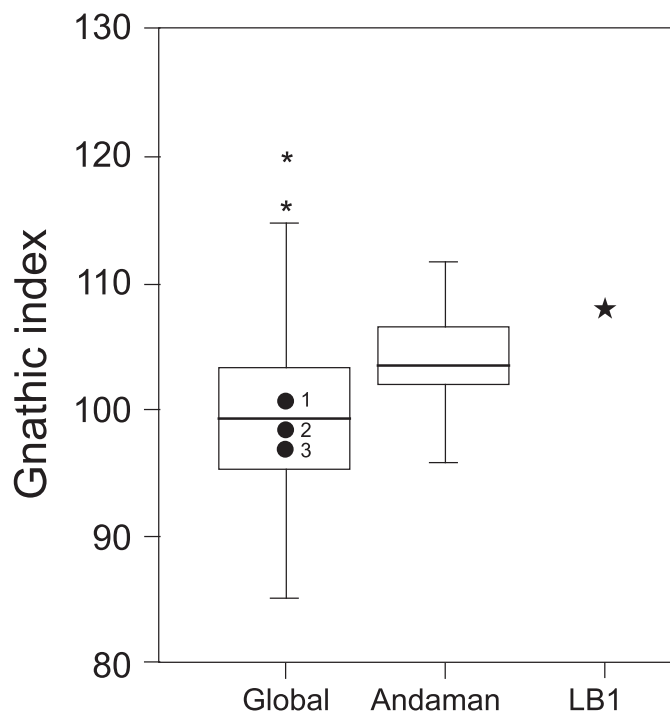
posterior fovea. Both LB1 and LB6 have P<sub>3s</sub> with bifurcated roots, with the MB + D pattern (Wood et al., 1988). P<sub>3s</sub> with this crown and root morphology are common in early australopiths, changing to a derived, molarized, bicuspid and symmetrical P<sub>3</sub> in later australopiths and early members of the genus *Homo* (Abbott, 1984; Wood et al., 1988). The morphology of these teeth contrasts with the derived condition in *H. sapiens* and most *H. erectus*, where the P<sub>3</sub> and P<sub>4</sub> are bicuspid, have occlusal outlines that are symmetrical and oval-shaped, and usually have a single, conical root (Wheeler, 1974; Abbott, 1984; Wood et al., 1988; Shields, 2005; Brown and Maeda, 2009).

The crown and root morphology of the *H. floresiensis* P<sub>3s</sub> are distinct from that in the deciduous M<sub>1s</sub> of *H. sapiens* and it would be difficult to confuse one for the other. Deciduous M<sub>1s</sub> have a deep central developmental groove, a prominent mesiolingual cusp, as well as mesiobuccal, distobuccal and distolingual cusps, and do not have a talonid buccal cusp (Fig. 8). These cusps and developmental grooves are not present in the LB1, LB2 and LB6 P<sub>3s</sub>, or the P<sub>3s</sub> of fossil hominins like LH4 (*A. afarensis*). Although the deciduous M<sub>1s</sub> in *H. sapiens* usually have a bifurcated root, the dimensions and shape of the root structure is different from that in the *H. floresiensis* P<sub>3s</sub>. In the deciduous teeth, the roots are more slender and flare out more near the cervix. The mesial root is the most substantial and usually has a developmental depression extending the length of the

mesial side. The distal root is rounder and shorter and tapers more apically (Wheeler, 1974). This contrasts with the P<sub>3s</sub> in LB1 and LB6, and early australopiths, where the roots are more robust, not widely divergent, the distal root is broad with developmental depression extending down the mesial and distal surfaces, and the mesial root is elongated and conical in cross section (Fig. 8). The degree of occlusal and interproximal wear in the LB1 and LB6 mandibular teeth is also consistent with the teeth developing and reaching occlusion in the normal sequence, without the extreme occlusal wear that would be evident on a retained, relatively thinly enamelled deciduous M<sub>1s</sub>. It is, thus, clear that the LB1 and LB6 P<sub>3s</sub> are not retained deciduous teeth and provide no support for delayed development or endemic cretinism in these hominins, contrary to Obendorf et al. (2008).

#### Brain comparison and measurement of the pituitary fossa (length of the sella turcica)

Lateral radiographs and direct observation of sectioned crania indicate that some cretins have greatly inflated (ballooned) sella turcica associated with an enlarged pituitary gland (Middlemass, 1959; Ferraris et al., 1967; Ortner and Hotz, 2005). Using “expanded images of the LB1 endocast (fig. S2E in Falk et al., 2005a)”, Obendorf et al. (2008: 1288) measured the “antero-



**Figure 7.** Box plots of the distribution of the gnathic index (basion-nasion\*100/basion-prosthion) in global *H. sapiens*, small-bodied *H. sapiens* (Andaman Islands) and LB1 *H. floresiensis*, with individual values for Swiss normal average (1) (Ortner and Hotz, 2005), their Swiss Cretin average (2) (Ortner and Hotz, 2005) and Sri Lankan cretin (3) (Hill, 1936). The gnathic index for LB1 is based on the reconstruction in Fig. 6, as nasion and prosthion are not preserved in the original.

posterior length of the pituitary fossa and whole brain of LB1". From this information, they estimated that the LB1 pituitary fossa had an antero-posterior dimension of 12.9 mm, and that this was consistent with data from He (1984) on the significantly enlarged pituitary fossa in Chinese ME cretins (Chinese ME cretins  $14.0 \pm 3.1$  mm,  $n = 58$ ), compared with a small sample of normal people (mean  $8.6 \pm 1.2$  mm,  $n = 5$ ). However, when the LB1 endocast is photographed in basal view, the maximum length of the endocast and the antero-posterior length of the pituitary fossa are in different image planes with respect to the focal plane and lens of the camera. Scaling your measurements with a known whole brain length will not allow one to record accurate measurements of a three-dimensional object in another plane, when compressed onto a two-dimensional surface (Gavan et al., 1952), which is a fairly common measurement error.

In 2003, the endocranial surface of LB1 was cleaned by the author and sediment removed from the brain case before the neurocranium was reassembled and attached to the facial skeleton (Brown et al., 2004). There was post-mortem damage to some of the finer bone of the sphenoids, including the anterior and posterior clinoid processes, tuberculum and dorsum sellae, and lesser wing of the sphenoids. However, the base of the hypophyseal fossa is preserved, as are the anterior and posterior sections where the fossa rises to the tuberculum sellae anteriorly and dorsum sellae posteriorly. Using a median sagittal section CT scan and a sectioned stereolithographic model, it is possible to estimate the length of the sella turcica in LB1 at  $\sim 8.5$  mm (Fig. 9b). Contrary to Obendorf et al. (2008), this is within the normal human range [Danish male  $n = 35$ ,  $X = 8.9$  mm, sd 0.9, range 7.4–10.7 mm, Danish female  $n = 37$ ,  $X = 8.4$  mm, sd 1.6, range 5.00–11.2 mm (Axelsson et al., 2004)] and consistent with the small-body and brain size of LB1.

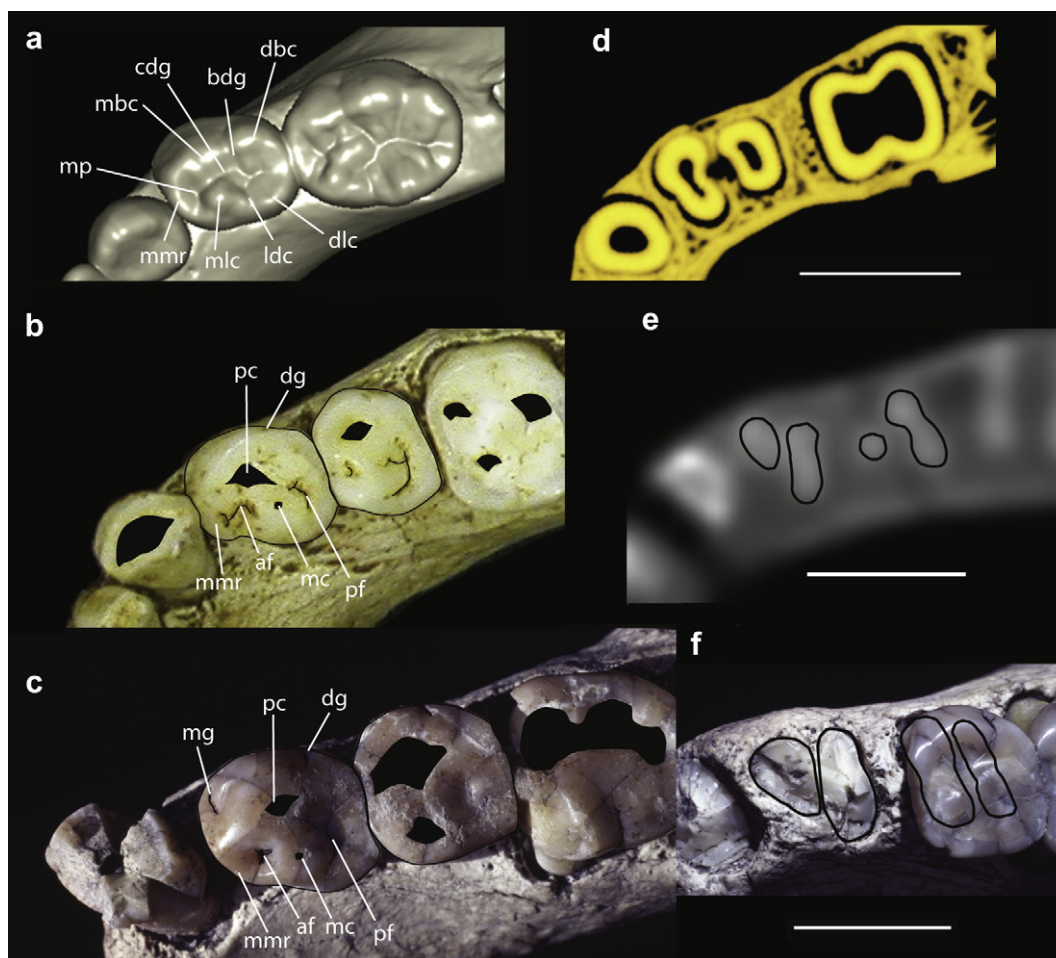
Obendorf et al. (2008) claim that "congenital hypothyroidism can reduce brain size by approximately 50%" (:1290) and that LB1's

brain size is "consistent with brain sizes reported in small brained populations and undernourished cretins" (1294). However, an example of an undernourished cretin with a brain the size of LB1 is not provided. Using a variety of procedures (mustard seeds, volumetric displacement, virtual reconstruction), the endocranial volume of LB1 has been estimated to range between 380 and 417 ml (Brown et al., 2004; Falk et al., 2005a; Holloway et al., 2006). Endocranial volume provides an overestimate of brain volume due to the mass occupied by non-neural tissues endocranially (brain volume =  $18.575 + \text{endocranial volume} * 0.769$  SE 32.949, calculated from data in Blinkov and Glezer, 1968). The brain volume for LB1 is therefore in the range 310–339 ml, with a weight of 321–351 g [specific gravity of the brain 1.036 (Gompertz, 1902; Lescot et al., 2005)]. This is less than the mean reported for human infants at birth ( $X$  378.2 range 239–506 g, Blinkov and Glezer, 1968) and approximately 25% of the average brain weight for normal adult Europeans and Cretins (Table 4).

Neurological cretins are characterized by a combination of mental deficiency, deaf-mutism, and spastic-motor disorders that result from impaired cerebral cortex association areas and defective cochlear and basal ganglia regions (DeLong et al., 1985). However, radiographic, computed tomography and pathological studies have recorded brain weights, volumes and cross sections that are in the normal range of human variation (Finkbeiner, 1923; Chen, 1988; Boyages et al., 1988a; Ruiz-Marcos, 1989; Ma et al., 1993). Myxedematous cretins usually have less severe intellectual impairment, head dimensions that are large relative to their dwarfed stature, and brain weights that are also in the normal human range (Delange and Ermans, 1971; Delange et al., 1972a; Boyages et al., 1988a; van den Broeck et al., 1993; Obendorf et al., 2008; Supplementary online tables and figures) (Fig. 10). Data on cretin brain mass are consistent with the results of animal models (rats, sheep and marmosets) that examined the impact of severely iodine deficient diets on foetal brain development (Potter et al., 1982, 1984; Li et al., 1986; Mano et al., 1987). There were indications of delayed brain maturation, increased neuronal density in the cerebral hemispheres, and cellular changes in the cerebellum, but only a slight reduction in body weight and brain weight in utero. For instance, iodine deficient newborn marmosets (*Callithrix jacchus*) had body weights reduced by 4.6% and brain weights 3.4% (Mano et al., 1987). Contrary to claims by Obendorf et al. (2008), a dramatic reduction in brain mass (>60%) has never featured in the clinical literature on human cretinism, and the small size of LB1's brain does not support their speculation about the pathological status of LB1.

#### Postcranial skeletal proportions and robusticity

Proportional differences largely based on external physical appearance and growth-related radiographs, between cretins and normal individuals are described with some consistency in the clinical, as well as in most of the anthropological literature (Dolega, 1891; Finkbeiner, 1923; Knaggs, 1928; Hill, 1936; Wilkins, 1941; Benda, 1947; Middlemass, 1959; Stanbury, 1973; Borg et al., 1975; Ortner and Hotz, 2005). Apart from short stature, most notably, hands and feet are described as short, broad and childlike, with characteristic short and broad metacarpals, and the carpal bones as extremely small, and often with unfused epiphyses in adults. The arms and legs are short relative to the length of the trunk, or vertebral column, or just referred to as short (Fig. 10). Skeletal proportions are considered to be infantile, long bone shafts slender with poorly developed areas of muscle attachment, and deformities associated with delayed growth and epiphyseal dysgenesis are common, particularly in the proximal femur (coxa vera, coxa plana, coxa magna). Most of the clinical literature resulting from



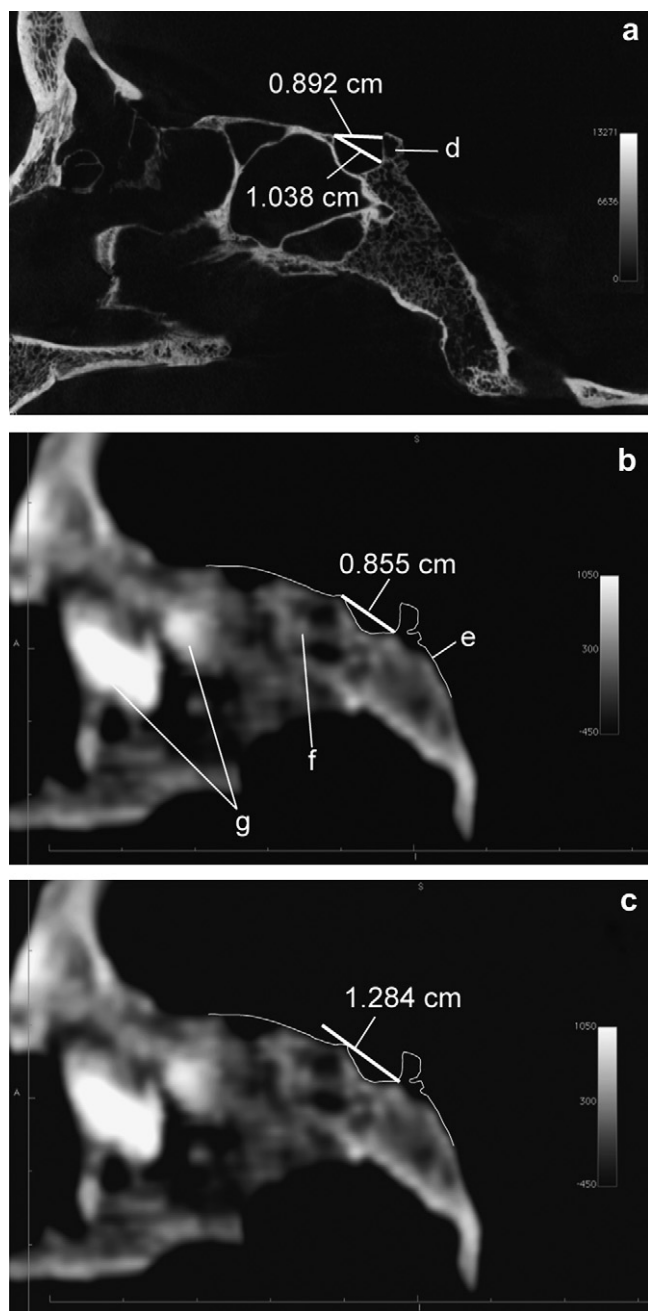
**Figure 8.** Comparative crown and root morphology of a deciduous first molar in (a) *H. sapiens* with (b) a permanent  $P_3$  in LB6 *H. floresiensis* and (c) a permanent  $P_3$  in LH4 *A. afarensis*. (a) Micro-CT 3D reconstruction, (d) micro-CT transverse section of (a) showing a cross section of the canine,  $dm_1$  and  $dm_2$  tooth roots. (e) Low resolution CT transverse section through the LB6 mandible showing the canine, premolar and first molar root cross sections, with the roots outlined for  $P_3$  and  $P_4$ . The CT scan was taken after the mandibular symphysis was damaged in 2004–2005 (Brown and Maeda, 2009). (f) Left side of the LH4 mandible reversed with exposed broken root sections for the canine and  $P_3$ . Exposed sections of root on the buccal and lingual margins of the LH4  $P_4$  suggest that it has a double root, similar to an *H. sapiens* mandibular molar. Photographs of LH4 courtesy Tim White. Abbreviations for (a): bdg = buccal developmental groove, cdg = central developmental groove, dbc = distobuccal cusp, dlc = distolingual cusp, ldg = lingual developmental groove, mbc = mesiobuccal cusp, mlc = mesiolingual cusp, mmr = mesial marginal ridge, mp = mesial pit) (b and c): pc = paracone, dg = distal groove, mmr = mesial marginal ridge, af = anterior fossa pf = posterior fossa, mg = mesial groove).

radiographs (predominantly hand-wrist, lateral head and pelvic girdle) associated with growth studies focus on epiphyseal union and dental development, with little attempt at recording skeletal dimensions.

By far the most detailed examination of cretin skeletons is by Finkbeiner (1923), who compared 19 adult skeletons, the majority with detailed case histories, from collections in Bern and Graz, with those of achondroplastic dwarfs, pygmies, rachitic and normal humans, as well as available Aurignacian and Neanderthal skeletons. In contrast to the more recent clinical literature on cretinism, Finkbeiner (1923) used standardised measurement procedures (Martin, 1914) to quantify and compare skeletal dimensions, proportions and indicators of torsion and robusticity. Finkbeiner's cretins were extremely short ( $n = 11$ ,  $X = 136.6$  cm,  $sd 7.5$ , range 123.5–147 cm), with short arms and legs, and the size relationships, for instance intermembral and brachial indices, mostly fall within the normal human range of variation, as does femur mid-shaft robusticity (Table 5, Figs. 11 and 12). An exception is the pilaster index, where the distinctive gait found in many cretins, is associated with increased antero-posterior curvature of the femur shaft, alterations in femur neck morphology and orientation, and a higher

femoral torsion angle (Finkbeiner, 1923). In cretins, elevated reinforcement of the posterior femur shaft seems to be the result of a delayed and pathological gait pattern during growth, resulting in abnormal mechanical loading of the shaft and articular surfaces, and a need to increase torsional rigidity and straighten the posterior femur shaft (Carriero et al., 2009; Cowgill et al., 2010). Finkbeiner's cretins were also distinguished by a relatively high intermembral index (relatively long arms), low average crural index (relatively short tibia), and low average humeral torsion angle (Table 5). However, all authors who have examined collections of cretin skeletons note the great extent of morphological variation, for instance in the projection of the pilaster (Table 5, Fig. 12), and some of the classic developmental indicators in the proximal femur may be less common than indicated in clinical studies (Ortner and Hotz, 2005). As Ortner and Hotz (2005) point out, this provides a major challenge for the unequivocal identification of cretinism in archeologically derived human skeletons.

Obendorf et al. (2008) argue on the one hand, based on a study of dog cretins, that cretinism should be accompanied by a reduced growth in limb bone lengths, more than widths, stimulating increased robusticity, but on the other hand that DC and LB1 have



**Figure 9.** Median sagittal section CT slices of the crania of (a) normal *H. sapiens* and (b) LB1 *H. floresiensis*, with antero-posterior dimensions of the sella turcica, and measurements of the pituitary fossa. In LB1 post-mortem damage includes the loss of the posterior clinoid process and damage to the edge of the anterior clinoid and prevents measurement of the standard antero-posterior dimension. (c) Post-mortem damage to the fronto-facial region of LB1. Based on digital measurements of the sella turcica in OsiriX (OsiriX imaging software), and direct measurement from sectioned stereolithographic models, it would not have been possible for the sella turcica in LB1 to have the 12–13 mm a–p dimension claimed by Obendorf et al. (2008) (c), (d) posterior clinoid process, (e) possible sagittal contour of sella turcica during life, (f) sphenoidal sinus partly full of sediment, (g) sediment in nasal and maxillary region.

long bones with poorly marked muscle scars, which is inconsistent with “true robusticity”. Finkbeiner’s (1923) cretins have similar levels of femoral robusticity to normal *H. sapiens*, but significantly greater humeral robusticity (Table 5, Fig. 12). However, LB1 has extremely high levels of robusticity for all limb bones, but without the prominent femoral pilaster present in cretins and most *H. sapiens* (Brown et al., 2004; Larson et al., 2009; Jungers et al.,

**Table 4**

Brain weights in Swiss cretins and unaffected Europeans (g).

Group	n	X	sd	Min	Max
Cretin <sup>c</sup>	22	1275.1 <sup>a</sup>	153.2	1050	1505
Bavarian male <sup>d</sup>	529	1363.1 <sup>b</sup>	110.6	1000	1650
Bavarian female <sup>d</sup>	323	1220.3	101.7	850	1550

<sup>a</sup> Significantly greater than Bavarian female mean,  $p > 0.01$ .

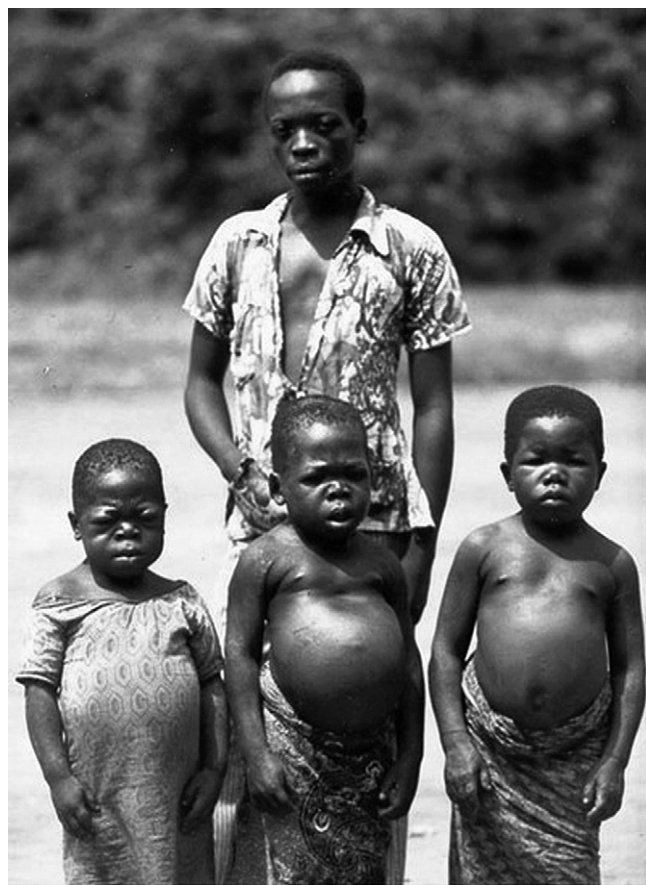
<sup>b</sup> Significantly greater than Cretin mean,  $p > 0.005$ .

<sup>c</sup> Cretin (Finkbeiner, 1923; Obendorf et al., 2008).

<sup>d</sup> Bavarian (Pearl, 1905).

2009b). Obendorf et al.’s (2008) claims about smooth limb bone shafts, without rugose areas of muscle insertion in LB1 are exaggerated, and are irrelevant to issues of skeletal robusticity, pathology and behaviour. This has been discussed in detail by Jungers et al. (2009b), who describe areas of muscle insertion in the LB1 femora, and point out that a modestly developed linea aspera, as seen in LB1, Neanderthals (Trinkaus, 1983) and A.L. 288-1 *A. afarensis* (Johanson et al., 1982), does not imply anything about muscularity and activity levels.

Based on Schinz et al. (1952), Obendorf et al. (2008) argue that human cretins have long arms relative to legs. They believe that this is the result of greater reduction in the length of weight bearing legs rather than in non-weight bearing arms. Without giving details, Obendorf and colleagues point out that humerofemoral index in LB1 has been “estimated to be 87”, and is therefore well



**Figure 10.** Three young women with myxedematous endemic cretinism (ME) in the Democratic Republic of Congo. The women, aged 15–20 years, with “severe long-standing hypothyroidism dwarfism, retarded sexual development, puffy features, dry skin and hair and severe mental retardation” stand in front of an unaffected adult man (Eastman and Zimmerman, 2009: Fig. 5). Note proportions of heads, arms and hands.

**Table 5**  
Descriptive statistics for the postcranial dimensions and indices in the *H. sapiens* global and cretin samples, and LB1 *H. floresiensis*.

Dimension	Groups	N	X	sd	SE
Femur length	1.00	828	429.5 <sup>a</sup>	30.5	1.06
	2.00	17	356.5	33.4	8.11
	LB1		281		
Tibia length	1.00	165	344.5 <sup>a</sup>	26.2	2.04
	2.00	9	289.2	32.2	10.75
	LB1		235–240		
Humerus length	1.00	778	308.8 <sup>a</sup>	23.3	0.83
	2.00	17	257.2	26.2	6.36
	LB1		243		
Radius length <sup>a</sup>	1.00	155	224.8 <sup>a</sup>	19.0	1.52
	2.00	9	196.2	23.2	7.38
	LB1		–		
Ulna length	1.00	152	240.8 <sup>a</sup>	19.6	1.59
	2.00	9	213.0	23.0	7.69
	LB1		205		
Intermembral index <sup>b</sup>	1.00	129	68.1	2.1	0.18
	2.00	6	69.7	1.4	0.59
	LB1		–		
Humerofemoral index	1.00	732	71.9	2.1	0.07
	2.00	16	71.9	2.9	0.72
	LB1		86.4		
Brachial index	1.00	146	75.5	3.8	0.31
	2.00	8	74.6	3.2	1.13
	LB1		78.1		
Cruval index	1.00	159	82.0 <sup>a</sup>	2.2	0.17
	2.00	8	79.2	1.6	0.59
	LB1		83.6		
Radiofemoral index	1.00	150	53.4	2.7	0.22
	2.00	8	53.2	1.7	0.60
	LB1		–		
Ulna intermembral index <sup>c</sup>	1.00	131	70.4	2.1	0.18
	2.00	6	72.2	1.3	0.55
	LB1		86.8		
Ulnahumeral index	1.00	146	81.3	3.9	0.33
	2.00	8	81.0	3.1	0.47
	LB1		84.3		
Ulnafemoral index	1.00	148	57.4	2.9	0.23
	2.00	8	57.8	1.3	0.47
	LB1		72.9		
Pilaster index	1.00	844	108.2	10.1	0.34
	2.00	16	115.7 <sup>a</sup>	20.5	5.12
	LB1		90.9		
Femoral robusticity index	1.00	175	19.3	1.2	0.09
	2.00	16	19.6	1.6	0.41
	LB1		23.4		
Femoral breadth index	1.00	812	5.9	0.5	0.01
	2.00	16	5.8	0.5	0.14
	LB1		7.8		
Humeral robusticity index	1.00	233	19.8	2.1	0.14
	2.00	16	24.4 <sup>a</sup>	2.33	0.58
	LB1		26.7		
Humeral torsion angle <sup>o</sup>	1.00	96	139.8 <sup>a</sup>	10.4	1.06
	2.00	17	111.8	12.1	2.95
	LB1		110–120 <sup>e</sup>		
Femoral torsion angle <sup>e-d</sup>	1.00	126	20.3	7.4	0.66
	2.00	16	25.5 <sup>a</sup>	7.6	
	LB1		–		
Femur neck-shaft angle <sup>o</sup>	1.00	127	128.5	4.52	0.40
	2.00	17	129.2	7.43	1.94
	LB1		128–130 <sup>f</sup>		

**Table 5 (continued)**

Dimension	Groups	N	X	sd	SE
Femur bicondylar angle <sup>o</sup>	1.00	140	9.3	2.08	0.17
	2.00	16	9.5	2.3	0.81
	LB1		14		

Cretin raw data from Finkbeiner (1923).

<sup>a</sup> Significantly greater mean value,  $p < 0.05$ .

<sup>b</sup> LB1 radius not preserved.

<sup>c</sup> Intermembral index calculated by substituting ulna length for radius length.

<sup>d</sup> Femoral torsion angle not measured for LB1 due to post-mortem damage.

<sup>e</sup> Range reported in Larson et al. (2009).

<sup>f</sup> Range reported in Jungers et al. (2009b).

outside their cretin range, but state that the significance of this is “unclear owing to uncertain measurement convention” (1289). However, the humerofemoral index for LB1 (Morwood et al., 2005) was measured, not ‘estimated’, using standard measurement procedures for maximum femur length (Martin femur 1) (Brown et al., 2004) and maximum humerus length (Martin humerus 1) (Morwood et al., 2005). Fortunately, these are the same measurement conventions employed by Finkbeiner (1923), which enables an examination of humerofemoral proportions in cretins and comparison with unaffected *H. sapiens* and LB1 (Table 5 and 6, Figs. 11 and 13). There is a tendency for cretins to have femora that are slightly shorter than would be predicted for humerus length, but the distribution for the larger cretins falls within the unaffected *H. sapiens* range, and the difference between the least squares regression slopes is not significant (Tables 5 and 6, Figs. 11 and 13). This is consistent with the clinical literature and numerous published photographs of cretins, indicating that their arms and legs are both relatively short, as are the lengths of the hands and feet. This contrasts with LB1, which has extremely short legs, both femora and tibia, relative to the length of the bones of the arm, and falls well outside the *H. sapiens* (including cretins) range of variation (Brown et al., 2004; Morwood et al., 2005; Brown and Maeda, 2009; Jungers et al., 2009a) (Table 5, Figs. 11 and 13).

Compared with unaffected *H. sapiens*, the cretin limb proportion pattern is distinguished by significantly lower crural ((tibia length\*100)/femur length) and larger intermembral ((humerus length + radius length)\*100)/(femur length + tibia length) indices, with tibia that are short relative to the lengths of other limb bones. Depending on which dimension was the dependent variable, there are significant differences between the least squares regression slopes for cretins and unaffected *H. sapiens* for each of the bivariate comparisons involving the tibia (Table 6). However, with the exception of the crural index, there is a great deal of overlap between all of the other limb indices (Table 5, Fig. 11). With three exceptions, LB1 *H. floresiensis* falls outside the *H. sapiens* range of variation for all other limb proportion indices (Fig. 11). The exceptions are for the brachial index (78.1), crural index (83.6) and ulnahumeral index (84.3), where LB1 has relatively high values, particularly in relation to the cretin sample, but falls within the *H. sapiens* range. The overall pattern of limb proportions, mid-shaft cross section shape and robusticity in LB1 *H. floresiensis* is distinct from cretins and unaffected *H. sapiens* and does not support (Obendorf et al., 2008) claims for cretinism in LB1.

Principal component analysis (PCA) of postcranial index data extracted three components with eigenvalues >1.0. Principal Component 1 (35.6% of variance) gives the highest positive scores to skeletons that have high femur and humerus robusticity indices, and to a lesser extent high humerofemoral and ulna-tibial indices (Table 7). This separates LB1 *H. floresiensis* from all of the *H. sapiens*. The cretins display a great deal of variation, but with one exception the cretin cases fall within the sample confidence ellipses ( $p > 90$ ) for the large and small-bodied *H. sapiens* (Fig. 15). Principal

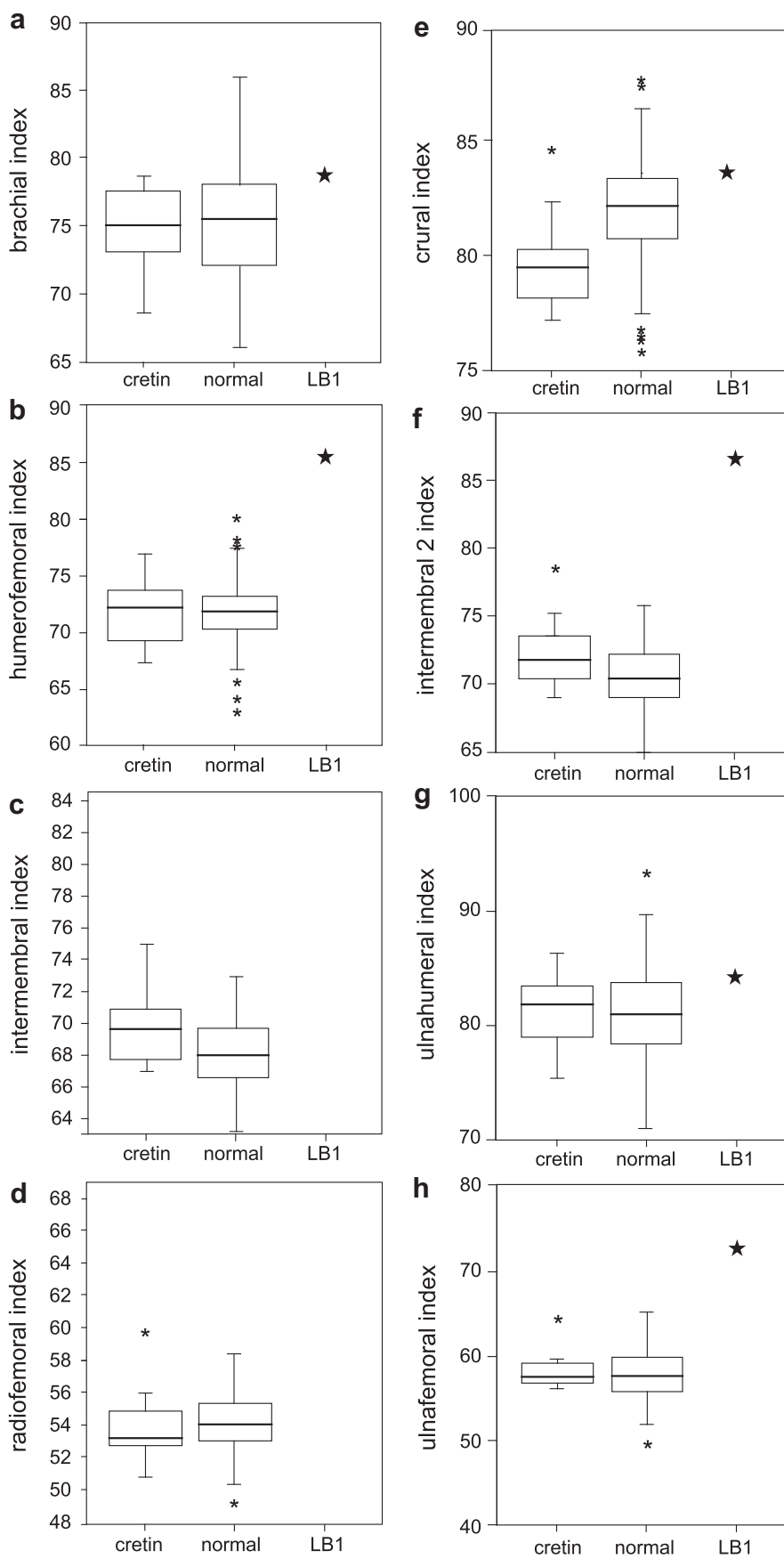
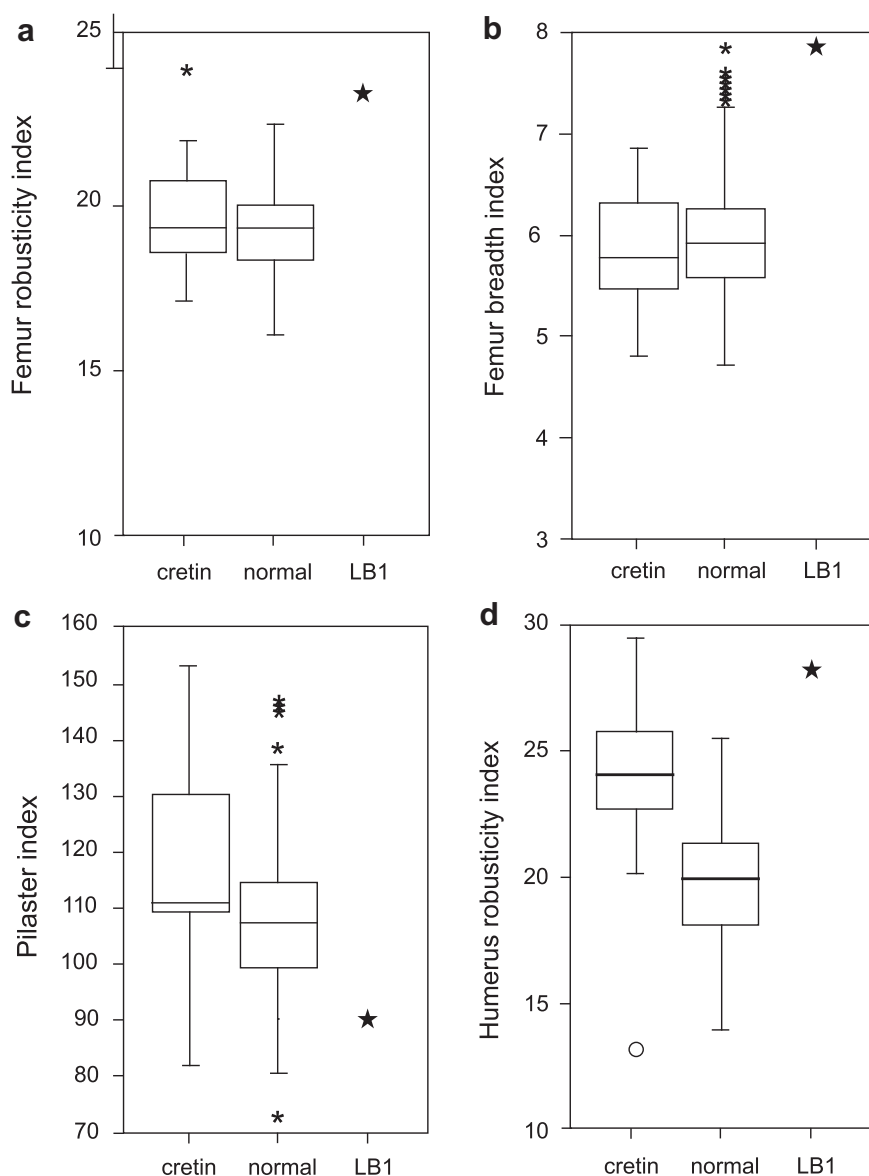


Figure 11. Box plots of the distribution of limb proportion indices in Swiss cretins, global *H. sapiens* and LB1 (*H. floresiensis*). For sample sizes see Table 4.

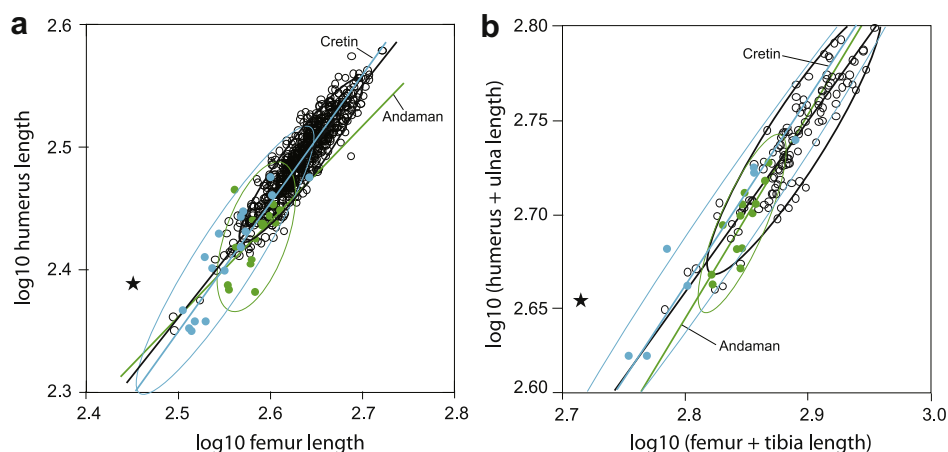


**Figure 12.** Box plots of the distribution of femur and humerus mid-shaft shape and robusticity indices in Swiss cretins, global *H. sapiens* and LB1 (*H. floresiensis*). For sample sizes see Table 4.

component 2 (21.8% of total variance) gives the highest positive scores to skeletons with high crural and humerofemoral indices. This also separates LB1 from all of the *H. sapiens* samples, but not to the same extent as the first component. Principal component 3 (17.1% of total variance) gives the highest positive scores to skeletons with a high pilaster index, which tends to move the cretin confidence ellipse away from the other *H. sapiens* and LB1 away from cretins. As a group, the small cretin sample is distinguished by their relatively great morphological variation compared with unaffected *H. sapiens*. In agreement with the univariate results (Table 5, Figs. 11 and 12), the pattern of limb proportions and robusticity in LB1 *H. floresiensis* separates this hominin from all known ranges of variation in *H. sapiens*.

Primarily due to their value in longitudinal growth studies and the ease with which they can be examined radiographically, there is a relatively large literature on the growth and dimensions of cretin wrists and hands. Without exception, hands as well as feet are described as being small, short and broad. Carpals are typically extremely small and may remain cartilaginous into adulthood.

Metacarpals, metatarsals, and phalanges are short, but broad and thickened, and epiphyseal union is often delayed (Dolega, 1891; Finkbeiner, 1923; Knaggs, 1928; Hill, 1936; Quervain and Wegelin, 1936; Wilkins, 1941; Vandendorp et al., 1959; Tumay et al., 1962; Borg et al., 1975) (Fig. 14). The LB1 feet have been described by Jungers et al. (2009a), with the individual metacarpals, metatarsals and phalanges described in Jungers et al. (2009b). The feet are exceptionally long relative to the length of tibia and femur, the metatarsals and tarsals are not shortened and broad in relation to their length, all epiphyses are fully fused, and some proportions and pedal features are ape-like. This is a complete contrast to the distinctive foot dimensions and indications of delayed development found in *H. sapiens* cretins. The bones of the LB1 wrist were described by Tocheri et al. (2007), with the individual carpals, metacarpals and phalanges described in detail by Larson et al. (2009). Tocheri et al.'s (2007) analysis of the left trapezoid, scaphoid and capitate from LB1 found that it retained wrist morphology that is primitive for the African ape-human clade, and without derived features found in Neanderthals and *H. sapiens*. As



**Figure 13.** Bivariate plots of the relationship between limb bone lengths in normal *H. sapiens* (hollow circle), small-bodied *H. sapiens* from the Andaman Islands (green circle), Swiss *H. sapiens* cretins (blue circle) and LB1 (star), with  $p > 0.90$  confidence ellipses and least squares regression slopes. ((a) global  $n = 715$   $y = -0.013 + 0.951 \times x$  SE 0.013, Andaman  $n = 17$   $y = 0.338 + 0.808 \times x$  SE 0.022, Cretin  $n = 20$   $y = -0.248 + 1.041 \times x$ ) ((b) global  $n = 117$   $y = 0.057 + 0.928 \times x$  SE 0.013, Andaman  $n = 14$   $y = -0.456 + 1.106 \times x$  SE 0.012, Cretin  $n = 9$   $y = -0.168 + 1.009 \times x$  SE 0.018). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Obendorf et al. (2008) discuss, the carpal bones of adult cretins have not been described, and in contrast to LB1 the carpals of their favoured adult cretins, DC and HC, are cartilaginous and not fully ossified. They provide no evidence that the hands and feet of cretins have anything in common with LB1 *H. floresiensis*, whereas the published radiographic details of cretin hand proportions provides unambiguous evidence that they have nothing in common. As the short and broad hands and feet of cretins are one of their most distinctive characteristics, this further undermines any attempt to classify LB1 as a human (*H. sapiens*) cretin.

**Discussion**

The clinical and osteological literature on the iodine deficiency disorders of euthyroid and hypothyroid cretinism provides no support for Obendorf et al.’s (2008) claim that LB1 and LB6 *H. floresiensis* may be examples of humans (*H. sapiens*) with myxoedematous endemic (ME) cretinism. There are no indications of delayed growth and development in the dentition, cranium, mandible or postcranial skeleton that are common in ME cretins. The pattern of skeletal proportions and robusticity in *H. floresiensis* is distinct from all known *H. sapiens*, including cretins, and the hands and feet of LB1 were certainly not short and broad as in cretins. Cretins have an endocranial volume and brain mass that is within the normal human range of variation, whereas LB1 *H. floresiensis* does not, and Obendorf et al. (2008) claim of an

enlarged pituitary fossa in LB1 is incorrect. Contrary to their claims, CT scans demonstrate that all fronto-maxillary sinuses are present and the mastoid region fully aerated in LB1. Dental occlusion and tooth wear does not support the anterior open bite, projecting incisors and tongue thrusting typical of cretins. Details of morphology (e.g., mandibles that are not hypoplastic, do not have a high mandibular angle and have a receding symphysis without a chin) are also incompatible with a diagnosis of ME cretinism. Apart from short stature, the only trait that LB1 *H. floresiensis* seems to share with modern human cretins is a high humeral torsion angle, a trait shared with *H. erectus* from Dmanisi (Lordkipanidze et al., 2007).

Obendorf et al. (2008) were not the first to use the interaction between iodine deficiency, skeletal growth and abnormal adult morphology to explain the appearance of a contentious fossil hominin. Previously, Dobson (1998) argued that the distinctive morphology of Neanderthals may have been due to iodine deficiencies leading to cretinism. In a brief and thoughtful commentary on Dobson’s hypothesis, Tattersall (2002) pointed out why this was unlikely. Neanderthals had a wide geographic distribution, maintained a consistent morphological pattern over a long period of time, their skeletal and dental morphology was inconsistent with a diagnosis of cretinism, and Dobson, a geographer, made errors in the assessment of details of morphology and the traits he selected were inappropriate for the hypothesis he was trying to test. In Tattersall’s (2002) view, a particular problem concerned “descriptive precision” (95), for instance in relation to the anatomy of diagnostic features like the mandibular symphysis (Schwartz and Tattersall, 2000; Brown and Maeda, 2009).

The recent conclusion by Obendorf et al. (2008: 1294) that a hypothesis of cretinism in LB1 “is supported by the presence of numerous skeletal features characteristic of congenital

**Table 6**  
Results of the pairwise significance tests for differences in slopes or y-intercepts for the relationship between limb bone lengths in cretins and unaffected *H. sapiens*.<sup>a</sup>

Dimension <sup>b</sup>	Tibia	Humerus	Radius	Ulna
Femur	NS/*	NS/NS	*/NS	*/NS
Tibia		*/NS	*/NS	*/NS
Humerus			NS/NS	NS/NS
Radius				NS/NS

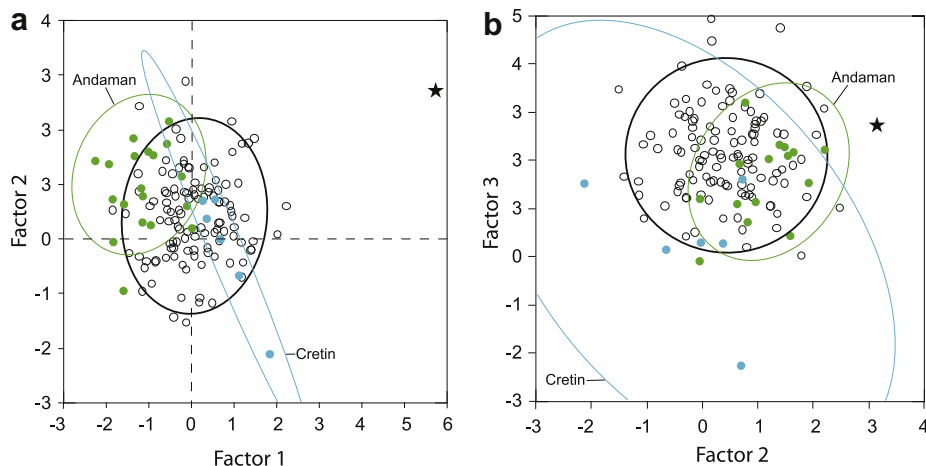
\* $p < 0.05$ ; NS, not significant.

<sup>a</sup> Statistical significance and identification of outliers was influenced by which dimension was the dependent variable. The results of significance tests for both are provided with dimensions on the left vertical axis listed as the dependent variable first.

<sup>b</sup> Femur maximum length (M1), tibia maximum length (M1a), humerus maximum length (M1), radius maximum length (M1), ulna maximum length (M1) (Martin and Saller, 1957).

**Table 7**  
Variable loadings for the components in the PCA for the six postcranial indices.

Index	Factor 1	Factor 2	Factor 3
Humerofemoral	0.688	0.507	0.147
Ulnatibial	0.596	0.357	-0.403
Humerus robusticity	0.762	-0.387	-0.151
Crural	-0.188	0.761	0.433
Pilaster	-0.154	0.395	-0.751
Femur robusticity	0.790	-0.080	0.277

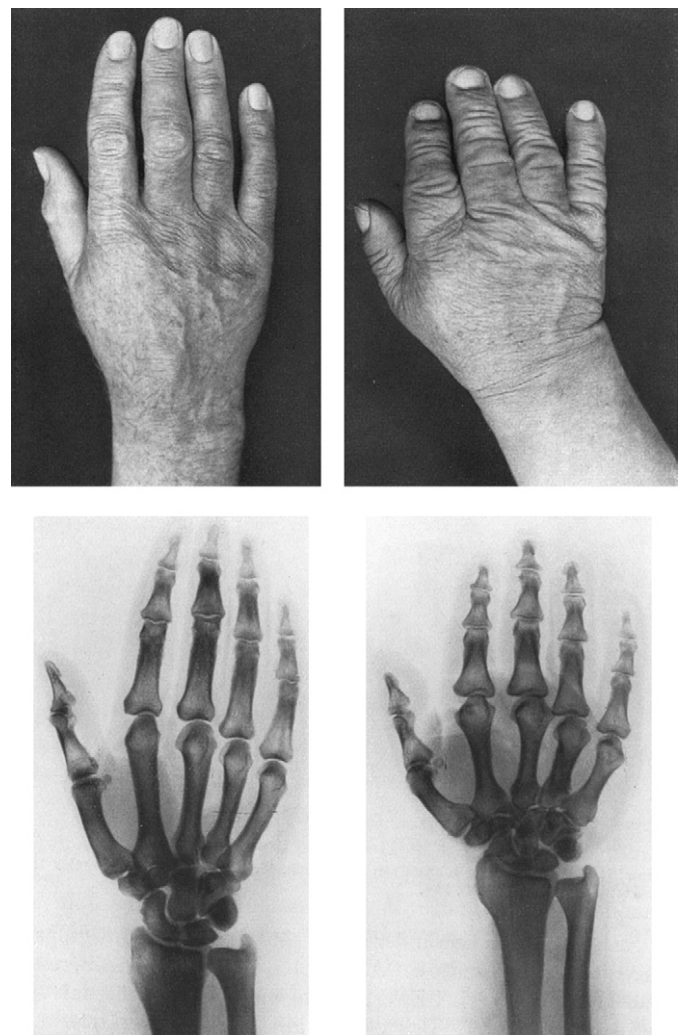


**Figure 14.** Bivariate plots of the component scores in the PCA analysis of five postcranial indices, unaffected global *H. sapiens* (open circles), Andaman Islanders (green circles), Swiss cretins (blue circles) and LB1 *H. floresiensis* (star), with distributions represented by sample confidence ellipses ( $p > 0.90$ ). (a) Factor 1 and Factor 2, (b) Factor 2 and Factor 3. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

hypothyroidism” has similar problems with descriptive precision. Obendorf et al. (2008) conclude by offering a behavioural explanation for the presence of the distinctive terminal Pleistocene hominin skeletons at Liang Bua, and the absence of recognizable modern humans (*H. sapiens*) in deposits of the same age. They argue that, “in seasonally mobile-hunter-gather populations, the limited mobility of cretins could lead to separation, particularly of adult cretins. Use of caves by adult cretins and lack of burial would explain the cretin remains at LB, while seasonal mobility, alternative shelters and systematic burial would explain the absence of normal individuals” (1294). Liang Bua cave contains an extinct fauna, which is contemporaneous with *H. floresiensis*, and the archaeological, environmental and cultural reconstructions of the Pleistocene deposits have been published in detail (Morwood et al., 2004, 2009; Brumm et al., 2006, 2010; Moore and Brumm, 2007; Westaway et al., 2007, 2009a, 2009b; Moore et al., 2009; Roberts et al., 2009; van den Bergh et al., 2009). This literature is worthwhile reviewing as it provides a test of their behavioural scenario and the context of *H. sapiens* at Liang Bua.

Archaeological excavations at Liang Bua were initiated by Theodor Verhoeven in 1950, and continued in 1965 when he found six Neolithic and Proto-Metallic age burials with grave goods, as well as concentrations of stone artifacts and faunal remains (Morwood et al., 2009). Between 2001 and 2004, excavations at Liang Bua were continued to the underlying Pleistocene deposits and bedrock (Morwood et al., 2004). These new excavations exposed evidence of hominin occupation between  $\sim 95$ –17 ka. The occupation evidence included a large number of stone artifacts, faunal remains including *Stegodon*, and the LB1 *H. floresiensis* skeleton (Brown et al., 2004; Morwood et al., 2004, 2005, 2009; Brumm et al., 2006). The Pleistocene occupation layers were capped by a thick consolidated layer of ‘black’ volcanic sandy silt and coarse silty sand, associated with a massive volcanic eruption at  $\sim 17$  ka. In stark contrast to the Holocene occupation, there was no evidence of the symbolic behaviour often associated with modern humans (burials, ochre, beads, art) in the Pleistocene deposits, the hominin skeletons are morphologically and metrically distinct from *H. sapiens*, and the layer of volcanic material appears to mark the extinction of both *Stegodon* and *H. floresiensis*.

Analysis of the stone artifacts has demonstrated continuity in materials and manufacturing techniques throughout the Pleistocene deposits at Liang Bua, and also with the much earlier deposits



**Figure 15.** Hand proportions in a normal adult *H. sapiens* (left side) and a myxoedematous cretin (right side), reproduced from (Quervain and Wegelin, 1936: Fig. 49).

(880–800 ka) at Mata Menge (Brumm et al., 2006; Moore et al., 2009). The earliest dates from Liang Bua (~95 ka), if associated with *H. sapiens*, would predate the other Australasian evidence for the dispersion of this species by ~40 ka (Brown, 2010; O'Connell et al., 2010), and Mata Menga by >0.6 Ma (Klein, 2008). Therefore, based on chronology and the geographic proximity of Java, the potential candidates for the Pleistocene tool manufacturers at Mata Menge and Liang Bua include *H. erectus* (Anton, 2003; Kaifu et al., 2008) and *H. floresiensis*, but not *H. sapiens*. These data are inconsistent with Obendorf et al. (2008) behavioural explanation for the presence of ME cretin *H. sapiens*, but not unaffected *H. sapiens* in the Pleistocene deposits at Liang Bua.

The Pleistocene deposits are culturally rich over an extended period of time, indicating frequent occupation of the cave by hominins who hunted *Stegodon* and manufactured stone tools. These activities would probably have been too challenging for ME cretins with impaired intellectual and locomotion skills. The earliest dates associated with stone tools at Liang Bua, as well as the LB2 P<sub>3</sub>, appear to be too early for *H. sapiens* to be in the region, and currently the only other candidate from Liang Bua is *H. floresiensis*. The Holocene deposits at Liang Bua have a considerable number of Neolithic and Palaeometalic burials (collections at ARKANAS and Gadjaja Mada University), and although undescribed, neither Radian Soejono nor the late Professor Tehku Jacob have indicated that evidence of either dwarfed *H. sapiens* or ME cretins were present. Given their familiarity with this collection and belief that *H. floresiensis* was a pygmy *H. sapiens* (Jacob et al., 2006), it would have been unusual for them not to present potentially paradigm-changing evidence from Liang Bua if it was available. The Liang Bua Holocene *H. sapiens* burials curated at ARKANAS are certainly of undistinguished *H. sapiens* morphology, stature and endocranial volume (PB personal observation, 2004–2005). There is currently no evidence that modern *H. sapiens*, with or without cretinism, were contemporary with *Stegodon* in the Pleistocene deposits at Liang Bua.

## Conclusion

Although *H. sapiens* was in the broad geographic region by 50 ka, there is currently no archaeological or human skeletal evidence from Flores or Liang Bua cave, in particular, that *H. sapiens* was on the island during the Late Pleistocene. Even if they were, comparison of the skeletal morphology and proportions of LB1 and LB6 *H. floresiensis* with the clinical and osteological traits associated with the iodine deficiency disorders (cretinism) in modern humans indicates that they were not myxoedematous endemic cretins. Contrary to the claims of Obendorf et al. (2008), there are no indicators of delayed linear growth and development consistent with cretinism, and in contrast to LB1, *H. sapiens* cretins have an average brain mass that is within the normal human range of variation. Apart from very short stature, the only trait that LB1 appears to share with *H. sapiens* cretins is a high humeral torsion angle, a trait also found in *H. erectus* from Dmanisi. The currently available archaeological evidence indicates that only one hominin species, *H. floresiensis*, was occupying Liang Bua cave during the Pleistocene, and they were responsible for the stone tools and evidence of *Stegodon* hunting found in association with their fossil remains.

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