

Australopithecus sediba: A New Species of Homo-Like Australopith from South Africa Lee R. Berger, et al. Science 328, 195 (2010); DOI: 10.1126/science.1184944

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Australopithecus sediba: A New Species of *Homo*-Like Australopith from South Africa

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Despite a rich African Plio-Pleistocene hominin fossil record, the ancestry of *Homo* and its relation to earlier australopithecines remain unresolved. Here we report on two partial skeletons with an age of 1.95 to 1.78 million years. The fossils were encased in cave deposits at the Malapa site in South Africa. The skeletons were found close together and are directly associated with craniodental remains. Together they represent a new species of *Australopithecus* that is probably descended from *Australopithecus africanus*. Combined craniodental and postcranial evidence demonstrates that this new species shares more derived features with early *Homo* than any other australopith species and thus might help reveal the ancestor of that genus.

The origin of the genus *Homo* is widely debated, with several candidate ancestors being proposed in the genus Australopithecus (1-3) or perhaps Kenvanthropus (4). The earliest occurrence of fossils attributed to Homo (H. aff. H. habilis) at 2.33 million years ago (Ma) in Ethiopia (5) makes it temporally antecedent to all other known species of the genus Homo. Within early Homo, the hypodigms and phylogenetic relationships between H. habilis and another early species, H. rudolfensis, remain unresolved (6-8), and the placement of these species within *Homo* has been challenged (9). H. habilis is generally thought to be the ancestor of H. erectus (10-13), although this might be questioned on the basis of the considerable temporal overlap that existed between them (14). The identity of the direct ancestor of the genus Homo, and thus its link to earlier Australopithecus, remains controversial. Here we describe two recently discovered, directly associated, partially articulated Australopithecus skeletons from the Malapa site in South Africa, which allow us to investigate several competing hypotheses regarding the ancestry of Homo. These skeletons cannot be accommodated within any existing fossil taxon; thus, we establish a new species, Australopithecus sediba, on the basis of a com-

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bination of primitive and derived characters of the cranium and postcranium.

The following is a description of *Au. sediba*: Order Primates Linnaeus 1758; suborder Anthropoidea Mivart 1864; superfamily Hominoidea Gray 1825; family Hominidae Gray 1825; genus *Australopithecus* DART 1925; species *Australopithecus sediba* sp. nov. **Etymology**. The word *sediba* means "fountain" or "wellspring" in the seSotho language.

Holotype and paratype. Malapa Hominin 1 (MH1) is a juvenile individual represented by a partial cranium, fragmented mandible, and partial postcranial skeleton that we designate as the species holotype [Figs. 1 and 2, supporting online material (SOM) text S1, figs. S1 and S2, and table S1]. The first hominin specimen recovered from Malapa was the right clavicle of MH1 (UW88-1), discovered by Matthew Berger on 15 August 2008. MH2 is an adult individual represented by isolated maxillary teeth, a partial mandible, and partial postcranial skeleton that we designate as the species paratype. Although MH1 is a juvenile, the second molars are already erupted and in occlusion. Using either a human or an ape model, this indicates that MH1 had probably attained at least 95% of adult brain size (15). Although additional growth would have occurred in the skull and skeleton of this individual, we judge that it would not have appreciably altered the morphology on which this diagnosis is based.

Locality. The two *Au. sediba* type skeletons were recovered from the Malapa site (meaning "homestead" in seSotho), situated roughly 15 km NNE of the well-known sites of Sterkfontein, Swartkrans, and Kromdraai in Gauteng Province, South Africa. Detailed information regarding geology and dating of the site is in (*16*).



Fig. 1. Craniodental elements of *Au. sediba.* UW88-50 (MH1) juvenile cranium in (**A**) superior, (**B**) frontal, and (**C**) left lateral views. (**D**) UW88-8 (MH1) juvenile mandible in right lateral view, (**E**) UW88-54 (MH2) adult mandible in right lateral view, (**F**) UW88-8 mandible in occlusal view, (**G**) UW 88-54 mandible in occlusal view, and (**H**) UW 88-50 right maxilla in occlusal view (scale bars are in centimeters).

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Diagnosis. Au. sediba can be distinguished from other species of Australopithecus by a combination of characters presented in Table 1; comparative cranial measures are presented in Table 2. A number of derived characters separate Au. sediba from the older chronospecies Au. anamensis and Au. afarensis. Au. sediba exhibits neither the extreme megadontia, extensive cranial cresting, nor facial prognathism of Au. garhi. The suite of derived features characterizing Au. aethiopicus, Au. boisei, and Au. robustus, in particular the pronounced cranial muscle markings, derived facial morphology, mandibular corpus robusticity, and postcanine megadontia, are absent in Au. sediba. The closest morphological comparison for Au. sediba is Au. africanus, as these taxa share numerous similarities in the cranial vault, facial skeleton, mandible, and teeth (Table 1). Nevertheless, Au. sediba can be readily differentiated from Au. africanus on both craniodental and postcranial evidence. Among the more notable differences, we observe that although the cranium is small, the vault is relatively transversely expanded with vertically oriented parietal walls and widely spaced temporal lines; the face lacks the pronounced, flaring zygomatics of Au. africanus; the arrangement of the supraorbital torus, nasoalveolar region, infraorbital region, and zygomatics result in a derived facial mask; the mandibular symphysis is vertically oriented with a slight bony chin and a weak post-incisive planum; and the teeth are differentiated by the weakly defined buccal grooves of the maxillary premolars, the weakly developed median lingual ridge of the mandibular canine, and the small absolute size of the postcanine dentition. These exact differences also align Au. sediba with the genus Homo (see SOM text S2 for hypodigms used in this study). However, we consider Au. sediba to be more appropriately positioned within Australopithecus, based on the following craniodental features: small cranial capacity, pronounced glabelar region, patent premaxillary suture, moderate canine jugum with canine fossa, small anterior nasal spine, steeply inclined zygomaticoalveolar crest, high masseter origin, moderate development of the mesial marginal ridge of the maxillary central incisor, and relatively closely spaced premolar and molar cusps.

Postcranially, Au. sediba is similar to other australopiths in its small body size, its relatively



Fig. 2. Associated skeletal elements of MH1 (**left**) and MH2 (**right**), in approximate anatomical position, superimposed over an illustration of an idealized *Au. africanus* skeleton (with some adjustment for differences in body proportions). The proximal right tibia of MH1 has been reconstructed from a natural cast of the proximal metaphysis.

long upper limbs with large joint surfaces, and the retention of apparently primitive characteristics in the upper and lower limbs (table S2). Au. sediba differs from other australopiths, but shares with Homo a number of derived features of the os coxa, including increased buttressing of the ilium and expansion of its posterior portion, relative reduction in the distance between the sacroiliac and hip joints, and reduction of distance from the acetabulum to the ischial tuberosity. These synapomorphies with Homo anticipate the reorganization of the pelvis and lower limb in H. erectus and possibly the emergence of more energetically efficient walking and running in that taxon (17). As with the associated cranial remains, the postcranium of Au. sediba is defined not by the presence of autapomorphic features but by a unique combination of primitive and derived traits.

Cranium. The cranium is fragmented and slightly distorted. The minimum cranial capacity of MH1 is estimated at 420 cm³ (SOM text S4). The vault is ovoid, with transversely expanded, vertically oriented parietal walls. The widely spaced temporal lines do not approach the midline. Postorbital constriction is slight. The weakly arched supraorbital torus is moderately developed and laterally extended, with sharply angled lateral corners and a weakly defined supratoral sulcus. A robust glabelar region is evident, with only a faint depression of the supraorbital torus at the midline. The frontal process of the zygomatic faces primarily laterally and is expanded medially but not laterally. The zygomatic prominence does not show anterolateral expansion. The zygomatics are weakly flared laterally, resulting in an uninterrupted frontal profile of the facial mask that is squared superiorly and tapered inferiorly. The zygomaticoalveolar crests are long, straight, and steeply inclined, resulting in a high masseter origin. The root of the zygomatic begins at the anterior margin of M¹. The nasal bones are widened superiorly, become narrowest about one-third of the way down, and flare to their widest extent at their inferior margin. The nasal bones are elevated as a prominent ridge at the internasal suture, with an increasingly anterior projection inferiorly. The bone surface of the maxilla retreats gently away from the nasal aperture laterally, resulting in an everted margin of the superolateral portion of the aperture relative to the infraorbital region. The inferolateral portion of the nasal aperture becomes bluntly rounded. The infraorbital region is slightly convex (18) and is oriented at an approximately right angle to the alveolar plane. There is a trace of a premaxillary suture near the superolateral margin of the nasal aperture. Prominent canine juga delineate moderately developed canine fossae. Anterior pillars are absent. The inferior margin of the nasal aperture is marked by a stepped nasal sill and a small but distinct anterior nasal spine. The subnasal region is straight in the coronal plane and only weakly projecting relative **Table 1.** List of characters used to diagnose *Au. sediba*. These characters are commonly used in hominin phylogenetic studies (*11, 38–40*) or have been recorded as diagnostic for various hominin taxa in the past (*3, 10, 36*). Recognizing the potential pitfalls of performing a cladistic analysis on possibly interdependent characters of uncertain valence, we produced a cladogram from the data in this table as a test of the phylogenetic position of *Au. sediba* (fig. 53). Our most parsimonious cladogram places *Au. sediba* at the stem of the *Homo* clade.

Numbers in parentheses in the first column refer to measures presented in Table 2; descriptions of these character states are provided in SOM text S3. Abbreviations are as follows: A-M, anteromedial; costa supr., costa supraorbitalis; intermed., intermediate; lat., lateral; med., medial; mesognath, mesognathic; mod., moderately; MMR, mesial marginal ridge; orthogn., orthognathic; procumb., procumbent; proj., projecting; TMJ, temperomandibular joint.

S3). Our most parsimonious clad	ogram places Au	. sediba at the	stem of the Ho	<i>omo</i> clade.	dibular joint.					
Characters	Au.	Au.	Au.	Au.	H.	н.	H.	Au.	Au.	Au.
	afarensis	garhi	africanus	sediba	habilis	rudolfensis	erectus	aethiopicus	boisei	robustus
Vault										
Cranial capacity (1)	Small	Small	Small	Small	Intermed.	Large	Large	Small	Small	Small
A-M incursion of	Strong	Moderate	Moderate	Weak	Weak	Weak	Weak	Strong	Strong	Strong
temporal lines on frontal										
Position of temporal lines	Crest	Crest	Variable	Wide	Variable	Wide	Wide	Crest	Crest	Crest
on parietal bones		,	5		5					
Compound temporal	Extensive	ż	Absent	Absent	Variable	Absent	Absent	Extensive	Variable	Absent
nuchal crest (males)										
Postorbital constriction	Marked	Moderate	Moderate	Slight	Moderate	Moderate	Slight	Marked	Marked	Marked
(5)										
Pneumatization of	Extensive	ż	Extensive	Reduced	Reduced	Reduced	Reduced	Extensive	Variable	Reduced
temporal squama										
Facial hafting	Low	Low	Low	Low	Low	Low	Low	High	High	High
Frontal trigon	Present	Present	Absent	Absent	Absent	Absent	Absent	Present	Present	Present
Supraglenoid gutter width	Narrow	ذ	Narrow	Narrow	Narrow	Narrow	Narrow	Wide	Wide	Wide
Horizontal distance	Long	~:	Long	Short	Short	Long	Short	Long	Long	Long
between TMJ and										
M2/M3 (6)										
Parietal transverse	Absent	Absent	Absent	Present	Present	Present	Present	Absent	Absent	Absent
expansion/tuber										
Facial skeleton										
Supraorbital expression	Costa supr.	Costa supr.	Intermed.	Torus	Torus	Intermed.	Torus	Costa supr.	Costa supr.	Costa supr.
Supraorbital contour	Less arched	Less arched	Variable	Arched	Arched	Arched	Arched	Less arched	Variable	Arched
Glabellar region forms as	No	No	Variable	Yes	No	Variable	No	No	Yes	Yes
prominent block										
Lat. half of infraorbital	No	ذ	No	No	No	No	No	Yes	No	Yes
margin blunt										
and protruding										
Zygomatic arch relative to	Above	ż	Level	Level	Level	ż	Level	Above	Above	Above
inferior orbital margin										
Convexity/concavity of	ż	ż	Convex	Convex	Concave	Concave	Convex	Concave	Concave	Concave
infraorbital region										
Nasal bone projection	Expanded	ż	Variable	No	No	No	No	Tapered	Expanded	Expanded
above frontomaxillary										
suture	1412 4 2	ſ		1412 41 -	- I I - I		1412 41 -		1-4-14	N
Interior whath of aroioction and home (25)	WIGe		variable	WIGe	Variable	Narrow	wide	Not proj.	Not proj.	Not proj.
projecting nasat buile (23) Infraorhital foraman	Hinh	د	Variahla	НілЬ	ніль	~	Hinh	1 OW		
hillaulultat 101 ameri heinht (22)	ligili	•		- iĥ	II AIII	•		FOM	L CW	FOW STREET

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Chara cters	Au. afarensis	Au. garhi	Au. africanus	Au. sediba	H. habilis	H. rudolfensis	H. erectus	Au. aethiopicus	Au. boisei	Au. robustus
Canine juga prominence/anterior nillars	Prominent	Prominent	Variable	Prominent	Variable	Weak	Weak	Weak	Weak	Pillars
Patency of premaxillary	Obliterated	ć	Occasional	Trace	Obliterated	Obliterated	Obliterated	Obliterated	Obliterated	Occasional
suture Inferolateral nasal	Sharp	Sharp	Variable	Blunt	Variable	Sharp	Blunt	Blunt	Variable	Blunt
aperture margin Eversion of superior nasal	2	~	None	Slight	Sliaht	Sliaht	Sliaht	Sliaht	Variable	None
aperture margin							11610			
Nasoalveolar triangular	Triangular	ż	Triangular	Triangular	Triangular	Triangular	Triangular	Gutter	Gutter	Gutter
Irame/gutter	Ctonnod	Ctonnod	Ctonnod	Ctonnod	0 Harine V	(+00000d	Ctonnod	C	Cmooth	Cth
Nasal cavity entrance Nasoalveolar clivus	Сопуех	Convex	Strainht	Straight	Straight	Strainht	Strainht	Concave	Concave	Concave
contour in coronal plane				5	2				5	2
Subnasal projection (38)	Marked	Marked	Variable	Weak	Variable	Weak	Weak	Marked	Moderate	Moderate
Canine fossa	Present	Present	Present	Present	Present	Absent	Absent	Absent	Absent	Absent
Maxillary fossula	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Absent	Present
Incisor procumbency	Procumb.	Procumb.	Variable	Vertical	Variable	Vertical	Vertical	Vertical	Vertical	Vertical
Anterior nasal spine rel. to	Absent	ć	Anterior	Anterior	Anterior	ż	Enlarged	Posterior	Posterior	Posterior
nasal aperture Expansion of frontal	Med. and lat.	ć	Med. and lat.	Medial	Medial	Medial	Medial	Med. and lat.	Med. and lat.	Med. and lat.
process of zygomatic bone										
Angular indentation of	ż	ć	Indented	Curved	Curved	Curved	Curved	ż	Curved	Curved
lateral orbital margin						1				
Zygomatic prominence	Prominent	ż	Prominent	Slight	Slight	ć	Slight	Prominent	Prominent	Prominent
ueverupritetit Lataral flaring of	hadren	~	hedren	Cliaht	Slinht	Slinht	Clinht	hadreM	hedred	hedren
zygomatic arches		•		יוואוור	1116117	ungine.	Julifine			
Outline of superior	Tapered	ż	Tapered	Squared	Squared	Squared	Squared	Tapered	Tapered	Tapered
facial mask										
Zygomaticoalveolar	Straight	ż	Straight	Straight	Notch	Notch	Notch	Straight	Straight	Straight
crest/malar notch										
Infraorbital plate angle	Obtuse	ċ	Obtuse	Right	Right	Right	Right	Obtuse	Obtuse	Obtuse
relative to alveolar plane	:	ſ	:	:	:	:	:	:	:	;
Zygomaticomaxillary	No	~;	No	No	No	No	No	No	No	Yes
			-			-		-	-	
Height of masseter	Low	LOW	High	High	Low	Low	Low	High	High	High
(12) (12) (12) (12) (12) (12) (12)	Thin	~	Thin	Thin	Thin	د	Thin	Thirl	Thick	Thick
Projection of zvaomatics	Posterior	Posterior	Variable	Posterior	Posterior	: Level	Posterior	Anterior	Anterior	Anterior
relative to nasal bones										
Facial prognathism (7) (sellion-prosthion angle)	Prognathic	Prognathic	Variable	Mesognath.	Mesognath.	Mesognath.	Orthogn.	Prognathic	Mesognath.	Mesognath.
Masseteric position	Anterior	ذ	Posterior	Posterior	Posterior	ذ	Posterior	Anterior	Anterior	Anterior
relative to sellion										
Lateral anterior facial contour	Bipartite	Bipartite	Variable	Straight	Variable	Straight	Straight	Straight	Straight	Straight

Characters	Au. afarensis	Au. garhi	Au. africanus	Au. sediba	H. habilis	H. rudolfensis	H. erectus	Au. aethiopicus	Au. boisei	Au. robustus
Palate										
Protrustion of incisors	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No
beyond bi-canine line	:	:	1	ſ		ſ		:	,	:
Anterior palatal depth	Shallow	Shallow	Deep	Deep	Variable	Deep	Variable	Shallow	Deep	Shallow
Dental arcade shape	Rectangle	Rectangle	Variable	Parabolic	Parabolic	Parabolic	Parabolic	Rectangle	Parabolic	Parabolic
Maxillary I2/C diastema	Present	Present	Absent	Absent	Variable	Absent	Absent	Absent	Absent	Absent
Mandible Oriontation of markings	Docodina	~	Docoding	Vortical	Instruction	Initial	Icritical	Initial	Icritical	Inditation
	Necentria		Nereallig	אבורורמו	עבו וורמו	עבו נורמו	עבו נורמו	עבו נורמו	ע כן נורמו	ע בו וורמו
sympus Bowy chin	Abcant	~	Slinht	Slight	Slinht	Slicht	Slinht	Clicht	Slinht	Slinht
(mentum accelum)			1116112	111Aire	ungur.	111Bit	1116112	201301	7113111	7113111
Direction of mental	Variahla	2	Variahle	latoral	lateral	lateral	atera	lateral	ater	lateral
foramen opening		•	Adliable	רמוכו מו	רמוכומו	רמוכומו	רמוכומו	רמוכומו	רמובומו	דמובו מו
Post-incisive nlanum	Prominent	2	Prominent	Acol	Prominent	AcoW	AcoW	Prominent	Prominent	Prominent
Torus marginalis and	Prominent	• ~	Moderate	Moderate	Moderate	Prominent	Prominent	2	Prominent	Prominent
marginal tubercles			5	5	5)))
Mandibular corpus	Small	ć	Small	Small	Small	Variable	Small	Large	Large	Large
cross-sectional area								3	1)
at M_1 (50)										
Teeth										
Incisor-to-postcanine ratio	Large	Moderate	Moderate	Moderate	Moderate	Moderate	Large	ż	Small	Small
(maxillary) (60)										
Canine-to-postcanine ratio	Large	Large	Large	Large	Large	Large	Large	ż	Small	Small
(maxillary/mandibular) (61, 62)							:			
Postcanine crown area	Moderate	Large	Large	Moderate	Moderate	Large	Small	Large	Large	Large
(maxillary/mandibular) (57, 59)	-						-			
Maxillary I*: MMR	Moderate	~	Moderate	Moderate	Weak	Weak	Weak	ż	Moderate	Moderate
development, lingual face	-	-	-	-	-	-	-	¢	-	-
Maxillary C: development	Marked	Marked	Marked	Weak	Weak	Marked	Marked	ż	Marked	Weak
of lingual ridges	;			;		1	;	-	-	-
MaXIllary premolar	None	MINOL	MINOL	None	MINOL	MINOL	None	warked	Marked	Marked
IIUII BZI IBIUII Professional Archivellivellivellivellivellivellivellivel	podrew	podrew	hodren	dee/M	dealM	podrew	Jeelin	د	dealM	400/01
bliccal grooves					WCGN	Marken	WCGN	•		WCGN
Median lingual ridge of	Prom	~	Prom	Weak	Weak	Weak	Weak	ć	Weak	Weak
mandibular canine										
Mandibular P ₃ root number	2	ż	2	2	1	2	1	ż	2	2
Protoconid/metaconid	Equal	ż	Equal	Protoconid	Protoconid	Protoconid	Protoconid	ć	Equal	Equal
more mesial cusp (molars)										
Peak of enamel forms	No	ż	Yes	Yes	No	No	No	ż	No	Yes
between roots of molars										
Relative enamel thickness	Thick	Thick	Thick	Thick	Thick	Thick	Thick	Hyper	Hyper	Hyper
Positions of apices of	LC at	LC at	LC slightly	LC slightly	LC at	LC at	LC at	LC mod.	LC mod.	LC mod.
lingual (LC) and buccal	margin, BC	margin, BC	buccal, BC	buccal, BC	margin, BC	margin, BC	margin, BC	buccal, BC	buccal, BC	buccal, BC
(BC) cusps of premolars	slightly 	slightly 	moderately 	moderately	slightly 	slightly 	slightly 	strongly	strongly 	strongly
and molars relative to	lıngual	lıngual	linguat	lıngual	lıngual	lıngual	lıngual	lıngual	lıngual	lınguat
occlusal margın										

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based on (lows: br, emporale; prion; pr,	Au. robustus	530	100	I	73	68	81	69	36	35	I	I	6	80	107	82	143	74	106	24	33	30	28	11	I	8	I	54	24	25	57	18	26	71	69	103	26	22	122	13	17
that are are as fo ft, frontote le; po, po	Au. boisei	515	66	116	64	61	82	99	50	36	87	84	12	100	108	93	165	65	119	24	37	сс СС	30	14	11	7	ъ	64	30	31	69	18	25	82	81	101	27	25	108	15	22
ed in Table 1 Abbreviations e temporale; e; or, orbita goorbitale.	Au. aethiopicus	419	94	125	65	65	94	41	51	33	I	I	10	66	100	101	153	I	126	23	36	41	3 D	12	19	11	4	72	80	30	53	20	30	80	73	110	23	12	192	15	21
tes present M text 53. Frontomolau nasospinal on; zyo, zy	H. erectus	006	126	121	89	80	57	72	37	76	103	66	12	76	107	66	135	84	105	25	39	36	18	13	24	18	6	52	30	32	51	12	16	67	70	96	16	21	79	16	13
character stat ovided in SO molare; fmt, f nasion; ns, illare; zy, zygi	H. rudolfensis	751	114	127	85	72	58	68	I	72	86	93	10	90	117	100	I	I	113	24	39	ŝ	20	ω	I	10	I	57	39	27	59	I	14	69	75	92	17	30	57	14	16
ptions of lble are pr ekm, ecto ontale; n, zygomaxi	H. habilis	631	103	104	76	70	51	65	27	99	83	80	œ	68	100	89	117	85	67	27	33	31	18	∞ ;	10	11	ω	45	28	25	47	œ	15	55	57	96	19	18	106	15	16
ed. Descri om this ta conchion; maxillofr inion; zm,	Au. sediba	420	100	104	73	85	45	65	21	70	75	74	8	68	86	78	102	84	84	20	31	31	26	ωı	J.	13	6	49	22	26	44	13	15	57	50	104	13	17	76	16	18
vise indicat urements fru ia; ek, ectoo abella; mf, nion; rhi, rh	Au. africanus	442	66	66	69	71	61	61	31	54	80	84	8	78	67	84	126	74	103	19	36	32	27	ц	11	11	4	20	26	53	53	13	12	67	09	112	23	21	108	13	15
y other e measu n bregm h g, glå s prosth	Au. afarensis	415	90	126	77	99	83	63	I	40	101	I	I	87	117	89	157	75	I	18	38	34	I	I	I	I	I	28	29	53	55	14	I	I	I	I	28	15	187	I	I
leasurements for early hominins in Africa. Au. sediba is represented b defined, measurements are based on (6). Some measures were is of Au. afarensis and Au. garhi, in which case the character states i Several character states in Table 1 are recorded as variable, although alues are presented here. Measurements are in millimeters unles	Measurement	Cranial capacity (cm ³)	Maximum parietal breadth	Bi-porionic breadth (po-po)	Postorbital constriction (narrowest point behind the orbits)	Postorbital constriction index (4/14 $ imes$ 100)	Horizontal distance between TMJ and M^2/M^3	Facial prognathism (sellion-prosthion angle)	Infratemporal fossa depth	Minimum frontal breadth (ft-ft)	Glabella to bregma (g-br)	Frontal chord (n-br)	Supraorbital torus vertical thickness	Superior facial height (n-pr)	Superior facial breadth (fmt-fmt)	Bi-orbital breadth (ek-ek)	Bizygomatic breadth (zy-zy)	Zygomatic breadth index (14/16 \times 100)	Bimaxillary breadth (zm-zm)	Interorbital breadth (mf-mf)	Orbital breadth (mf-ek)	Orbital height (perpendicular to 20)	Nasal bridge length (n-rhi)	Nasal bridge breadth superior	Nasal bridge breadth at anterior lacrimal crests	Nasal bridge breadth inferior	Nasal bridge height (nasion subtense at anterior lacrimal crests)	Nasal height (n-ns)	Nasal aperture height (rhi-ns)	Maximum nasal aperture width	Orbitoalveolar height (or-alveolar plane)	Malar thickness	Infraorbital foramen height (to inferior orbital margin)	Prosthion to zygomaxillare (pr-zm)	Prosthion to zygoorbitale (pr-zyo)	Masseter origin height index (33/34 $ imes$ 100)	Subnasale to prosthion (horizontal projection)	Subnasal to prosthion (vertical projection)	Subnasale projection index (36/37 $ imes$ 100)	Incisor alveolar length	Premolar alveolar length
 Craniodental n Unless otherwise able for specimer were estimated. 	Measurement description in (6		6	11					75	8	17		62	43	49	50	52		53	55	56	57	71	73		74		69	20	68		60					47	48		94	96
Table MH1. I MH1. I unavail Table 1 only sp	ltem	1	2	m	4	ß	9	7	8	6	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40

continued on next page

ltem	Measurement description in (6)	Measurement	Au. afarensis	Au. africanus	Au. sediba	H. habilis	H. rudolfensis	H. erectus	Au. aethiopicus	Au. boisei	Au. robustus
41	98	Intercanine distance	26	30	30	30	33	31	I	29	27
42	88	Palate breadth (ekm-ekm)	68	64	63	70	80	99	83	82	67
43	141	Mandibular symphysis height	39	38	32	27	36	34	I	47	42
44	142	Mandibular symphysis depth	60	20	19	19	24	19	I	28	25
45	147	Mandibular corpus height at P ₄	34	33	28	30	38	30	I	42	38
46	148	Mandibular corpus depth at P4	19	21	18	20	22	19	I	28	24
47	149	Cross-sectional area at P_4 (calculated as an ellipse)	511	558	382	427	653	458	I	910	709
48	150	Mandibular corpus height at M_1	33	32	28	29	36	30	35	41	37
49	151	Mandibular corpus depth at M_{1}	19	21	18	20	23	20	26	28	26
50	152	Cross-sectional area at M_1 (calculated as an ellipse)	488	532	396	421	667	469	715	913	759
51	154	Mandibular corpus height at M ₂	31	31	25	31	36	30	I	41	35
52	155	Mandibular corpus depth at M ₂	22	25	22	23	26	21	I	31	28
53	156	Cross-sectional area at M_2 (calculated as an ellipse)	536	612	436	537	745	504	I	980	770
54	162	Height of mental foramen relative to alveolar margin	20	19	13	13	17	13	I	20	20
55		Maxillary incisor crown area (I ¹ +I ²)	143	135	109	132	137	136	I	117	109
56		Maxillary canine crown area	107	104	79	95	118	96	I	76	79
57		Maxillary postcanine crown area	713	868	731	755	829	617	I	1012	941
58		Mandibular canine crown area	87	95	68	83	I	79	I	72	61
59		Mandibular molar crown area	550	651	536	565	668	466	I	781	678
60		Maxillary incisor to postcanine ratio	20.0	15.6	14.9	17.4	16.6	22.1	I	11.5	11.6
61		Maxillary canine to postcanine ratio	15.0	11.9	10.8	12.6	14.2	15.5	I	7.5	8.4
62		Mandibular canine to molar ratio	15.8	14.6	12.7	14.6	I	16.7	I	9.2	9.0

to the facial plane. The face is mesognathic. The palate is consistently deep along its entire extent, with a parabolic dental arcade.

Mandible. Descriptions apply to the more complete juvenile (MH1) mandible unless otherwise stated. The nearly vertical mandibular symphysis presents a weak lateral tubercle, resulting in a slight mental trigone, and a weak mandibular incurvation results in a slight mentum osseum. The post-incisive planum is weakly developed and almost vertical. Both mandibular corpora are relatively gracile, with a low height along the alveolar margin. The extramolar sulcus is relatively narrow in both mandibles. In MH1, a moderate lateral prominence displays its greatest protrusion at the mesial extent of M₂, with a marked decrease in robusticity to P₄; in MH2 the moderate lateral prominence shows its greatest protrusion at M₃, with a marked decrease in robusticity to M2. The alveolar prominence is moderately deep with a notable medial projection posteriorly. The anterior and posterior subalveolar fossae are continuous. The ramus of MH1 is tall and narrow, with nearly parallel, vertically oriented anterior and posterior borders; the ramus of MH2 is relatively broader, with nonparallel anterior and posterior borders (fig. S2). The mandibular notch is relatively deep and narrow in MH1 and more open in MH2. The coronoid extends farther superiorly than the condyle. The condyle is mediolaterally broad and anteroposteriorly narrow. The endocondyloid buttress is absent in MH1, whereas in MH2 a weak endocondyloid buttress approaches the condyle without reaching it.

Dental size and proportions. The dentition of the juvenile (MH1) is relatively small, whereas preserved molars of the adult (MH2) are even smaller (Fig. 3 and fig. S4). For MH1, the maxillary central incisor is distinguishable only from the reduced incisors of Au. robustus. The maxillary canine is narrower than all canines of Au. africanus except TM 1512, whereas the mandibular canine falls well below the range of Au. africanus. Premolars and molars are at the lower end of the Au. africanus range and within that of H. habilis-H. rudolfensis and H. erectus. Molar dimensions of the adult individual (MH2) are smaller than those of Au. africanus, are at or below the range of those of H. habilis-H. rudolfensis, and are within the range of those of H. erectus. Au. sediba mirrors the Au. africanus pattern of maxillary molars that increase slightly in size posteriorly, though it differs in that the molars tend to be considerably larger in the latter taxon. Conversely, the Au. sediba pattern varies slightly from that seen in specimens KNM-ER 1813, OH 13, and OH 65 and H. erectus, wherein the molars increase from M¹ to M² but then decrease to M³. In broad terms, the teeth of Au. sediba are similar in size to teeth of specimens assigned to Homo but share the closely spaced cusp apices seen in Australopithecus.

Postcranium. Preserved postcranial remains of *Au. sediba* (table S1) denote small-bodied

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hominins that retain an australopith pattern of long upper limbs, a high brachial index, and relatively large upper limb joint surfaces (table S2). In addition to these aspects of limb and joint proportions, numerous other features in the upper limb are shared with sibling species of Australopithecus (to the exclusion of later Homo), including a scapula with a cranially oriented glenoid fossa and a strongly developed axillary border; a prominent conoid tubercle on the clavicle, with a pronounced angular margin; low proximal-to-distal humeral articular proportions; a distal humerus with a marked crest for the brachioradialis muscle, a large and deep olecranon fossa with a septal aperture, and a marked trochlear/capitular keel (19); an ulna with a pronounced flexor carpi ulnaris tubercle; and long, robust, and curved manual phalanges that preserve strong attachment sites for the flexor digitorum superficialis muscle.

Numerous features of the hip, knee, and ankle indicate that Au. sediba was a habitual biped. In terms of size and morphology, the proximal and distal articular ends of the femur and tibia fall within the range of variation of specimens attributed to Au. africanus. However, several derived features in the pelvis link the Malapa specimens with later Homo. In the os coxa (Fig. 4), Au. sediba shares with Homo a pronounced acetabulocristal buttress; a more posterior position of the cristal tubercle; a superoinferiorly extended posterior iliac blade, with an expanded retroauricular area; a sigmoid-shaped anterior inferior iliac spine; a reduced lever arm for weight transfer between the auricular surface and the acetabulum; an enlarged and rugose iliofemoral ligament attachment area; a tall and thin pubic symphyseal face; and a relatively short ischium with a deep and narrow tuberoacetabular sulcus. These features are present in taxonomically unassigned postcranial remains from Koobi Fora (KNM-ER 3228) and Olduvai Gorge (OH 28), which have been argued to represent early *Homo* (20), as well as in early *Homo erectus* (21). An os coxa from Swartkrans (SK 3155) has been considered by some to also represent early *Homo* (22) but can be seen to possess the australopith pattern in most of these features. In addition, *Au. sediba* shares with later *Homo* the humanlike pattern of low humeral-to-femoral diaphyseal strength ratios, in contrast to the ape-like pattern seen in the *H. habilis* specimen OH 62 (table S2).

Although aspects of the pelvis are derived, the foot skeleton is more primitive overall, sharing with other australopiths a flat talar trochlea articular surface with medial and lateral margins with equal radii of curvature, and a short, stout, and medially twisted talar neck with a high horizontal angle and a low neck torsion angle



Fig. 3. Dental size of a selection of *Au. sediba* teeth compared to other early hominin taxa; see fig. S4 for additional teeth. Dental measurements were taken as described by Wood (*6*). Owing to small sample sizes, *H. habilis* and *H. rudolfensis* were combined. (**A**) Upper central incisor mesiodistal (MD) length. (**B**) Upper canine MD length. (**C**) Lower canine MD length. (**D**) Square root of calculated [MD × BL (BL, buccolingual)] upper third premolar area. (**E**) Square root of calculated (MD × BL) upper second molar area. (**F**) Square root of calculated (MD × BL) lower second molar area. Measures were taken on original specimens by D.J.D. for *Au. africanus*, *Au. robustus*,

and *Au. sediba*. Measurements for *Au. afarensis*, *H. habilis*, *H. rudolfensis*, and *H. erectus* are from (*6*). P⁴ is not fully erupted on the right side of MH1, therefore measures of the maxillary postcanine dentition are presented for the left side only. Dental metrics for *Au. sediba* are as follows (MD, BL, in millimeters): Maxillary: MH1: RI1 10.1, 6.9; LI2 7.7 (damaged), 5.1; RC 9.0, 8.8; LP3 9.0, 11.2; LP4 9.2, 12.1; LM1 12.9, 12.0; LM2 12.9, 13.7; LM3 13.3, 14.1; MH2: RM3 11.3, 12.9. Mandibular: MH1: LC 8.0, 8.5; RM1 12.5, 11.6; RM2 14.4, 12.9; RM3 14.9, 13.8; MH2: RM1 11.8, 11.1; RM2 14.1, 12.2; RM3 14.2, 12.7; LM3 14.1, 12.5.



Fig. 4. Representative ossa coxae, in lateral view, from left to right, of *Au. afarensis* (AL 288-1), *Au. africanus* (Sts 14), *Au. sediba* (MH1), and *H. erectus* (KNM-WT 15000). The specimens are oriented so that the iliac blades all lie in the plane of the photograph (which thus leads to differences between specimens in the orientation of the acetabula and ischial tuberosities). MH1 possesses derived, *Homo*-like morphology compared to other australopithecines, including a relative reduction in the weight transfer distance from the sacroiliac (yellow) to hip (circle)

joints; expansion of the retroauricular surface of the ilium (blue arrows) (determined by striking a line from the center of the sphere representing the femoral head to the most distant point on the posterior ilium; the superior arrow marks the terminus of this line, and the inferior arrow marks the intersection of this line with the most anterior point on the auricular face); narrowing of the tuberoacetabular sulcus (delimited by yellow arrows); and pronouncement of the acetabulocristal (green arrows) and acetabulosacral buttresses.

(table S2 and fig. S5). The calcaneus is markedly primitive in its overall morphology: the bone is strongly angled along the proximodistal axis, with the point of maximum inflexion occurring at an enlarged peroneal trochlea; the lateral plantar tubercle is lacking; the calcaneal axis is set about 45° to the transverse plane; and the calcaneocuboid facet is vertically set and lacks an expanded posterior projection for the beak of the cuboid (23).

Discussion. The age and overall morphology of Au. sediba imply that it is most likely descended from Au. africanus, and appears more derived toward Homo than do Au. afarensis, Au. garhi, and Au. africanus. Elsewhere in South Africa, the Sterkfontein cranium Stw 53, dated to 2.0 to 1.5 Ma, is generally considered to represent either H. habilis (10, 24, 25) or perhaps an undiagnosed form of early Homo (26). It played an important role in the assignment of OH 62 to H. habilis (27). However, the derived craniodental morphology of Au. sediba casts doubt on the attribution of Stw 53 to early Homo [see also (28)]: Stw 53 appears to be more primitive than MH1 in retaining closely spaced temporal lines: marked postorbital constriction; a weakly developed supraorbital torus; narrow, nonprojecting nasal bones; anterior pillars; marked nasoalveolar prognathism; medial and lateral expansion of the frontal process of the zygomatic bone; and laterally flared zygomatics. If Stw 53 instead represents Au. africanus, the assignment of OH 62 to H. habilis becomes tenuous. Attribution of the partial skeleton KNM-ER 3735 to H. habilis was tentatively based, in part, on a favorable comparison with OH 62 and on the hypothesis that there were no other contemporaneous nonrobust australopith species to which it could be assigned in East Africa (29). As a result, the interpretation of KNM-ER 3735 as *H. habilis* also becomes uncertain.

The phylogenetic significance of the cooccurrence of derived postcranial features in Au. sediba, H. erectus, and a sample of isolated fossils generally referred to Homo sp. indet. (table S2) is not clear: The latter might represent early H. erectus, it might sample the postcranium of H. rudolfensis (which would then imply an evolutionary pathway from Au. sediba to H. rudolfensis to H. erectus), or it might represent the postcranium of H. habilis [which would suggest that OH 62 and KNM-ER 3735 (two specimens with ostensibly more primitive postcranial skeletons) do not belong in this taxon]. If the latter possibility holds, it could suggest a phylogenetic sequence from Au. sediba to H. habilis to H. erectus. Conversely, although the overall postcranial morphology of Au. sediba is similar to that of other australopiths, a number of derived features of the os coxa align the Malapa hominins with later Homo (H. erectus) to the exclusion of other australopiths. Additionally, Au. sediba shares a small number of cranial traits with H. erectus that are not exhibited in the H. habilis-H. rudolfensis hypodigm, including slight postorbital constriction and convexity of the infraorbital region (18). Following on this, MH1 compares favorably with SK 847 (H. erectus) in the development of the supraorbital torus, nasal bones, infraorbital region, frontal process of the zygomatic, and subnasal projection. However, MH1 differs from SK 847 in its relatively smaller size, the robust glabelar region, the weakly developed supratoral sulcus, the steeply inclined zygomaticoalveolar crests with a

high masseter origin, and the moderate canine juga, all features aligning MH1 with *Australopithecus*. It is thus not possible to establish the precise phylogenetic position of *Au. sediba* in relation to the various species assigned to early *Homo*. We can conclude that combined craniodental and postcranial evidence demonstrates that this new species shares more derived features with early *Homo* than does any other known australopith species (Table 1 and table S2) and thus represents a candidate ancestor for the genus, or a sister group to a close ancestor that persisted for some time after the first appearance of *Homo*.

The discovery of a <1.95-million-year-old (16) australopith that is potentially ancestral to Homo is seemingly at odds with the recovery of older fossils attributed to the latter genus (5) or of approximately contemporaneous fossils attributable to H. erectus (6, 30). However, it is unlikely that Malapa represents either the earliest or the latest temporal appearance of Au. sediba, nor does it encompass the geographical expanse that the species once occupied. We hypothesize that Au. sediba was derived via cladogenesis from Au. africanus (\approx 3.0 to 2.4 Ma), a taxon whose first and last appearance dates are also uncertain (31). The possibility that Au. sediba split from Au. africanus before the earliest appearance of Homo cannot be discounted.

Although the skull and skeleton of *Au. sediba* do evince derived features shared with early *Homo*, the overall body plan is that of a hominin at an australopith adaptive grade. This supports the argument, based on endocranial volume and craniodental morphology, that this species is most parsimoniously attributed to the genus *Australopithecus*. The Malapa specimens dem-

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onstrate that the evolutionary transition from a small-bodied and perhaps more arboreal-adapted hominin (such as Au. africanus) to a largerbodied, possibly full-striding terrestrial biped (such as H. erectus) occurred in a mosaic fashion. Changes in functionally important aspects of pelvic morphology, including a reduction of the sacroacetabular weight-bearing load arm and enhanced acetabulosacral buttressing (reflecting enhancement of the hip extensor mechanism), enlargement of the iliofemoral ligament attachment (reflecting a shift in position of the line of transfer of weight to behind the center of rotation of the hip joint), enlargement of the acetabulocristal buttress (denoting enhancement of an alternating pelvic tilt mechanism), and reduction of the distance from the acetabulum to the ischial tuberosity (reflecting a reduction in the moment arm of the hamstring muscles) (20, 32)occurred within the context of an otherwise australopith body plan, and seemingly before an increase in hominin encephalization [in contrast to the argument in (33)]. Relative humeral and femoral diaphyseal strength measures (table S2) also suggest that habitual locomotor patterns in Au. sediba involved a more modern human-like mechanical load-sharing than that seen in the H. habilis specimen OH 62 (34, 35). Mosaic evolutionary changes are mirrored in craniodental morphology, because the increasingly wide spacing of the temporal lines and reduction in postorbital constriction that characterize Homo first appeared in an australopith and before significant cranial expansion. Moreover, dental reduction, particularly in the postcanine dentition, preceded the cuspal rearrangement (wide spacing of postcanine tooth cusps) that marks early Homo.

The pattern of dental eruption and epiphyseal fusion exhibited by MH1 indicates that its age at death was 12 to 13 years by human standards, whereas in MH2 the advanced degree of occlusal attrition and epiphyseal closure indicates that it had reached full adulthood (SOM text S1). Although juvenile, MH1 exhibits pronounced development of the supraorbital region and canine juga, eversion of the gonial angle of the mandible, and large rugose muscle scars in the skeleton, all indicating that this was a male individual. And, although fully adult, the mandible and skeleton of MH2 are smaller than in MH1, which, combined with the less rugose muscle scars and the shape of the pubic body of the os coxa, suggests that MH2 was a female. In terms of dental dimensions, MH1 has mandibular molar occlusal surface areas that are 10.7% (M_1) and 8.1% (M_2) larger than those of MH2. Dimorphism in the postcranial skeleton likewise is not great, though the juvenile status of MH1 tends to confound efforts to assess adult body size. The diameter of the proximal epiphysis for the femoral head of MH1 (29.8 mm) is approximately 9.1% smaller than the superoinferior diameter of MH2's femoral head (32.7 mm). It is likely that MH1 would have experienced some appositional increase in joint size before maturity, thus this disparity would probably have decreased somewhat. The distal humeral epiphysis of MH1 is fully fused and its articular breadth (35.3 mm) is only marginally larger than that of MH2 (35.2 mm). Thus, although the dentition and postcranial skeleton are at odds in the degree of apparent size differences, the overall level of dimorphism, if these sex attributions are correct, appears slight in the Malapa hominins and was probably similar to that evinced by modern humans.

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- 19. Some humeri that are probably best attributed to Australopithecus lack marked development of the trochlear/capitular keel [or "lateral crest": see (37)], and thus the absence of a marked crest does not reliably differentiate Australopithecus from Homo. However, although some specimens of early Homo (such as KNM-WT 15000) have crests that are more strongly developed than those of modern humans, none exhibit the marked crests of the australopiths. Thus, the marked crest seen in the Malapa humeri can be seen to be shared with Australopithecus rather than Homo.
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- 41. We thank the South African Heritage Resources Agency for the permits to work at the Malapa site: the Nash family for granting access to the Malapa site and continued support of research on their reserve; the South African Department of Science and Technology, the South African National Research Foundation, the Institute for Human Evolution, the Palaeontological Scientific Trust, the Andrew W. Mellon Foundation, the AfricaArray Program, the U.S. Diplomatic Mission to South Africa, and Sir Richard Branson for funding: the University of the Witwatersrand's Schools of Geosciences and Anatomical Sciences and the Bernard Price Institute for Palaeontology for support and facilities; the Gauteng Government, Gauteng Department of Agriculture, Conservation and Environment and the Cradle of Humankind Management Authority; E. Mbua, P. Kiura, V. Iminjili, and the National Museums of Kenya for access to comparative specimens: Optech and Optron: Duke University; the Ray A. Rothrock Fellowship of Texas A&M University; and the University of Zurich 2009 Field School, Numerous individuals have been involved in the ongoing preparation and excavation of these fossils, including C. Dube, B. Eloff, C. Kemp, M. Kgasi, M. Languza, J. Malaza, G. Mokoma, P. Mukanela, T. Nemvhundi, M. Ngcamphalala, S. Jirah, S. Tshabalala, and C. Yates. Other individuals who have given significant support to this project include B. de Klerk, C. Steininger, B. Kuhn, L. Pollarolo, B. Zipfel, J. Kretzen, D. Conforti, J. McCaffery, C. Dlamini, H. Visser, R. McCrae-Samuel, B. Nkosi, B. Louw, L. Backwell, F. Thackeray, and M. Peltier. T. Stidham helped construct the cladogram in fig. S3, 1, Smilg facilitated computed tomography scanning of the specimens. R. Clarke and F. Kirera provided valuable discussions on these and other hominin fossils in Africa.

www.sciencemag.org/cgi/content/full/328/5975/195/DC1 SOM Text 1 to 4 Figs. S1 to S5 Tables S1 and S2 References

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CORRECTIONS & CLARIFICATIONS

ERRATUM

Post date 17 December 2010

Research Articles: "Australopithecus sediba: A new species of Homo-like Australopith from South Africa" by L. R. Berger *et al.* (9 April, p. 195). In the legend of Fig. 3, the mesiodistal diameter of the RM2 of the mandible of the adult individual MH2 should be 13.1 mm (not 14.1 mm). In Fig. 4, the specimen number of the pelvis of Australopithecus afarensis (Lucy) should be A.L. 288-1 (not A.L. 228-1). These errors do not affect the Research Article's conclusions.



LETTERS

edited by Jennifer Sills

China's Plan Flawed But Courageous

IN HER NEWS FOCUS STORY "HAS CHINA OUTgrown the one-child policy?" (17 September, p. 1458), M. Hvistendahl explores the consequences of China's fertility policies. Overall, the story presents the one-child policy in a negative light, buttressed by statistical data, such as the current gender ratio of 119:100 at birth and the projected graying of the Chinese population. These data are accurate but misleadingly incomplete. The single most relevant statistic is the one that drove the original decision to implement the policy: the total population of China as a function of time. Even with the reduced population growth that came with the one-child policy and with China's rapid shift toward



an urbanized and export-driven economy, those numbers are sobering. In 1960, China had a population of 646 million; in 1980, it was 981 million; by 2000, it had grown to 1.267 billion; and in 2010, it is projected to be 1.354 billion (1). In the past 50 years, China's population has increased by an amount equal to or greater than the population of all of Central and North America (~500 million). Without defending or criticizing the one-child policy, we can at least recognize that it stands as a brave attempt by the inhabitants of an overcrowded planet to create a more livable future for our children and grandchildren.

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Reference

 United Nations, Department of Economic and Social Affairs, Population Division, Population Estimates and Projections Section, World Population Prospects: The 2008 Revision (http://esa.un.org/unpd/wpp2008/ tab-sorting_population.htm).

ScienceReaders' PicksTALK

Your Breakthrough Nominations

EVERY YEAR, THE EDITORS AT *SCIENCE* GET TOGETHER TO LOOK back and decide which scientific advances merit the title of Breakthrough of the Year. This year, we also asked you, our readers, to weigh in with your nominations on our Web site. You responded immediately with a wide range of worthy ideas, and your comments were still pouring in as the magazine went to press.

As it turned out, almost all of your nominations overlapped with our selections. However, you felt that our number-one pick, the first quantum machine, was a distant dark horse to the synthetic-biology results we deemed a runner-up.

You also pointed to some results that didn't make our list. Of these nominations, the overwhelming favorite was the arsenic-based bacterium that *Science* published online on 2 December. The News editors who selected our breakthroughs agree that the idea of a life form with arsenic in its DNA is, as one of you put it, "effing badass!" But because the paper ran late in the year, we feel it is prudent to allow for further analysis before giving it a nod. Other recent results you felt warranted attention, such as the apparent reversal of aging in genetically engineered mice by researchers at Harvard University, fell into our wait-and-see category as well.

CERN physicists' success in trapping atoms of antihydrogen, reported in November, also justifiably impressed readers. We passed it over only because it's sure to be quickly overshadowed by follow-up experiments to measure critical properties of the mysterious antimatter.

The rest of your suggestions were all over the scientific map. They include basic research (the crystal structure of the eukaryotic ribosome and quantum entanglement in solid-state circuits); far-flung results such as the detection of free oxygen on Saturn's moon Rhea ("totally amazing"); various transformations of stem cells; and mind-boggling speculations from theoretical physics (the holographic universe). Only a couple of inventions crept in, notably a mechanical walker for paralyzed people. One techminded reader asked, "Is there any way we can sneak the commercial realization of memristors in here?" (That's not *Science*'s kind of breakthrough, but you could try *Business Week*.)

We thank the many readers who participated in our Breakthrough discussion. You can read all the suggestions sent by your fellow readers, including those sent after our press deadline, at *Science*'s Talk page (talk.sciencemag.org) and the Facebook page for our online news outlet, *Science*NOW. *SCIENCE* NEWS STAFF

Regulating Genetic Tests: Account for Benefits

THE POLICY FORUM "REGULATING DIRECT-TOconsumer personal genome testing" (A. L. McGuire *et al.*, 8 October, p. 181) perpetuates the myth that risk-based stratification represents the best way to regulate direct-toconsumer genome tests. In fact, risk-based regulation fails to account for tolerability of risk (I), where the greater the expected benefit, the greater should be the tolerability of risk. The proposed method would likely delay access to all test results deemed high risk, regardless of the potential benefit of those results to the patient.

Sophisticated regulation based on tolerability of risk reduces the approval time and evidentiary requirements for the products with the highest potential for benefit. The U.S. Food and Drug Administration (FDA) already applies this strategy by granting an accelerated approval process for life-saving drugs, yet the agency often appears to take the opposite approach for diagnostic tests. This is an important issue as FDA considers expanding its reach into tests developed in laboratories. For many direct-to-consumer genetic tests, it is the absence of actionable benefit that appropriately reduces the tolerability of risk, not a high level of risk in absolute terms. The Policy Forum should have more explicitly stated that for patients, the harm caused by delaying a new test can be greater than the benefit of the regulation itself.

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Reference

 F. Bouder, D. Slavin, R. Lofstedt, *The Tolerability of Risk:* A New Framework for Risk Management (Earthscan, London, 2007).

Regulating Genetic Tests: Who Owns the Data?

DIRECT-TO-CONSUMER (DTC) GENETIC TESTing is not as dangerous as A. L. McGuire *et al.* suggest ("Regulating direct-to-consumer personal genome testing," Policy Forum, 8 October, p. 181). The belief that genetic information will compel consumers to behave unreasonably is unfounded.

Unlike the classical genetic tests that look for rare genetic abnormalities (such as Huntington's disease), genetic tests sold directly to consumers cannot diagnose a disease. They merely provide information about DNA sequence variations, or singlenucleotide polymorphisms (SNPs). Certain SNPs can be found more often among individuals with a particular disease or condition. For example, one particular combination of two SNPs in the APOE gene occurs 3 to 20 times more frequently in individuals with Alzheimer's (1). Consequently, a person with this particular combination of SNPs could be at a greater risk to develop Alzheimer's; the mere presence of these SNPs is not diagnostic.

There is no reason to require government approval before allowing a person to see his or her own genetic information. After receiving results that indicate a healthrelated risk, a person will likely see a doctor to determine the next appropriate step. This action would be no different from a person's response to learning that he or she has increased blood pressure, cholesterol, or weight. Should DTC sales of weight scales be regulated too?

The real question is what will happen if governments, big pharma, committees, and other faceless bodies gain control of our genetic information. College admissions based on genotype? Advertising geared to those with a particular SNP? This is a question for the ethicists to ponder.

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Reference

1. L. Bertram et al., Nat. Genet. 39, 17 (2007).

Response

IN OUR POLICY FORUM "REGULATING DIRECTto-consumer personal genome testing" (8 October, p. 181), we recommend a riskstratified regulatory approach for direct-toconsumer (DTC) genetic tests. If tests are low risk (as existing data indicate for the vast majority of tests sold DTC) then the oversight should be minimal and should focus on ensuring that consumers have accurate and truthful information. Only high-risk tests would be subject to greater oversight and enhanced scrutiny by agencies such as the U.S. Food and Drug Administration (FDA).

Williams argues that this type of riskbased strategy fails to account for the impact of benefit on the tolerability of risk. We agree that benefit is an important consideration. A high-risk test that has the potential to benefit consumers significantly, and thus has proven therapeutic utility, should be cleared or approved for distribution. In fact, the sort of external data-driven review that would be required to assess benefit is precisely what the FDA would provide when evaluating a high-risk new test product. However, the primary goal of regulatory oversight is to ensure consumer safety, so regardless of the potential for benefit, a test that poses significant risk ought to be subject to external review. The data required for the review in this circumstance allow regulators to take into account both risks and benefits.

Williams also argues that delayed access to a new test may prevent the introduction of life-saving diagnostics. We are not aware of any evidence that life-saving genetic tests, such as those used in newborn screening, are being delayed, but we agree that waiting for robust effectiveness data could effectively regulate DTC companies out of existence and should be avoided. We therefore believe that the FDA's premarket oversight should focus on the legitimacy of claims made and that there should be enhanced postmarket data collection and surveillance. This approach is quite flexible in terms of the amount and type of evidence required for a test to move to market. It is more hospitable to innovative tests than is the case in many other countries, such as Germany, where DTC testing has been banned.

Baskys believes that all individuals have a right to receive their genetic information. We do not necessarily disagree. We simply argue that consumers need access to accurate and truthful information in order to make informed decisions. For tests that have the potential to influence important medical decisions, this includes contextual information about the individual's other risk factors, including family history, environmental exposures, and biological symptoms. We agree that there is a dearth of scientific evidence on the potential risks associated with receiving genetic information DTC; there is also a lack of evidence of the potential benefits. As noted by Baskys, there are few, if any, DTC tests that have as much predictive value as a blood pressure test or a weight scale. Indeed, available evidence tells us that genetic risk information does little to motivate healthy behavior change (1). Given this reality, it seems appropriate that the vast majority of

Letters to the Editor

Letters (~300 words) discuss material published in *Science* in the previous 3 months or issues of general interest. They can be submitted through the Web (www.submit2science.org) or by regular mail (1200 New York Ave., NW, Washington, DC 20005, USA). Letters are not acknowledged upon receipt, nor are authors generally consulted before publication. Whether published in full or in part, letters are subject to editing for clarity and space. DTC tests will not require significant oversight, as per our stratified approach.

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Reference

 T. M. Marteau *et al.*, "Effects of communicating DNA-based disease risk estimates on risk-reducing behaviours" (*Cochrane Database of Systematic Reviews*, issue 10, 10.1002/14651858.CD007275.pub2, 2010).

CORRECTIONS AND CLARIFICATIONS

Books *et al.*: "How neuromythologies support sex role stereotypes" by D. F. Halpern (3 December, p. 1320). An error was introduced during the production process. Reference 5 should read: R. A. Lippa, M. L. Collaer, M. Peters, *Arch. Sex. Behav.* **39**, 997 (2010).

Reports: "A low-magnetic-field soft gamma repeater" by N. Rea *et al.* (12 November, p. 944). Paolo Esposito's

affiliation contained an error. He is at the Osservatorio Astronomico di Cagliari. The affiliation has been corrected in the HTML version online.

Random Samples: "What, us bitter?" (8 October, p. 157). The accompanying photograph mistakenly showed a scene in the Swiss Alps, not the Pamir Mountains.

Research Articles: "Australopithecus sediba: A new

species of *Homo*-like Australopith from South Africa" by L. R. Berger *et al.* (9 April, p. 195). In the legend for Fig. 3, the mesiodistal diameter of the RM2 of the mandible of the adult individual MH2 should be 13.1 mm (not 14.1 mm). In Fig. 4, the specimen number of the pelvis of *Australopithecus afarensis* (Lucy) should be A.L. 288-1 (not A.L. 228-1). These errors do not affect the Research Article's conclusions.

TECHNICAL COMMENT ABSTRACTS

Comment on "The Incidence of Fire in Amazonian Forests with Implications for REDD"

Jennifer K. Balch, Daniel C. Nepstad, Paulo M. Brando, Ane Alencar

Aragão and Shimabukuro (Reports, 4 June 2010, p. 1275) reported that fires increase in agricultural frontiers even as deforestation decreases and concluded that these fires lead to unaccounted carbon emissions under the United Nations climate treaty's tropical deforestation and forest degradation component. Emissions from post-deforestation management activities are, in fact, included in these estimates—but burning of standing forests is not. Full text at www.sciencemag.org/cgi/content/full/330/6011/1627-b

Response to Comment on "The Incidence of Fire in Amazonian Forests with Implications for REDD"

Luiz E. O. C. Aragão and Yosio E. Shimabukuro

Balch *et al.* suggest that the increased fire frequency reported in our study is principally due to post-deforestation activities. We present a new analysis demonstrating that for the majority of grid cells with positive fire trends, there is a low likelihood that these trends have resulted exclusively from post-deforestation activities. We therefore confirm that fires pose a growing threat to reducing emissions from deforestation and degradation (REDD) policies. Full text at www.sciencemag.org/cgi/content/full/330/6011/1627-c



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