

Species comparison of stages_full text

	CfS	dog (Travis, Meyers-Wallen)	TS	mouse (reference: Theiler) 1-20 hrs	CS	human (reference: O'Rahilly & Miller)
	CfS 1	Litters: TM_IVF_090, d6	TS 1	Theiler stage characterized by	CS 1	Carnegie stage
gamete or zygote		One cell oocyte in oviduct (Primary oocyte)		One celled egg Begins with fertilization of egg in metaphase stage of the meiotic second maturation division Male and female pronuclei present at 20 hrs		Ovulated oocyte to unicellular zygote prior to first cleavage

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	CfS	dog (Travis, Meyers-Wallen)	TS	mouse (reference: Theiler) 1-20 hrs	CS	human (reference: O'Rahilly & Miller)
	CfS 2	Litters: TM_IVF_090, d8	TS 2	Theiler stage characterized by	CS 2	Carnegie stage
gamete or zygote		Zygote at 2 cell stage		Beginning of zygote segmentation Starts with completion of first cleavage division, ends with zygotes at 2 cell stage maximum		Zygotes at 2 cells or more, but not including blastocyst stage

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	CfS	dog (Travis, Meyers-Wallen)	TS	mouse (reference: Theiler) 2 dpc	CS	human (reference: O'Rahilly & Miller)
	CfS 3	Litters: TM_IVF_090, d8-9	TS 3	Theiler stage characterized by	CS 2	Carnegie stage
gamete or zygote		Zygotes at 4-16 cell stage morulae but morulae have no cavity present between cells		Advanced segmenting embryos, morulae Includes zygotes from 2 cells to 16 cell morulae but no cavity present between cells of morulae		Zygotes at 2 cells or more, but not including blastocyst stage

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	CfS	dog (Travis, Meyers-Wallen)	TS	mouse (reference: Theiler) 4 days	CS	human (reference: O'Rahilly & Miller)
	CfS 4	Litter: Kim & Travis, d14	TS 5	Theiler stage characterized by free blastocyst	CS 3	Carnegie stage
gamete or zygote		Blastocysts free floating in the uterus Embryoblastic cells are clustered at the embryonic pole		Blastocysts free floating in the uterus Embryoblastic cells are clustered at the embryonic pole		Free blastocyst, as soon as the blastocystic cavity is present & prior to attachment

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	CFS	dog (Meyers-Wallen)	TS	mouse (references: Theiler/eMAP/GUDmap)	CS	human (reference: O'Rahilly & Miller)
	CFS 14	Litters: PMDS 158	TS 17	Theiler stage characterized by deep lens indentation in eye	CS 14	Carnegie stage
forelimb	CFS 14	Tapering, rounded at tip, but no indentation in stalk (A996)	TS 17			
hindlimb	CFS 14	Triangular, short with very wide base (A994)	TS 17		CS 14	
head	CFS 14	Eye: lens vesicle has pore-like opening to the surface Can identify: tel-, di- mes- and met-encephalon (A994) Telencephalon is an anterior clear vesicle Clear longitudinal vesicle posterior to eye is surrounded anteriorly by diencephalon & posteriorly by mes- & met-encephalon (A990, A994) No premaxilla present. Frontal view- maxillary process present	TS 17	Olfactory discs form a distinct marginal lip 1st branchial bar is divided into maxillary & mandibular processes All pharyngeal pouches seen in lateral view	CS 14	Invagination of lens disc but an open lens pit
head histology	CFS 14	Nasal pits lateral & rostral, with groove open ventrally between the lateral & medial nasal processes (A994) No premaxilla present. Present: mandibular & hyoid processes, auditory groove, which is the cleft between the mandibular & hyoid processes	TS 17	Most prominent feature is advancing development of the brain tube Optic recess/groove is a depression Rathke's pouch is narrowed	CS 14	
brain histology	CFS 14	Optic stalk/recess branching off from 3rd ventricle (A990) Rathke's pouch & infundibulum present (A996)	TS 17	Cerebral vesicles are distinct bulges Rhombencephalic portion is relatively large Optic recess present- floor of 3rd ventricle Rathke's pouch is an open indentation in pharynx floor	CS 14	Future hemispheres & cerebellar plates appear (telencephalon and metencephalon shelf)
eye gross	CFS 14	No gross retinal pigment visible (A994)	TS 17	Lens vesicle forms deep pocket or pore-like opening to the surface	CS 14	Invagination of lens disc Lens pit is open to the surface
eye histology	CFS 14	Invagination of lens pit but lens vesicle open to the surface (A996)	TS 17	Lens vesicle forms deep pocket or pore-like opening to the surface	CS 14	
lungs	CFS 14	Two primary bronchi & sacs present (A991). Advanced ones have slight bulge on primary bronchi (A989) or definite bulge on one primary bronchus (A991)	TS 17	Lung bud elongating	CS 14	
liver	CFS 14	Not examined	TS 17	Hepatic cords invading mesenchyme of septum transversum	CS 14	
metanephric kidney	CFS 14	Ureteric bud has started & has small metanephrogenic cap (A989)	TS 17	Ureteric bud forming	CS 14	Ureteric bud acquires metanephrogenic cap
cloaca/not	CFS 14	Not examined	TS 17	Cloacal membrane not yet ruptured	CS 14	
genital tracts	CFS 14	Gonad has not emerged from mesonephros (A994)	TS 17	Mesonephric (Wolffian) duct ends blindly in cloacal wall Mesonephros has no glomeruli	CS 14	
ear	CFS 14	Auditory vesicle present (A990)	TS 17	Otic vesicle has a short endolymphatic duct	CS 14	
heart	CFS 14	Grossly, heart bulges above the ventral body wall (A990) Cardiac tube has looped, but is still a single tube, and has 2 atrial buds and 2 ventricular swellings (A990, A995)	TS 17	Heart is a single curved tube with 2 constrictions: sulcus atrioventricularis & sulcus sinuatrialis	CS 14	

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	CfS	dog (Meyers-Wallen)	TS	mouse (references: Theiler/eMAP/GUDmap)	CS	human (reference: O'Rahilly & Miller)
	CfS 15	Litters: PMDS 159 & 161	TS 18	Theiler stage characterized by Closure of lens vesicle	CS 15	Carnegie stage
forelimb	CfS 15	Longer than CfS 14, with rounded tip Stalk is indented on one side (A998)	TS 18			
hindlimb	CfS 15	Larger than CfS 14, still triangular with wide base & no stalk (A998)	TS 18		CS 15	
head	CfS 15	No premaxilla (A998, A1015) Head till translucent so can see internally Nasal pits more frontal than previous stage Lateral nasal process present	TS 18	Lens vesicle closed	CS 15	Note prominent lateral border of nasal pit = lateral nasal process
head histology	CfS 15	No example	TS 18	Olfactory pit deeper & bordering rims beginning to unite Otocyst has an elongated endolymphatic duct	CS 15	
brain histology	CfS 15	No example	TS 18	Infundibular recess distinct Lateral ventricles beginning to form Diencephalon basal recesses clear Olfactory plate deeper & bordering rims uniting	CS 15	
eye gross	CfS 15	Retinal pigment absent (A1015) or just begun as faint semicircle with thinnest portion rostroventrally (A998)	TS 18		CS 15	Retinal pigment appears in external layer of optic cup (in histology, not obvious grossly)
eye histology	CfS 15	Lens vesicle is closed, has round shape & closely apposed to overlying ectoderm (A990, A1001)	TS 18	Lens vesicle closed Lens vesicle begins to detach from ectoderm	CS 15	Lens vesicle is closed Lens can still be attached to surface Retinal pigment appears in optic cup external layer
lungs	CfS 15	2 primary bronchi & sacs present Each sac has ≥ 2 lateral swellings with a rounded tip (A998)	TS 18	Lung bud present	CS 15	Swelling of main bronchi starts in CS 15 Lobar buds appear as focal swellings at the sites of future secondary bronchi
liver	CfS 15	Liver has 2 small flat lobes of similar size (A999, A1017)	TS 18	Stomach present	CS 15	
metanephric kidney	CfS 15	Ureteric bud has longer stalk & a bifurcated swelling at the tip that will become the pelvis of the ureter (A998) Metanephrogenic cap is larger than in CfS 14 (A998) Kidney is located near the caudal end of the mesonephros (A998)	TS 18		CS 15	Ureteric bud is longer and its tip is expanded as the pelvis of the ureter The primary urogenital sinus is distinguishable Kidney is located at the level of the sacrum
cloaca/not	CfS 15	Not examined	TS 18	Cloaca not yet subdivided	CS 15	
genital tracts	CfS 15	Gonad grossly inapparent at medial mesonephros, as in CfS 14 Male (A1017) and female (A1015) gonads are SF1 + by WMISH	TS 18	Mesonephros- no change since previous stage Genital ridge more distinct, sex diagnosis not possible	CS 15	Gonadal ridges contain numerous cells
ear	CfS 15	No example	TS 18	Otocyst has an elongated endolymphatic duct	CS 15	
heart	CfS 15	Heart bulges a little above the ventral body wall (A1001) and otherwise grossly appears similar to CfS 14 (A999, A1017)	TS 18	Heart is a curved undivided tube bulbar ridges can be seen in sagittal sections	CS 15	
GI	CfS 15	Stomach is triangular (A999)	TS 18		CS 15	

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	CfS	dog (Meyers-Wallen)	TS	mouse (references: Theiler/eMAP/GUDmap)	CS	human (reference: O'Rahilly & Miller)
	CfS 16	Litters: PMDS 148, 164; SR 141	TS 19	Theiler stage characterized by complete lens closure & lens vesicle separated from surface ectoderm	CS 16	Carnegie stage
forelimb	CfS 16	Paddle shaped: stalk indented on both sides (A1043) Rounded tip, stalk width is smaller than paddle width No digital rays or notching of footplate border (A1043)	TS 19	Footplate formed, as indicated by definite constriction below tip of limb bud	CS 16	
hindlimb	CfS 16	Triangular shape or barely indented at base, stalk wider than or same width as the tip (A1043) No digital rays or notching of footplate border	TS 19	Hindlimb bud has no footplate yet	CS 16	
head	CfS 16	Insufficient translucence to view all structures within (A1043) Nasal pits face frontal & widely separated (A1042) Frontal view: elliptical nasal pits closing ventrally (joining of premaxilla process edge medially) causing ventrolateral slit Mandibular processes touching but not joined at center Premaxillary processes widely separated (A1042)	TS 19	Nostrils are narrow slits Nasolacrimal grooves clearly visible	CS 16	Nasal pits face ventral (no longer visible in lateral view) Cerebellar primordium increases the groove between it and the mesencephalon
head histology	CfS 16	Optic stalk closer to orbit of eye (C3287)	TS 19	Nasal pit is separated from oral cavity by the bucconasal membrane Vomeronasal (Jacobson's) organ present	CS 16	Neurohypophyseal evagination developing in advanced embryos (ie 50%) but is not very distinct
brain histology	CfS 16	Large optic recess to optic stalk (C3287) Optic stalk open almost to retina (C3287) Rathke's pouch below 3rd ventricle is circular (C3287)	TS 19	Little change from CfS 15 The opening of Rathke's pouch is constricted	CS 16	Cerebellar hemispheres bulge laterally No longitudinal fissure yet between cerebral hemispheres
eye gross	CfS 16	Retinal pigment is a faint circle Rostroventral aspect of retina is faintest (A1043)	TS 19		CS 16	Retinal pigment in external layer of retina is now apparent grossly Lens pit is D-shaped
eye histology	CfS 16	Lens vesicle closed, but near ectoderm (C3287) Two retinal layers visible: retinal pigment epithelium and sensory layers (C3287)	TS 19	Most conspicuous feature this stage is complete closure of lens vesicle & its detachment from the ectoderm Retinal pigment layer cells contain pigment granules	CS 16	Retinal pigment cells have few pigment granules
lungs	CfS 16	Two primary bronchi and sacs present (A1043) Three to four secondary buds on right primary bronchus Three secondary buds on left primary bronchus Some tertiary buds starting (A1045)	TS 19	Primary (stem) bronchi are developing secondary branches (lobar bronchi)	CS 16	
liver	CfS 16	Liver has 2 round lobes, only attached at one point medially Lobe width is less than stomach length (A1045) Stomach is triangular shape, widest at fundus (A1042)	TS 19	Liver is composed of broad hepatic cords separated by large sinusoids containing nucleated erythrocytes Stomach is much enlarged & separated from pancreas	CS 16	
metanephric kidney	CfS 16	No example	TS 19	Ureteric buds are distended & surrounded by condensed metanephrogenic tissue Glomerular anlagen may be recognized	CS 16	Pelvis of ureter becoming bipartite
cloaca/not	CfS 16	Not examined	TS 19	Cloacal membrane evident but has not ruptured	CS 16	
genital tracts	CfS 16	Spindle-shaped gonad present on medial mesonephros, can be seen by microscopy without staining (A1043) No gross difference between testis & ovary Male (A910) gonad is <i>SOX9</i> negative by WMISH	TS 19	Genital ridge is at the sexually indifferent stage Gonocytes have completed migration into gonads Mesonephric (Wolffian) ducts terminate blindly at cloaca	CS 16	Paramesonephric (Mullerian) duct begins to appear as an invagination of the coelomic epithelium over the mesonephros
ear & vestibular apparatus	CfS 16	Auricular hillocks appearing (A1043)	TS 19	Six tubercles that will form the pinna are visible Endolymphatic duct longer Utricle and saccule begin to appear	CS 16	Auricular hillocks beginning to appear Thickenings in walls of vestibular area indicate start of semicircular canals
heart	CfS 16	Heart bulges a little above ventral body wall (A1042) Both ventricles outflow to one blood vessel (A1044, A1047) Two atria & 2 ventricle precursors, one ventricle larger (C3287)	TS 19	Atria almost partitioned off by septum primum Intraluminally, ventricles are not separated yet by AV cushions	CS 16	Foramen secundum present between atria
GI	CfS 16	No example	TS 19		CS 16	Counterclockwise intestinal rotation begins

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	CFS	dog (Meyers-Wallen)	TS	mouse (references: Theiler/eMAP/GUDmap)	CS	human (reference: O'Rahilly & Miller)
	CFS 17	Litters: PMDS 152, 156, 160, 162; SR 140, 216	TS 20	Theiler stage characterized by earliest sign of digits	CS 17	Carnegie stage
forelimb	CFS 17	Paddle shaped, round edge, linear digital rays visible (A1023), stalk smaller than paddle width	TS 20	Earliest sign of digits Angular contour of plate (not round)		Hand plate has definite digital rays Handplate begins to have crenated rim from digit tips
hindlimb	CFS 17	Paddle shaped, round edge, stalk just smaller than paddle width, no evidence of digital rays (A1020)	TS 20	Footplate demarcated from rest of limb	CS 17	Hindfoot has a rounded digital plate separate from rest of limb
head	CFS 17	Nasal pits face forward, such that are not visible on lateral view (A972, A974, A1020) Maxilla has dorsal notch at center (A974) Premaxillary processes not joined medially (A972, A974) Mandibular arches fused medially (A974) (C3614 head RNA-seq)	TS 20		CS 17	Nasal pit further medial and directed ventrally Distinct nasofrontal grooves present in lateral view Emergence of nose and upper jaw (premaxilla) features Auricular hillocks exhibit characteristic form at this stage: 3 bumps on mandibular arch & 3 on hyoid arch
head histology	CFS 17	Telencephalon has 2 lobes (A974, early lateral ventricles) Auditory vesicle present (A974)	TS 20	Pharyngeal pouches #3&4 now budding out, still connecting to pharynx (#3 is thymus & parathyroid, #4 is ultimobranchial body) Tongue anlagen delimited from lower jaw by a furrow Tooth anlagen appear as epithelial thickenings Thyroid primordium attached near aortic arch	CS 17	Primordium of the palate established as primary palate Neurohypophysis is distinct evagination in all Adenohypophysis is still open toward pharyngeal cavity
brain histology	CFS 17	Rathke's pouch present (A974) Optic stalk attached to posterior pole of globe (A974)	TS 20		CS 17	Olfactory bulb starts as slight elevation in brain surface Adenohypophysis flattened dorsoventrally, spreads wide so its 2 wings enclose the infundibulum on each side
eye gross	CFS 17	Gross: retinal pigment rectangular shaped (A972) Pigment thinnest at rostroventral border (A972)	TS 20	Posterior wall of lens vesicle markedly thickened due to lens fiber differentiation	CS 17	
eye histology	CFS 17	Lens vesicle is round (reverse D-shaped: A1020) Retina layers: pigment epithelium and 2 sensory (A1020) Cell layer & space present between lens and exterior but no anterior chamber yet (A1020) Optic stalk has wide diameter, extends to posterior globe (A974)	TS 20	Eye has lens vesicle (vesicle anterior, reverse D) Lens fiber nuclei are at posterior lens Loose mesenchyme layer in cornea area, with no space between it and anterior lens Pigmented retinal epithelium present	CS 17	Retinal fissure is largely closed Lens cavity is becoming crescent shaped (thin reverse D) due to increasing lens fibers Starting: rostral migration of cells from posterior retina primary zone to form internal neuroblastic layer of retina Retinal pigment granules clearly visible microscopically
lungs	CFS 17	Two primary bronchi present. Five secondary branches on right primary bronchus, four on left (A1023) ≥2 secondary branches have 2 buds at tip (A1012, A1023) (C3614 lung RNA-seq)	TS 20	Lung buds have secondary (lobar) and tertiary (segmental) bronchi	CS 17	Bronchial tree shows segmental buds Condensations appear that will form tracheal cartilages Larynx becomes defined at this stage
liver	CFS 17	Two horizontal discs now joined medially (A1011, C3278) Width of discs larger than stomach length (A1011) (C3614 liver RNA-seq)	TS 20	Liver contains megakaryocytes (hematopoiesis) stomach distended	CS 17	Hepatic duct now apparent Intrahepatic biliary ducts form along portal vein branches
metanephric kidney	CFS 17	Kidney still located at mesonephros caudal pole Kidney has thin elliptical shape (A973), with two poles & ureter (A973) Renal pelvis extends as one tube, cranial to caudal (A973)	TS 20	Early this stage, kidney has only two polar tubes (pelvic poles), but advanced ones this stage have many secondary buds	CS 17	Beginning of metanephric calices Pelvis of ureter has 3 main divisions and calices appear Kidneys ascend to level of lumbar area (CS 17-23)
cloaca/not	CFS 17	Not examined	TS 20	Urorectal septum has not reached cloacal membrane	CS 17	
genital tracts	CFS 17	Gonad well emerged from medial mesonephros (A976) Testis is SOX9+ by WMISH (A1011) Ovary is SOX9 negative by WMISH (A1010) Testis & ovary are SF1+ by WMISH (A949, A950)	TS 20	Ureter opens into Mesonephric (Wolffian) duct, which then ends blindly in UG sinus epithelium Both gonads at sexually indifferent stage GUDmap: cranial mesonephros shows some evidence of regression	CS 17	Urogenital sinus is divided into 2 parts: pelvic (vesico urethral) and phallic (definitive UG sinus) Nipples appear as buds on mammary crest
ear	CFS 17	Auricular hillocks (A972) are an arrow shaped slit in lateral neck, ventral to eye & mouth Auditory vesicle present (A974, histology)	TS 20	Subdivisions of labyrinth present but semicircular canals are flat rather than tubes Auditory capsules still mesenchyme (not cartilage)	CS 17	Full complement of auricular hillocks present Auditory ossicles defined Semicircular canals not yet present
heart	CFS 17	4 subdivisions present as seen externally (A970, A1011) (C3614 heart RNA-seq)	TS 20	Truncus arteriosus being partitioned into two vessels Atrial septation is complete	CS 17	Foramen secundum & semilunar cusps apparent Foramen primum now obliterated. IV foramen open Fusion of AV cushions: R & L AV canals become separate Mitral & tricuspid valves still composed of mesenchyme
GI	CFS 17	Stomach length is smaller than liver width (A1011)	TS 20		CS 17	The intestinal loop herniates into the umbilical cord without rotation or coils

	TS	mouse (references: Theiler/eMAP/GUDmap)	CS	human (reference: O' Rahilly & Miller)
	TS 21	Theiler stage characterized by: indented hand plate	CS 18	Carnegie stage
forelimb	TS 21	Footplate is indented Digital rays started Forelimb contains cartilage, but footplate is mesenchyme	CS 18	Forelimb digital plate: Distinct digital rays and interdigital notches at rim (Reliable staging at this and further stages is dependent on histologic features of internal organs)
hindlimb	TS 21	Footplate is just becoming indented	CS 18	Rearlimb has digital rays in some, but rim is not notched
head	TS 21	Pinna forms a crest at right angles to head	CS 18	Still a small gap between premaxilla (frontal) Nose, nostrils, nasal septum now clearly identifiable Upper lip not differentiated as separate structure
head histology	TS 21	Choroid plexus projects into the lateral 4th ventricle (finger-like projections) Tongue projects from mouth floor Oral & nasal cavity communicate (palate totally open) Palatine processes are in vertical position (palate open) Dental lamina of molars present Meckel's cartilage present Epiglottis discretely separated from rest of larynx	CS 18	Nasal choanae develop Vomeronasal organ present as a groove in the medial wall of the nasal cavity (choanae) Nasal septum cartilage present in some First signs of choroid plexus in rostral lateral ventricles Olfactory bulb delineated, may have olfactory ventricle
brain histology	TS 21	Choroid plexus fully developed in lateral hemispheres & 4th ventricle, forming finger-like projections Pineal gland distinct Hypophysis rapidly developing Neurohypophysis & adenohypophysis closely apposed	CS 18	Adenohypophysis now closed off from the pharyngeal cavity
eye gross	TS 21		CS 18	Eye folds (early eyelids) present in advanced Pigmented retina is conspicuous in fixed (translucent) specimens
eye histology	TS 21	Lens vesicle has no lumen, is a solid sphere Vitreous body very small Retina: nuclear layers still indistinguishable from each other Lens fiber nuclei at midline Retinal pigment layer separate caudally	CS 18	Mesenchyme invades between lens epithelium and surface ectoderm (or earlier) to form anterior chamber Lens vesicle cavity is being obliterated by lens fibers
lungs	TS 21	Lungs clearly subdivided into lobes & segmented Bronchi are continuing to branch	CS 18	Segmental bronchi defined, subsegmental buds develop Larynx undergoing specialization Trachea has connective tissue coat
liver	TS 21	Liver well developed & contains blood-forming foci Liver, stomach, spleen (small) present	CS 18	
metanephric kidney	TS 21	Kidney has distended pelvis, well marked primary calyces & metanephric cap tissue (some form vesicles) S-shaped tubules and differentiating glomeruli present in some areas Ureter continuous with distended pelvis, contacts mesonephric duct and UG sinus	CS 18	Collecting tubules develop from calices Renal corpuscles not yet present Mesonephric duct and ureter open independently into vesicourethral canal (common excretory duct disappears) Kidneys ascend to lumbar level (CS 17-23)
cloaca/not genital tracts	TS 21	Cloaca completely subdivided: UG vs rectum	CS 18	Cloacal membrane ready to rupture
	TS 21	Sexual differentiation recognizable Testis: gonadal cords present (seminiferous tubules) & large primordial germ cells (1st seen 12.5 dpc) Ovary: female germ cells located peripherally, some dividing (oocytes in prophase shown) Mesonephric duct more developed in male Paramesonephric duct more developed in female	CS 18	Testicular cords appear in testis Paramesonephric duct grows caudally most of the way down the mesonephros (present in all embryos) Gonad is an elongated oval, distinct from mesonephros
ear	TS 21	Pinna forms a crest at right angles to head	CS 18	Auricular hillocks forming different parts of auricle Semicircular canals form in internal ear, in order of: anterior, posterior, & lateral Cochlear duct is L-shaped, stapedius can be identified
heart	TS 21	Aortic and pulmonary trunks completely separate Membranous part of IV septum not yet closed Fine coronary arteries visible All heart valves present in primitive form	CS 18	4 chambers present Pulmonary artery & aorta are separate outflow tracts Septum secundum appears: foramen ovale beginning Membranous part of IV septum beginning to form Pulmonary & aortic valves becoming cup shaped Only mesenchyme ridges present for AV valves
GI	TS 21	Stomach does not yet have differentiated glands Spleen appears as triangle in cross sections Pancreas has numerous sprouts in dorsal mesentery	CS 18	Fundus of stomach begins to develop (or at CS 19)

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	TS	mouse (references: Theiler/eMAP/GUDmap)	CS	human (reference: O'Rahilly & Miller)
	TS 22	Theiler stage characterized by: fingers separate distally	CS 19	Carnegie stage
forelimb	TS 22	Footplate: digits are just visible and separated distally	CS 19	(At \geq CS 19, it is necessary to use internal structure characteristics to accurately stage specimens) Humerus- chondrogenesis up to stage 3 but no signs of ossification
hindlimb	TS 22	Digits have deep indentations between them but are not yet separated	CS 19	Toe rays are prominent but interdigital notches not present yet at footplate rim
head	TS 22	Prominent eyelids	CS 19	
head histology	TS 22	Meckel's cartilage present, larynx is precartilaginous Tracheal rings are mesenchymal condensations Palatine processes are elevating but not fused, palate still open Tooth bud of 1st molar visible (others appear later) Anlagen of incisors may be present	CS 19	Adenohypophysis- Pars intermedia just present & lateral lobes present that will form pars tuberalis Vomeronasal organ- is a thickening of nasal epithelium & is the lining of a shallow groove Submandibular gland is an area of mesenchyme beneath the duct
brain histology	TS 22	Choroid plexus projects far into lateral ventricle lumen Sphenoid bone below pituitary is only cartilage at this stage Present: adenohypophysis, neurohypophysis, & pars intermedia Telencephalon: formation of primary cortex (superficial cortical layer) has begun	CS 19	Choroid plexus of 4th ventricle present in most embryos
eye gross	TS 22	Eyelids prominent but open	CS 19	
eye histology	TS 22	Vitreous body cavity much increased in size Ganglionic (clear) layer of retina appears as zone of clear nuclei, but the 2 darker inner layers are not separated	CS 19	Thin layer of mesenchyme lies anterior to cornea Optic nerve- fibers run a short distance from retina but do not reach middle region of the optic stalk
lungs	TS 22	Bronchi distended & have numerous branches Tracheal rings are mesenchymal condensations	CS 19	First generation of subsegmental bronchi complete
liver	TS 22		CS 19	
metanephric kidney	TS 22	eMAP: meta blastema in cortex & few tubules Circular structures appearing in medulla	CS 19	Metanephric kidney- formation of renal vesicles is beginning at tip of collecting tubules Kidneys ascend to level of lumbar area (CS 17-23)
cloaca/not genital tracts	TS 22		CS 19	Cloacal membrane ruptures (CS 18 or 19)
	TS 22	Ureter & mesonephric (Woffian) duct open separately to UG sinus Seminiferous tubules are solid strands of cells No cords in ovary In females: paramesonephric (Mullerian) ducts more developed than mesonephric (Woffian) ducts Tunica albuginea present in testis	CS 19	Rete testis develops from seminiferous tubules between CS19-23, & tunica albuginea forms Cords of the rete ovarii developing
ear	TS 22	Cochlear duct is a full circle bordered by thin cartilage capsule Pinna is turned forward & covers 1/2 of external auditory meatus	CS 19	Cochlear duct- the tip of the L-shaped cochlear duct turns upward
heart	TS 22	Ventricular septum is closed Definitive prenatal circulation now established	CS 19	Fusion of aortic & mitral endocardial cushion occurs
GI	TS 22		CS 19	

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	CfS 20	Litters: PMDS 170; SR 195, 211, 213, 218, 219, 220	TS 22	Theiler stage characterized by: fingers separate distally	CS 20	Carnegie stage
forelimb	CfS 20	Digits separated approx 50% of digit length, no nails at all Digit #1 is pointed & at 30 degree angle (A1098)	TS 22	Footplate: digits are just visible and separated distally	CS 20	
hindlimb	CfS 20	Digits separated approx 30% of digit length, no nails at all (A1096)	TS 22	Digits have deep indentations between them but are not yet separated	CS 20	
head	CfS 20	Palpebrae longer but not fused (A1099, C3584) (RNA-seq head C3594)	TS 22	Prominent eyelids	CS 20	
head histology	CfS 20	Meckel's cartilage present Larynx and tracheal rings present (C3584) Palatal shelves are horizontal but not touching (C3584) Tooth primordia present, maxilla & mandible (C3584) Auditory canal open from external to pharynx (C3584) Cochlea present, encased in cartilage (C3584)	TS 22	Meckel's cartilage present, larynx is precartilaginous Tracheal rings are mesenchymal condensations Palatine processes are elevating but not fused, palate still open Tooth bud of 1st molar visible (others appear later) Anlagen of incisors may be present	CS 20	Vomeronasal organ is a shallow blind sac with a broad opening Submandibular duct is long & knobby within gland
brain histology	CfS 20	Choroid plexus present in lateral ventricles (C3584) Adenohypophysis large, neurohypophysis communicating by stalk (C3584) Telencephalon: primary cortex present (C3584)	TS 22	Choroid plexus projects far into lateral ventricle lumen Sphenoid bone below pituitary is only cartilage at this stage Present: adenohypophysis, neurohypophysis, & pars intermedia Telencephalon: formation of primary cortex (superficial cortical layer) has begun	CS 20	Choroid plexus present in lateral ventricles Adenohypophysis has capillaries at rostral surface Stalk now long and slender
eye gross	CfS 20	Palpebrae longer but not fused (A1099, C3584)	TS 22	Eyelids prominent but open	CS 20	
eye histology	CfS 20	No lens vesicle (C3584) No evidence of posterior lens suture (C3584) Thin layer of cells between anterior lens and developing mesenchyme of cornea (C3584)	TS 22	Vitreous body cavity much increased in size Ganglionic (clear) layer of retina appears as zone of clear nuclei, but the 2 darker inner layers are not separated	CS 20	No lens vesicle Lens suture begins to form Cornea has anterior epithelium, an acellular layer and a posterior epithelium Optic stalk lumen is >50% length but becoming occupied by few optic nerve fibers Some optic nerve fibers reach the optic chiasma
lungs	CfS 20	Both lung lobes present, difficult to see segmental branching except at periphery (C3589, C3587) (RNA-seq lung C3594)	TS 22	Bronchi distended & have numerous branches Tracheal rings are mesenchymal condensations	CS 20	
liver	CfS 20	All lobes present, wide enough to entirely cover stomach length (A1100, C3626, C3515) (RNA-seq liver C3594)	TS 22		CS 20	
metanephric kidney	CfS 20	Bean-shaped, approx 75% size of mesonephros (A1100, C3626) Kidney is located cranial to the gonads (A1100) Histology: Few renal vesicles in & rare tubules in outer cortex (C3620) (RNA-seq kidney C3594)	TS 22	eMAP: meta blastema in cortex & few tubules Circular structures appearing in medulla	CS 20	Renal vesicles developing S-shaped lumina External renal surface slightly lobulated Kidneys ascend to level of lumbar area (CS 17-23)
cloaca/not	CfS 20	Not examined	TS 22		CS 20	
genital tracts	CfS 20	Testis oval, has a faint longitudinal blood vessel laterally Ovary oval, no lateral vessel (A1096 m vs A1097 f) Testis is >50% length of mesonephros (C3594, C3587) (RNA-seq gonads PMDS 170)	TS 22	Ureter & mesonephric (Woffian) duct open separately to UG sinus Seminiferous tubules are solid strands of cells, no cords in ovary In females: paramesonephric (Mullerian) ducts more developed than mesonephric (Woffian) ducts Tunica albuginea present in testis	CS 20	Testis elliptical from now on, smooth surface Present: testis tubules, rete testis, tunica albuginea Ovary cylindrical from now on, coarse surface (ovary determined by absence of testis features)
ear	CfS 20	Cochlea present, encased in cartilage (C3584) Pinna triangular & flattened against head (A1099, C3584)	TS 22	Cochlear duct is a full circle bordered by thin cartilage capsule Gross: pinna is turned forward & covers 1/2 of ext auditory meatus	CS 20	Cochlear duct now growing horizontally
heart	CfS 20	Externally has all 4 chambers. Aorta and pulmonary artery outflow tracts appear separate (C3587, C3617, C3621) (RNA-seq heart C3594)	TS 22	Ventricular septum is closed Definitive prenatal circulation now established	CS 20	
GI	CfS 20	No example	TS 22		CS 20	

Species comparison of stages_full text

	CFS	dog (Meyers-Wallen)	TS	mouse (references: Theiler/eMAP/GUDmap)	CS	human (reference: O'Rahilly & Miller)
	CFS 21	Litters: PMDS 60, 61, 62, 67, 167, 169; SR 227, 228	TS 23	Theiler stage characterized by: toes separate (Theiler)	CS 21	Carnegie stage
forelimb	CFS 21	All digits present, nails present (A1076) Volar pads present (C3680 SR 228)	TS 23	Digits clearly divergent (but not parallel) Long bones of extremities have periosteal bone starting but only microscopically	CS 21	Fingers longer, show early tactile pads Humerus cartilaginous phases 1-4 present
hindlimb	CFS 21	All digits present, no nails or only a small bump on distal end (A1076)	TS 23	Digits clearly divergent (but not parallel)	CS 21	Feet approaching each other, toes may touch
head	CFS 21	Pinna is a single triangle, sits away from head (A1086, A1076) Bumps on head skin, no gross pigment or hair (A1086) Frontal: nares developed with alar slit & philtrum (A1079) Muzzle bumps for vibrissae present (A1079) (RNA-seq head C3680-C3683) Palpebrae nearly fusing (SR 228) or fused (all others)	TS 23	Hair follicles (bumps) all over the body	CS 21	
head histology	CFS 21	Palatal shelves closed, fine line at junction (C3679) Palate has not yet fused to nasal septum (C3679) Tooth primordia present maxilla & mandible (C3679) Vestibular semicircular canals present (C3679) Auditory ossicles & cochlea present, cartilaginous (C3679) Bone present, mandible, beneath Meckel's cartilage (C3679) Nasal septum cartilage present (C3679)	TS 23	Palate completely separates oral & nasal cavities Palatal processes now fusing with nasal septum Incisor enamel organs advanced, molars just starting with stellate reticulum Salivary glands are distinct trees Ossification of os temporale just started Well developed cartilage of larynx and upper trachea	CS 21	Submandibular gland has knobbed branches Vomer nasal organ is an expanded sack with a short narrow neck
brain histology	CFS 21	Telencephalon: primary cortex present (C3679) Choroid plexus present in lateral hemispheres (A1079) Adeno- & neuro-hypophysis & infundibulum present above sphenoid cartilage (C3679)	TS 23	Cerebral hemisphere cortex easily recognized Hypophysis is no longer connected to pharynx roof	CS 21	Adenohypophysis: thread-like stalk beginning to be absorbed
eye gross	CFS 21	Palpebrae nearly fusing (SR 228) or fused (all others) (A1076, A1079, A1086)	TS 23	Eyelids still open	CS 21	
eye histology	CFS 21	Retina: has complete light staining inner ganglion layer & outer dark staining nuclear layer (C3679) Very dark staining iris/ciliary body present (C3679) Corneal mesenchyme & conjunctival space present (C3679) No anterior chamber present (C3679) Optic nerve visible to optic chiasm	TS 23	Retina near pupil margin still has only 1 cell layer Retinal ganglion cell layer may be distinguished from nuclear layers	CS 21	Corneal cells beginning to invade postepithelial layer to become substantia propria of cornea Optic nerve- hyaloid groove visible at bulbar end Optic nerve tract reaches approximately to site of lateral geniculate body
lungs	CFS 21	All lung lobes present (A1079, A1087) All laryngeal cartilages present (C3679, A1079) Tracheal rings can be seen grossly (A1087)	TS 23	Well developed cartilage of larynx and upper trachea	CS 21	
liver	CFS 21	Gross: liver & stomach final conformation (A1076, A1088)	TS 23		CS 21	
metanephric kidney	CFS 21	Histology: Proximal convoluted tubules first present in cortex, collecting tubules present in pelvis (A337, A377) Gross: adrenal present cranial to kidney (A1077, A1091)	TS 23	eMAP histol: Proximal convoluted tubules present (few) Collecting tubules present in pelvis	CS 21	Spoon-shaped glomerular capsules developing but no large glomeruli present Kidneys ascend to lumbar level (CS 17-23)
cloaca/not genital tracts	CFS 21	Not examined	TS 23		CS 21	
	CFS 21	Testis has lateral longitudinal blood vessel (C3678, A1077) Ovary is elliptical and has no lateral vessel (A1089, A1093) Histology: testis has seminiferous tubules (A350, A337, A376) ovary has mesenchymal medulla and proliferation of cortical surface epithelium (A346, A333, A377) (RNA-seq gonads PMDS 169)	TS 23	Testis has well differentiated solid seminiferous tubules and surface tunica albuginea Ovary has dividing gonocytes grouped in clusters GUDmap: First evidence of differentiated genital tubercle to glans penis	CS 21	Testis has flat surface epithelium, tunica albuginea underneath, & branching, anastomosing cords (pre-seminiferous tubules)
ear	CFS 21	Pinna has 3 tips (arrow like,) points rostral to ventral (A1086) Auditory ossicles & cochlea present, cartilaginous (C3679)	TS 23	Pinna covers >0.5 external auditory meatus	CS 21	Cochlear duct tip points definitely downward
heart	CFS 21	Coronary vasculature first visible externally (A1075) Aorta & pulmonary artery grossly separate (A1075, C3674)	TS 23	AV & semilunar valves well developed Final fetal circulation: arteries & veins	CS 21	Chordae tendinae form CS 21-23
GI	CFS 21	No example	TS 23	Stomach distinctly in 2 parts histologically Umbilical hernia still present	CS 21	

Species comparison of stages_full text

	CfS	dog (Meyers-Wallen)	TS	mouse (references: Theiler/eMAP/GUDmap)	CS	human (reference: O'Rahilly & Miller)
	CfS 22	Litters: PMDS 58, 172; SR 196, 204, 221, 229, 230	TS 24	Theiler stage characterized by: reposition of umbilical hernia	CS 22	Carnegie stage
forelimb		5 digits & nails present, Digit #1 at 30-45 degree angle to digit 2 (A1113)	TS 24	Digits #2-5 nearly parallel to each other	CS 22	Fingers of opposite hands may overlap Humerus: formation of osteoblasts beginning
hindlimb	CfS 22	4 digits, nails present & more than a distal bump (A1113)	TS 24	Digits not parallel to each other	CS 22	
head	CfS 22	Pigment spots over forehead skin (A1113)	TS 24	Skin wrinkling over whole body	CS 22	
head histology	CfS 22	Nasal septum is fused to palate (C3637) Bone present in mandible & lateral maxilla (C3637) Tooth primordia in maxilla & mandible (C3637)	TS 24	Ossification centers appear in anterior arch of atlas	CS 22	Vomer nasal organ intermediate between CS 21-3 Submandibular duct has secondary branches Submandibular gland is solid but may have small lumen near oral portion
brain histology	CfS 22	No example	TS 24	Primary cortex thickened Choroid plexus larger, divided into folds & villi Hypophysis still differentiating	CS 22	Adenohypophysis- remnants of the incomplete stalk (to pharynx) are present at each end Cortical plate begins to appear in cerebral hemispheres
eye gross	CfS 22	Palpebrae fused over anterior orbit (C3637)	TS 24	Eyelids fused in most	CS 22	Eyelids rapidly encroaching upon eyes
eye histology	CfS 22	Definitely a separate layer in corneal area (C3664) Anterior chamber now present (C3637) & extends beyond pupillary margin	TS 24	Thin epithelial layer is over the cornea Iris and ciliary body can't be distinguished yet Anterior chamber extends beyond pupillary margin Retina - little change from previous stage	CS 22	Cornea- Cellular invasion of the postepithelial layer is complete centrally in some eyes Optic nerve mesenchyme forms definite sheath
lungs	CfS 22	Gross: appear same as previous stage (C3555, A1114) (RNA-seq lungs A1113)	TS 24	No change from previous stage	CS 22	
liver	CfS 22	Gross: appears same as previous stage (C3557) (RNA-seq liver A1113)	TS 24	Final lobulation is apparent Blood cell production increasing	CS 22	
metanephric kidney	CfS 22	Kidney has ascended cranial to mesonephros (C3556) Histology, cortex: Several proximal convoluted tubes throughout & moderate number of mature glomeruli (A317, A1114) (RNA-seq kidney A1113)	TS 24	Histology (eMAP): cortex has several glomeruli & collecting ducts that enter the pelvis Ureter present from the pelvis Many glomeruli well developed near center (Theiler)	CS 22	A few large glomeruli are present Kidneys ascend to lumbar level (CS 17-23)
cloaca/not	CfS 22	Not examined	TS 24		CS 22	
genital tracts	CfS 22	Can identify sex by external genitalia or testis/not testis Testis has lateral longitudinal blood vessel (A1115) Male genital tubercle is long with groove throughout ventrocaudal midline, scrotum inapparent (C3693) Male Histology: Testis has interstitial cells, rete testis, & tunica albuginea, paramesonephric duct regressing (A317) Female genital tubercle is short, points caudally (C3692) Female Histology: Ovary has 3 distinct zones: cortex, primitive tunica albuginea & dense medullary core (A319) Cortical epithelial cells in strands project toward medulla into the primitive tunica albuginea (A319) Mesonephric & paramesonephric ducts present (A319) (PRO-seq: ovary A1113; testis C3557, C3639, C3640)	TS 24	Testis- distinct interstitial cells now present Appendix epididymis first recognized in late TS 24 (GUDmap) Adrenals present Female: mesonephric & paramesonephric ducts present	CS 22	Paramesonephric ducts lie in parallel caudally & show rostral (vertical), middle (transverse), & caudal (vertical) portions
ear	CfS 22	No example	TS 24	Pinna almost completely covers external auditory canal Well developed cartilage capsule around labyrinth encloses semicircular canals and cochlear duct Sensory epithelium thickened but not well differentiated	CS 22	Auricle has progressed Cochlear duct points upward for a second time
heart	CfS 22	Coronary vasculature more prominent externally (A1113) than previous stage (RNA-seq heart A1113)	TS 24	Heart & great vessels have final prenatal configuration	CS 22	Chordae tendinae form CS 21-23
GI	CfS 22	Gross: stomach has same shape as previous stage (C3556) Gross: spleen present (C3556)	TS 24	Umbilical hernia is disappearing Stomach rapidly enlarging, spleen has arteries & veins	CS 22	

Species comparison of stages_full text

	Cfs	dog (Meyers-Wallen)	TS	mouse (references: Theiler/eMAP/GUDmap)	CS	human (reference: O'Rahilly & Miller)
	Cfs 23	Litters: PMDS 80, 171; SR 225	TS 25	Theiler stage characterized by: fingers and toes joined together	CS 23	Carnegie stage
forelimb	Cfs 23	All digits have nails (A1104) All digits are thinner than previous stage & elongated	TS 25	Digits are parallel	CS 23	Humerus - all 5 cartilaginous phases present
hindlimb	Cfs 23	All digits have nails (A1108) All digits are thinner than previous stage	TS 25	Digits are parallel	CS 23	
head	Cfs 23	Pigment spots present on head skin (A1110) Skin has developing hair follicles (C3664) (RNA-seq head C3659-C3663)	TS 25	Little change in shape of oral or nasal cavities Skin wrinkled & thickened all over body	CS 23	
head histology	Cfs 23	Optic nerve reaches the chiasma (C3664) Temporomandibular joint is ossified (C3664) Enamel organs and dental lamina, maxilla & mandible (C3664) Skin has pigment spots and developing hair follicles (C3664)	TS 25	Basal ossification center developing in dens Axis centrum has not yet appeared	CS 23	Vomer nasal organ sac beginning to retrogress & narrow canal seen in the long tapering duct Submandibular gland: terminal branches of duct have lumina, angiogenesis around epithelium Palatal shelves in contact with epithelial adhesion
brain histology	Cfs 23	Adeno- & neuro-hypophysis developed (C3664) Choroid plexus present (C3664)	TS 25		CS 23	Adenohypophysis: epithelial lobules project into mesodermal component, oriented epithelial follicles present, capillaries present Cerebellum: external granular layer begins to develop on rostral surface Interventricular foramen reduced to a dorsoventral slit Brain surrounded by loose tissue that is the forerunner of the subarachnoid space
eye gross	Cfs 23	Palpebrae are fused (A1107, C3664)	TS 25	Eyelids fused & thickened	CS 23	Eyelids may be fused laterally and medially but most of the eye is open
eye histology	Cfs 23	Cornea, iris and ciliary body present (C3664) Nictitans membrane larger, upper & lower, than previous stage (C3664)	TS 25	Ciliary body is present Third eyelid developing ventral to lacrimal puncta	CS 23	Cornea has anterior epithelium & its basement membrane, substantia propria, & posterior epithelium Optic nerve sheath is distinct & vascular canal is present Retina contains pigmented layer, external limiting membrane, proliferative zone, external neuroblastic layer, transient fiber layer, internal neuroblastic layer, nerve fiber layer, & internal limiting membrane Secondary vitreous body & secondary lens fibers forming
lungs	Cfs 23	All lung lobes present (C3663) (RNA-seq lung C3662)	TS 25		CS 23	
liver	Cfs 23	No example (RNA-seq liver C3662)	TS 25		CS 23	
metanephric kidney	Cfs 23	Shape and position same as previous stage (C3663) Histology (A1110, A462, A466, A469): many glomeruli in cortex Many proximal convoluted tubules & collecting ducts (RNA-seq kidney C3662)	TS 25	see GUDmap	CS 23	Secretory tubules changing from short to long & more convoluted Large glomeruli are numerous Kidneys now have ascended to the lumbar level at vertebrae 1-3 (L1-3)
cloaca/not genital tracts	Cfs 23	Not examined	TS 25		CS 23	
	Cfs 23	Gross: Testis has lateral blood vessel (A1109), Ovary is smaller & has no lateral blood vessel (A1107) Male: Preputial orifice on ventral abdomen, with scrotum beginning to form at caudal aspect (A1106) Testis histology (A462): Seminiferous tubules, interstitial cells & rete testis present. Mesonephric duct present, not differentiated. Paramesonephric duct Grade 4+ regression (A462) Female: Genital tubercle at caudal perineum, protrudes & points caudally (A1107) Ovary histology (A464): Numerous cortical cords projecting through primitive tunica albuginea, reaching medulla Paramesonephric & mesonephric ducts present (A464) (RNA-seq gonads PMDS 171)	TS 25	Testis has well formed tunica albuginea, numerous interstitial cells Ovary has many oocytes, often grouped, which have entered meiotic prophase	CS 23	External genitalia well developed but insufficient for accurate sex assignment Male: Seminiferous tubules identifiable Cell clusters differentiating into interstitial cells Rete testis contacts, but does not connect with the mesonephros Female: Rete ovarii close to, but does not connect with, the mesonephros Paramesonephric ducts meet urogenital sinus & fuse with each other in the median plane
ear	Cfs 23	Pinna is a long triangle, curves away from head & points rostrally (A1107)	TS 25	Capsule of labyrinth has assumed final shape	CS 23	Cochlear duct tip points downward again Cochlear duct coiled to its full extent (2.5 turns)
heart	Cfs 23	No gross external change from previous stage (A1104) (RNA-seq heart C3662)	TS 25		CS 23	
GI	Cfs 23	No example	TS 25	Umbilical hernia has disappeared in all	CS 23	

Species comparison of stages_full text

	CfS	dog (Meyers-Wallen)	TS	mouse (references: Theiler/eMAP/GUDmap)	CS	human (reference: O'Rahilly & Miller)
	>CfS 23	Litters: PMDS 81	TS 26		>CS 23	Carnegie stage
metanephric kidney	>CfS 23	Many collecting ducts in medulla emptying into large pelvic ureter (A468, A469)	TS 26		>CS 23	
genital tracts	>CfS 23	Male Histology: Testis, Large seminiferous tubules and large areas of interstitial cells (A468, A470) Mesonephric duct has characteristics of early epididymis (A470) No paramesonephric duct present (A468) Female Histology: Ovary, Definite cortical and medullary organization, with rete ovarii present (A469) Paramesonephric duct moderately large (A469) Mesonephric duct has regressed (A469)		see GUDmap for urogenital tract characteristics		limited information available for any organs
other organs	>CfS 23	No examples	TS 26	see Theiler stages and eMAP	>CS 23	as above