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(54) Titre : **MUSCLE CARDIAQUE HUMANISE**
(54) Title: **HUMANIZED HEART MUSCLE**

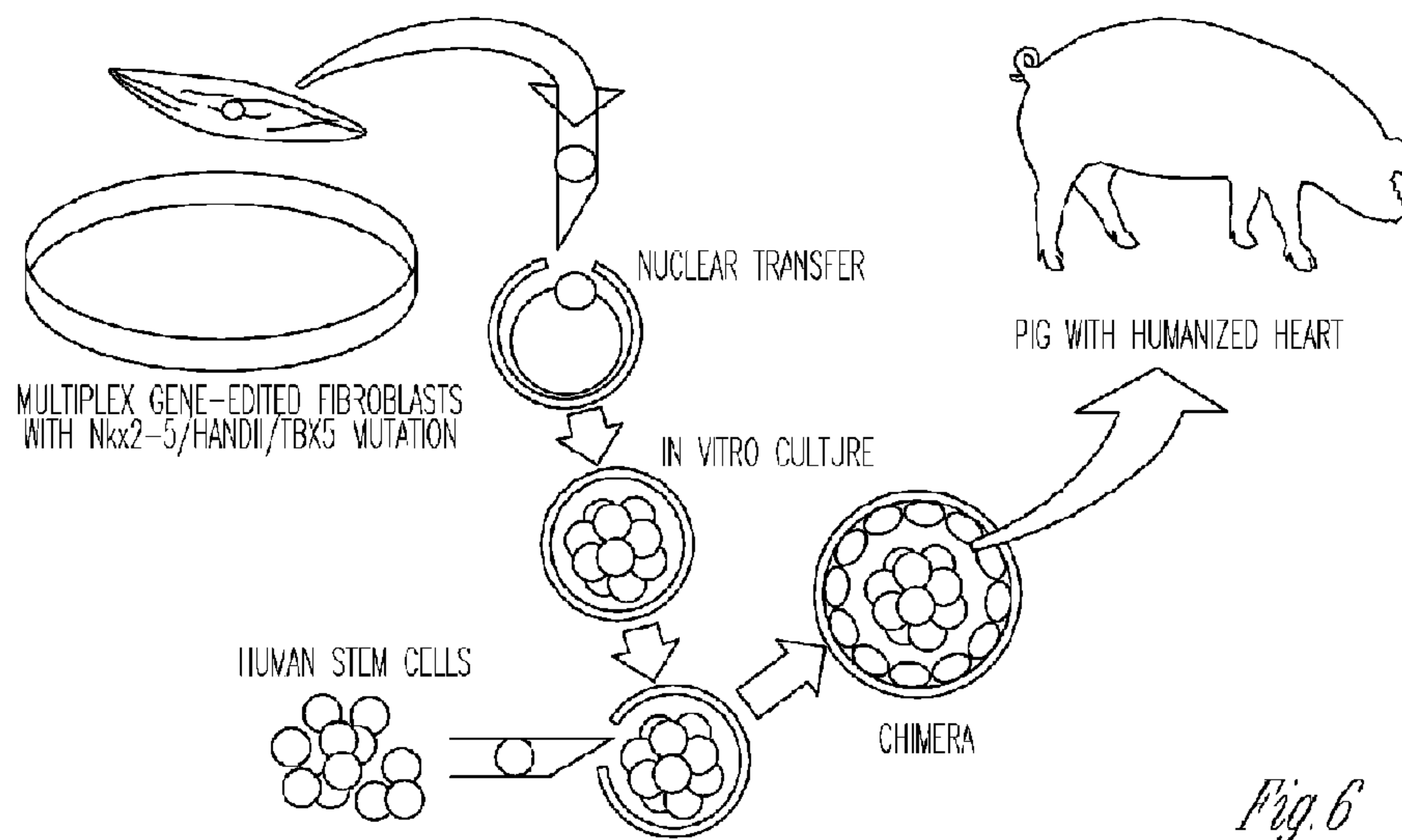


Fig. 6

(57) **Abrégé/Abstract:**

Described herein is a method for producing a chimeric non-human animal expressing a human NKX2-5, HAND1, TBX5 gene or a combination thereof gene comprising: a) generating a NKX2-5, HAND1, TBX5 or combination thereof null non-human animal cell, wherein both copies of the non-human NKX2-5, HAND1, TBX5 gene or combination thereof carry a mutation that prevents production of functional NKX2-5, HAND1, TBX5 protein or combination thereof in said non-human animal; b) creating a NKX2-5, HAND1, TBX5 or combination thereof null non-human blastocyst by somatic cell nuclear transfer comprising fusing a nucleus from said NKX2-5, HAND1, TBX5 or combination thereof null non-human animal cell of a) into an enucleated non-human oocyte and activating said oocyte to divide so as to form an NKX2-5, HAND1, TBX5 or combination thereof null non-human blastocyst; c) introducing human stem cells into the NKX2-5, HAND1, TBX5 or combination null non-human blastocyst of b); and d) implanting said blastocyst from c) into a pseudopregnant surrogate non-human animal to generate a chimeric non-human animal expressing human NKX2-5, HAND1, TBX5 or combination thereof.

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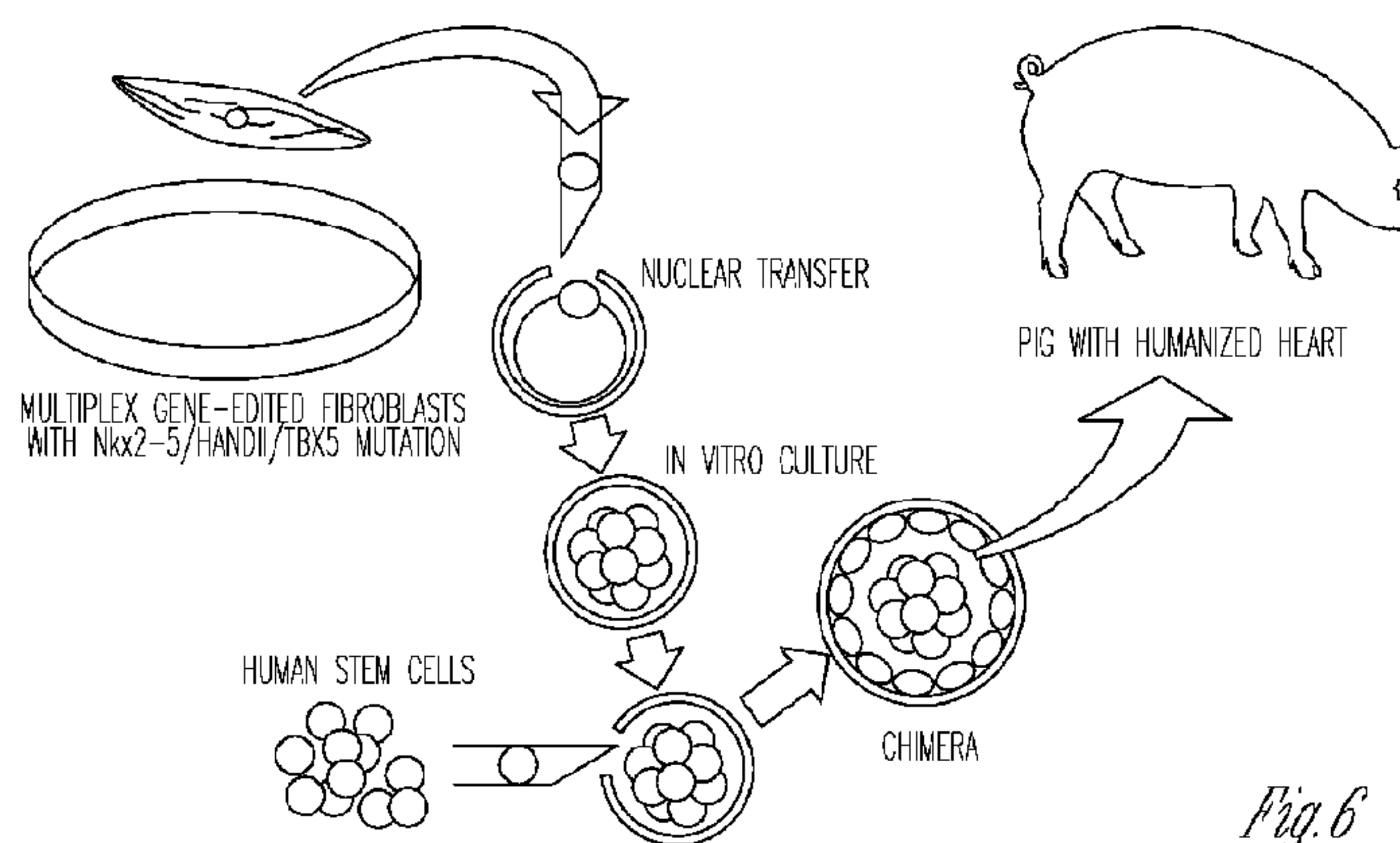


Fig. 6

(57) Abstract: Described herein is a method for producing a chimeric non-human animal expressing a human NKX2-5, HANDII, TBX5 gene or a combination thereof gene comprising: a) generating a NKX2-5, HANDII, TBX5 or combination thereof null non-human animal cell, wherein both copies of the non-human NKX2-5, HANDII, TBX5 gene or combination thereof carry a mutation that prevents production of functional NKX2-5, HANDII, TBX5 protein or combination thereof in said non-human animal; b) creating a NKX2-5, HANDII, TBX5 or combination thereof null non-human blastocyst by somatic cell nuclear transfer comprising fusing a nucleus from said NKX2-5, HANDII, TBX5 or combination thereof null non-human animal cell of a) into an enucleated non-human oocyte and activating said oocyte to divide so as to form an NKX2-5, HANDII, TBX5 or combination thereof null non-human blastocyst; c) introducing human stem cells into the NKX2-5, HANDII, TBX5 or combination thereof null non-human blastocyst of b); and d) implanting said blastocyst from c) into a pseudopregnant surrogate non-human animal to generate a chimeric non-human animal expressing human NKX2-5, HANDII, TBX5 or combination thereof.

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HUMANIZED HEART MUSCLE

Claim of Priority

This application claims the benefit of priority of U.S. Provisional Patent Application No. 62/187,040, filed 30 June 2015, the benefit of priority of which is
5 claimed hereby, and which is incorporated by reference herein in its entirety.

Background of the Invention

Congenital heart disease (CHD) afflicts approximately 1% of all live births and has considerable morbidity and mortality (1-5). Cardiovascular disease is the number one cause of death worldwide and it has been the most common cause of death in the
10 United States each year since 1900. Today, one in every three adults is living with cardiovascular disease. Finally, congenital heart defects are the most common form of birth defect in the general population and it contributes to advanced or endstage heart failure in the pediatric and adult population. Congenital Heart Disease and other cardiovascular diseases can progress to heart failure. The only cure for end stage heart
15 failure is cardiac transplantation, but, due to the shortage of organs for transplantation, relatively few patients receive such lifesaving therapy. Patients that do receive a heart transplant, require medications to prevent rejection of the heart and these medications often have long term side effects that also limit survival

Summary of the Invention

20 Described herein is the development of NKX2-5/HAND2/TBX5 knockout pigs or other animals, such as cow or goat, as hosts for production of personalized human/humanized cardiac muscle tissue/cardiac muscle cells for clinical applications.

NKX2-5/HAND2/TBX5 null porcine embryos have been generated using gene editing technologies and we have used human stem cells to produce human-animal
25 chimeras. Performing multiplex gene edits for NKX2-5/HAND2/TBX5 provide a permissive niche for the repopulation of the heart using human cells with pluripotent capacity, to yield humanized cardiac cells and/or tissues (including organs, such as the heart).

One embodiment provides a non-human animal cell, morula or blastocyst
30 wherein the genome carries a mutation in both alleles of the NKX2-5 gene, HAND2 gene, TBX5 gene or a combination thereof such that the non-human animal cell, morula or blastocyst lacks functional NKX2-5 protein, HAND2 protein, TBX5 protein or a combination thereof. In one embodiment, the mutation is a deletion of the NKX2-5 gene, HAND2 gene, TBX5 gene or a combination thereof. In another
35 embodiment, the non-human animal cell, morula or blastocyst is a porcine, bovine, equine or goat.

One embodiment provides a chimeric non-human animal morula or blastocyst expressing human NKX2-5, HANDI, TBX5 or a combination thereof and lacking expression of non-human animal NKX2-5, HANDI, TBX5 or a combination thereof. In one embodiment, the non-human animal produces
 5 humanized cardiac cells and/or tissue.

One embodiment provides a chimeric pig expressing exogenous pig NKX2-5, HANDI, TBX5 or a combination thereof and lacking expression of endogenous pig NKX2-5, HANDI, TBX5 or a combination thereof (a pig-pig chimera). In one embodiment, the non-human animal is a porcine, bovine,
 10 equine or goat.

One embodiment provides a method for producing a chimeric non-human animal expressing a human NKX2-5 gene, HANDI gene, TBX5 gene or a combination thereof comprising: a) generating a NKX2-5, HANDI, TBX5 or a combination thereof null non-human animal cell, wherein both copies of the
 15 non-human NKX2-5 gene, HANDI gene, TBX5 gene or a combination thereof gene carry a mutation that prevents production of functional NKX2-5 protein, HANDI protein, TBX5 protein or combination thereof; b) creating a NKX2-5, HANDI, TBX5 or a combination thereof null non-human morula or blastocyst by somatic cell nuclear transfer comprising fusing a nucleus from said NKX2-5,
 20 HANDI, TBX5 or a combination thereof null non-human cell of a) into an enucleated non-human oocyte and activating said oocyte to divide so as to form a NKX2-5, HANDI, TBX5 or a combination thereof null non-human morula or blastocyst; c) introducing human stem cells into the non-human NKX2-5, HANDI, TBX5 or a combination thereof null morula or blastocyst of b); and
 25 d) implanting said morula or blastocyst from c) into a pseudopregnant surrogate non-human animal to generate a chimeric non-human animal expressing human NKX2-5, HANDI, TBX5 or a combination thereof.

Another embodiment provides a method for producing a chimeric pig expressing an exogenous NKX2-5 gene, HANDI gene, TBX5 gene or a combination
 30 thereof comprising: a) generating a NKX2-5, HANDI, TBX5 or a combination thereof null pig cell, wherein both copies of the endogenous pig MYF5 gene, MYOD gene, MRF4 gene or a combination thereof gene carry a mutation that prevents production of functional endogenous pig MYF5 protein, MYOD protein, MRF4 protein or combination thereof; b) creating a NKX2-5, HANDI, TBX5 or a combination thereof
 35 null pig morula or blastocyst by somatic cell nuclear transfer comprising fusing a

nucleus from said NKX2-5, HANDII, TBX5 or a combination thereof null pig cell of a) into an enucleated pig oocyte and activating said oocyte to divide so as to form a NKX2-5, HANDII, TBX5 or a combination thereof null pig morula or blastocyst; c) introducing pig stem cells into the pig NKX2-5, HANDII, TBX5 or a combination thereof null morula or blastocyst of b); and d) implanting said morula or blastocyst from c) into a pseudopregnant surrogate pig to generate a chimeric pig expressing exogenous pig NKX2-5, HANDII, TBX5 or a combination thereof.

Another embodiment provides a method of producing human or humanized cardiac cells in a non-human animal comprising: a) generating a NKX2-5, HANDII, TBX5 or a combination thereof null non-human cell, wherein both alleles of the non-human NKX2-5 gene, HANDII gene, TBX5 gene or a combination thereof carry a mutation that prevents production of functional the non-human NKX2-5 protein, HANDII protein, TBX5 protein or combination thereof; b) creating a NKX2-5, HANDII, TBX5 or a combination thereof null non-human morula or blastocyst by somatic cell nuclear transfer comprising fusing a nucleus from said MYF5, MYOD, MRF4 or a combination thereof null non-human cell of a) into an enucleated non-human animal oocyte and activating said oocyte to divide so as to form a NKX2-5, HANDII, TBX5 or a combination thereof null non-human animal morula or blastocyst; c) introducing human stem cells into the NKX2-5, HANDII, TBX5 or a combination thereof null non-human animal blastocyst or morula of b); and d) implanting said blastocyst or morula from c) into a pseudopregnant surrogate non-human animal so as to generate a non-human animal expressing human or humanized cardiac cells.

In one embodiment the non-human animal is a porcine, bovine, equine or goat. In another embodiment the human stem cell is a tissue specific stem cell, pluripotent stem cell, multipotent adult stem cell, induced pluripotent stem cell or umbilical cord blood stem cell (UCBSC). In another embodiment the induced pluripotent cell is formed from a fibroblast cell.

One embodiment provides a pig cell, morula or blastocyst wherein the genome carries a mutation in both alleles of the NKX2-5 gene, HANDII gene, TBX5 gene or a combination thereof such that the pig cell or blastocyst lacks functional NKX2-5 protein, HANDII protein, TBX5 protein or a combination thereof. In one embodiment, the mutation is a deletion of the NKX2-5 gene, HANDII gene, TBX5 gene or a combination thereof.

One embodiment provides a chimeric pig expressing human NKX2-5, HANDII, TBX5 or a combination thereof and lacking expression of pig NKX2-5, HANDII, TBX5 or a combination thereof. In one embodiment, the chimeric pig produces humanized cardiac cells and/or tissue.

One embodiment provides a method for producing a chimeric pig expressing a human NKX2-5 gene, HANDII gene, TBX5 gene or a combination thereof comprising:

a) generating a NKX2-5, HANDII, TBX5 or a combination thereof null pig cell, wherein both copies of the pig NKX2-5 gene, HANDII gene, TBX5 gene or a combination thereof gene carry a mutation that prevents production of functional pig NKX2-5 protein, HANDII protein, TBX5 protein or combination thereof; b) creating a NKX2-5, HANDII, TBX5 or a combination thereof null pig morula or blastocyst by somatic cell nuclear transfer comprising fusing a nucleus from said NKX2-5, HANDII, TBX5 or a combination thereof null pig cell of a) into an enucleated pig oocyte and activating said oocyte to divide so as to form a NKX2-5, HANDII, TBX5 or a combination thereof null pig morula or blastocyst; c) introducing human stem cells into the pig NKX2-5, HANDII, TBX5 or a combination thereof null morula or blastocyst of b); and d) implanting said morula or blastocyst from c) into a pseudopregnant surrogate pig to generate a chimeric pig expressing human NKX2-5, HANDII, TBX5 or a combination thereof.

Another embodiment provides a method of producing humanized cardiac cells in pigs comprising: a) generating a NKX2-5, HANDII, TBX5 or a combination thereof null pig cell, wherein both alleles of the pig NKX2-5 gene, HANDII gene, TBX5 gene or a combination thereof carry a mutation that prevents production of functional pig NKX2-5 protein, HANDII protein, TBX5 protein or combination thereof; b) creating a NKX2-5, HANDII, TBX5 or a combination thereof null pig morula or blastocyst by somatic cell nuclear transfer comprising fusing a nucleus from said MYF5, MYOD, MRF4 or a combination thereof null pig cell of a) into an enucleated pig oocyte and activating said oocyte to divide so as to form a NKX2-5, HANDII, TBX5 or a combination thereof null pig morula or blastocyst; c) introducing human stem cells into the pig NKX2-5, HANDII, TBX5 or a combination thereof null blastocyst of b); and d) implanting said blastocyst from c) into a pseudopregnant surrogate pig so as to generate a pig expressing humanized cardiac cells. In one embodiment, the human stem cell is a human induced pluripotent stem cell, a human pluripotent stem cells or a human umbilical cord blood stem cell. In another embodiment, the human induced pluripotent cell is formed from a fibroblast cell.

It would be useful to make human or humanized tissues and organs personalized to each recipient's immune complex. As disclosed herein, it is possible to do so by using a large animal as a host and editing its genome to knock out or debilitate genes responsible for the growth and/or differentiation of a target organ and inoculating that animal at a blastocyst or zygote stage with donor stem cells to complement the missing genetic information for the growth and development of the organ. The result is

a chimeric animal in which the complemented tissue (human/humanized organ) matches the genotype and phenotype of the donor. Such organs may be made in a single generation and the stem cell may be taken or generated from the patient's own body. As disclosed herein, it is possible to do so by simultaneously editing multiple genes in a
 5 cell (see, for example, WO 2015/168125, which is incorporated herein by reference). Multiple genes can be targeted for editing using targeted nucleases and homology directed repair (HDR) templates in vertebrate cells or embryos.

Brief Description of the Drawings

Figure 1 depicts a schematic of cardiac morphogenesis in the mouse. (Left to
 10 right) Formation of the cardiac crescent (E7.5), linear heart tube (E8.5), looped heart (E9.5) and four-chambered heart (E10.5).

Figure 2 demonstrates Nkx2-5 and HandII (also known as dHand) double knockouts lack both ventricles (rv and lv) and have a single, small primitive atrium (dc) (Yamagishi 2001).

15 Figures 3A-C depict triple knockout of NKX2-5, HANDII and TBX5 in swine fibroblasts. A) Schematics of the coding sequence for each gene are shown; alternating colors indicate exon boundaries, the blue region (below) indicates the DNA binding domain of each transcription factor, and the triangles indicate the location TALENs binding sites. B) RFLP analysis of fibroblast colonies for biallelic KO of TBX5 and
 20 NKX2-5. The asterisk marks double biallelic KO colonies. C) Results of colony screening (n=480). HANDII mutation rate was analyzed by sequencing in only TBX5 and NKX2-5 double positive clones.

Figure 4 depicts Nkx2-5/HANDII/TBX5 triple knockout porcine embryos have acardia. Triple knockout porcine embryos lack a heart with essentially no Gata4
 25 immunohistochemically positive cells (marking the heart) at E18.0 (h, heart and fg, foregut).

Figures 5A-F demonstrate that Nkx2-5 governs networks in CPCs and is a factor for cardiogenesis. (A) A cardiac enhancer region of the Nkx2-5 gene was fused to the fluorescent reporter (EYFP) and used to generate transgenic mice. (B) The Nkx2-5
 30 enhancer directs EYFP expression to the cardiac progenitor cell population in transgenic mouse embryos. (C) RNA was isolated from the sorted CPCs, amplified and gene expression was evaluated using Affymetrix array analysis. Results of Affymetrix array analysis of Nkx2-5-EYFP CPCs vs. the respective negative cell populations from single embryos (E7.75-E9.5) reveal increased gene expression associated with cardiac
 35 development and identifies HandII and Tbx5 as factors in the cardiac crescent. Identification of genes upregulated in Nkx2-5 null cardiac progenitor cells (CPCs). (D) EYFP is directed to the CPCs in the 6kbNkx2-5-EYFP: WT and 6kbNkx2-5-EYFP:

Nkx2-5 null littermates at E8.0 and E9.5. (E) Venn diagram of array analysis for genes that were significantly upregulated in EYFP positive Nkx2-5 null (-/-) vs. WT (+/+) CPCs isolated at E8.0 and E9.5 stages. (F) Schematic which summarizes the results of the studies demonstrating the role of Nkx2-5 in the repression of blood formation, the
 5 promotion of the endothelial lineage (via *Etv2*) and the promotion of the cardiac lineage (by regulating *Bnp*, *Anf*, *Mlc-2v* and *Cripto*).

Figure 6 depicts the overall strategy to produce a humanized heart in a pig model. Multiplex gene editing will be utilized to produce NKX2-5/HAND1/TBX5 mutant pig fibroblasts, as well as SCNT and human stem cell delivery to engineer a pig
 10 with a humanized heart.

Figures 7A-B depict TALEN-mediated knockout of *ETV2*. (A) Three-tiered PCR assay utilized to detect gene editing. Amplification from primers a-d indicated a deletion allele was present. To distinguish between heterozygous and homozygous clones, primers a-b and c-d were used to amplify the wild type allele. Only when the a-
 15 d product is present and both a-b, c-d products are absent is the clone considered homozygous for the deletion allele. (B) Clones fitting these criteria are enclosed by green boxes.

Figures 8A-H demonstrate that loss of porcine *ETV2* recapitulated the mouse *Etv2* mutant phenotype. Wild-type E18.0 pig embryo (A) and *ETV2* knockout embryo
 20 (B) at the 24 somites stage. Insets show enlarged views of the allantois. Note an abnormal overall morphology with lack of vascular plexus formation in the mutant (inset). (C-H) Sections through the allantois (C, D), the heart level (E, F) and the trunk level (G, H) of the embryos shown in A and B, respectively, were stained for Tie2, an endothelial marker; Gata4, a cardiac lineage marker; and DAPI, a nuclear counterstain.
 25 The wild-type allantois was highly vascularized with Tie2 positive endothelial lining (C, arrows), whereas, the mutant lacked this cell population (D). The endocardium, cardinal veins (CV), and dorsal aortae (DA) are clearly visible in the wild-type embryo (E, G). In contrast, *ETV2* null embryos completely lacked these structures although the heart progenitors and gut marked by Gata4 (green) were present (F and H, respectively).
 30 Scale bars: 1000 μ m (A, B), 200 μ m (insets in A, B), 100 μ m (C-H).

Figures 9A-B depict (A) Blastocyst with DiI-labeled hiPSC in the ICM. Arrows indicate cells positive for DiI and HNA. (B) Blastocyst with EdU-labeled hiPSCs in the ICM. hiPSC were labeled with 40 μ M EdU for 24 hours and injected. Blastocysts were pulsed with 10 μ M BrdU for an hour to label dividing cells. Double
 35 positive cells are indicated by arrows. BrdU+/EdU- cells are dividing host cells. Note that the blastocysts are beginning to hatch (brackets), which signifies developmental progression. HNA: human nuclear antigen; OL: overlay.

Detailed Description of the Invention

Cardiovascular disease is the number one cause of death in this country and across the world. Currently one in three adults are living with cardiovascular disease. Congenital heart defects are common and can progress to end stage heart failure. While heart transplantation is the only cure for end stage heart failure, relatively few patients receive this therapy due to limited availability of donor organs. In short, there is an inadequate supply of hearts to treat patients who need this curative therapy. Moreover, there are no relevant human models to test new devices, pharmacological or surgical therapies for congenital or heart failure diseases. Thirdly, there are no relevant human models to identify or examine factors that promote cardiac regeneration, which could eliminate the need for cardiac transplantation. Lastly, a source of personalized human tissues that can be generated using the patient's own stem cells is provided herein (thereby obviating ethical issues such as organ donation or use of human embryonic stem cells). Thus provided herein is the utilization of emerging technologies to revolutionize the field by engineering a humanized heart in a large animal model.

Presented herein are compositions and methods to generate a human organ (a heart)/humanized tissues in pigs, which will serve as an unlimited source of hearts/tissues for transplantation and provide a large animal model to study the regeneration of the human heart and/or the response of a human heart to experimental medications.

In particular, provided herein are compositions and methods to provide personalized heart tissue or a heart for millions of people that would benefit from such therapy. This strategy will revolutionize cardiovascular medicine and provide a cure for this devastating disease. Personalized heart valves, heart tissue, coronary arteries and entire hearts can be available for patients, which would obviate the use of immunosuppression agents. Moreover, provided herein is a platform for the generation of other tissues such as personalized blood, vasculature, muscle, bones and lungs.

Previously, transgenic and gene disruption mouse models were engineered to define networks that are necessary and sufficient for cardiogenesis. Roles for Nkx2-5 as a transcriptional activator of cardiac development, as a repressor of blood formation and as an activator of Etv2, a master endothelial/endocardial factor (5-21), have been demonstrated. Based on the data and other publications, it was believed that a mutant animal for Nkx2-5/Hand2/Tbx5 would completely lack a heart (22-26). Using state-of-the-art gene editing technologies, mutant porcine embryos were generated, which are lethal during early development and have perturbed or absent cardiovascular lineages. In addition to serving as a novel source of human tissues for the treatment of cardiovascular disease, the humanized pigs can also serve as a large animal model to

study the regeneration of human lineages or response(s) to pharmacological agents and lead to improved therapies for cardiovascular diseases including congenital and heart failure diseases. The approach combines innovative and emerging technologies to decipher the networks and stem cell populations that govern cardiovascular lineages and
5 produce human-specific tissues in a porcine host.

Definitions

The following definitions are included to provide a clear and consistent understanding of the specification and claims. As used herein, the recited terms have the following meanings. All other terms and phrases used in this specification have their
10 ordinary meanings as one of skill in the art would understand. Such ordinary meanings may be obtained by reference to technical dictionaries, such as Hawley's Condensed Chemical Dictionary 14th Edition, by R.J. Lewis, John Wiley & Sons, New York, N.Y., 2001.

References in the specification to "one embodiment", "an embodiment", etc.,
15 indicate that the embodiment described may include a particular aspect, feature, structure, moiety, or characteristic, but not every embodiment necessarily includes that aspect, feature, structure, moiety, or characteristic. Moreover, such phrases may, but do not necessarily, refer to the same embodiment referred to in other portions of the specification. Further, when a particular aspect, feature, structure, moiety, or
20 characteristic is described in connection with an embodiment, it is within the knowledge of one skilled in the art to affect or connect such aspect, feature, structure, moiety, or characteristic with other embodiments, whether or not explicitly described.

As used herein, the articles "a" and "an" refer to one or to more than one, i.e., to at least one, of the grammatical object of the article. By way of example, "an element"
25 means one element or more than one element.

The term "and/or" means any one of the items, any combination of the items, or all of the items with which this term is associated. The phrase "one or more" is readily understood by one of skill in the art, particularly when read in context of its usage. For example, one or more substituents on a phenyl ring refers to one to five, or one to four,
30 for example if the phenyl ring is disubstituted.

As used herein, "or" should be understood to have the same meaning as "and/or" as defined above. For example, when separating a listing of items, "and/or" or "or" shall be interpreted as being inclusive, *e.g.*, the inclusion of at least one, but also including more than one, of a number of items, and, optionally, additional unlisted
35 items. Only terms clearly indicated to the contrary, such as "only one of" or "exactly one of," or, when used in the claims, "consisting of," will refer to the inclusion of exactly one element of a number or list of elements. In general, the term "or" as used

herein shall only be interpreted as indicating exclusive alternatives (i.e., “one or the other but not both”) when preceded by terms of exclusivity, such as “either,” “one of,” “only one of,” or “exactly one of.”

As used herein, the terms “including”, “includes”, “having”, “has”, “with”, or
5 variants thereof, are intended to be inclusive similar to the term “comprising.”

The term “about” can refer to a variation of $\pm 5\%$, $\pm 10\%$, $\pm 20\%$, or $\pm 25\%$ of the value specified. For example, “about 50” percent can in some embodiments carry a variation from 45 to 55 percent. For integer ranges, the term “about” can include one or two integers greater than and/or less than a recited integer at each end of the range.
10 Unless indicated otherwise herein, the term “about” is intended to include values, e.g., weight percentages, proximate to the recited range that are equivalent in terms of the functionality of the individual ingredient, the composition, or the embodiment. The term about can also modify the end-points of a recited range.

As will be understood by the skilled artisan, all numbers, including those
15 expressing quantities of ingredients, properties such as molecular weight, reaction conditions, and so forth, are approximations and are understood as being optionally modified in all instances by the term “about.” These values can vary depending upon the desired properties sought to be obtained by those skilled in the art utilizing the teachings of the descriptions herein. It is also understood that such values inherently contain
20 variability necessarily resulting from the standard deviations found in their respective testing measurements.

As will be understood by one skilled in the art, for any and all purposes, particularly in terms of providing a written description, all ranges recited herein also encompass any and all possible sub-ranges and combinations of sub-ranges thereof, as
25 well as the individual values making up the range, particularly integer values. A recited range (e.g., weight percentages or carbon groups) includes each specific value, integer, decimal, or identity within the range. Any listed range can be easily recognized as sufficiently describing and enabling the same range being broken down into at least equal halves, thirds, quarters, fifths, or tenths. As a non-limiting example, each range
30 discussed herein can be readily broken down into a lower third, middle third and upper third, etc. As will also be understood by one skilled in the art, all language such as “up to,” “at least,” “greater than,” “less than,” “more than,” “or more,” and the like, include the number recited and such terms refer to ranges that can be subsequently broken down into sub-ranges as discussed above. In the same manner, all ratios recited herein also
35 include all sub-ratios falling within the broader ratio. Accordingly, specific values recited for radicals, substituents, and ranges, are for illustration only; they do not

exclude other defined values or other values within defined ranges for radicals and substituents.

One skilled in the art will also readily recognize that where members are grouped together in a common manner, such as in a Markush group, the invention
5 encompasses not only the entire group listed as a whole, but each member of the group individually and all possible subgroups of the main group.

Additionally, for all purposes, the invention encompasses not only the main group, but also the main group absent one or more of the group members. The invention therefore envisages the explicit exclusion of any one or more of members of a recited
10 group. Accordingly, provisos may apply to any of the disclosed categories or embodiments whereby any one or more of the recited elements, species, or embodiments, may be excluded from such categories or embodiments, for example, for use in an explicit negative limitation.

The term "isolated" refers to a factor(s), cell or cells which are not associated
15 with one or more factors, cells or one or more cellular components that are associated with the factor(s), cell or cells *in vivo*.

The term "contacting" refers to the act of touching, making contact, or of bringing to immediate or close proximity, including at the cellular or molecular level, for example, to bring about a physiological reaction, a chemical reaction, or a physical
20 change, e.g., in a solution, in a reaction mixture, *in vitro*, or *in vivo*.

The terms "cell," "cell line," and "cell culture" as used herein may be used interchangeably. All of these terms also include their progeny, which are any and all subsequent generations. It is understood that all progeny may not be identical due to deliberate or inadvertent mutations.

25 "Cells" include cells from, or the "subject" is, a vertebrate, such as a mammal, including a human. Mammals include, but are not limited to, humans, farm animals, sport animals and companion animals. Included in the term "animal" is dog, cat, fish, gerbil, guinea pig, hamster, horse, rabbit, swine, mouse, monkey (e.g., ape, gorilla, chimpanzee, or orangutan), rat, sheep, goat, cow and bird.

30 In one embodiment, the stem, progenitor or precursor cells are embryonic stem cells, adult stem cells, induced pluripotent stem cells, and/or multipotent stem cells (such as multipotent mesodermal precursors). In one embodiment, the stem, progenitor or precursor cells are mammalian cells. In one embodiment, the stem cells include, but are not limited to, induced pluripotent stem cells, umbilical blood cord stem cells,
35 mesenchymal stem cells, pluripotent stem cells. In one embodiment, the stem cells are of human origin. In another embodiment, the stem cells are of pig origin.

Totipotent (a.k.a. omnipotent) stem cells can differentiate into embryonic and extraembryonic cell types. Such cells can construct a complete, viable organism. These cells are produced from the fusion of an egg and sperm cell. Cells produced by the first few divisions of the fertilized egg are also totipotent. Pluripotent stem cells are the
 5 descendants of totipotent cells and can differentiate into nearly all cells, i.e. cells derived from any of the three germ layers. Multipotent stem cells can differentiate into a number of cell types, but only those of a closely related family of cells. Oligopotent stem cells can differentiate into only a few cell types, such as lymphoid or myeloid stem cells. Unipotent cells can produce only one cell type, their own,[4] but have the property
 10 of self-renewal, which distinguishes them from non-stem cells (e.g. progenitor cells, muscle stem cells).

“Expansion” refers to the propagation of cells without differentiation.

“Progenitor cells” are cells produced during differentiation of a stem cell that have some, but not all, of the characteristics of their terminally-differentiated progeny.
 15 Defined progenitor cells are committed to a lineage, but not to a specific or terminally-differentiated cell type. The phrase “endothelial cells” encompasses not only terminally-differentiated cells types, but also cells that are committed to an endothelial lineage, but are not terminally-differentiated.

“Differentiation factors” refer to cellular factors, preferably growth factors or
 20 angiogenic factors that induce lineage commitment.

The terms “pig,” “swine” and “porcine” are used interchangeably and are generic terms referring to the same type of animal without regards to gender, size or breed. It is also noted that terms “pig,” “swine” and “porcine”, such as the null “pig,” “swine” and “porcine” that is complemented with human or pig genes, the “pig,”
 25 “swine” and “porcine” may be embryos, neonates or adults (including newborns and young pigs).

The terms “Hand2” and “HandII” are used interchangeably.

As used herein, the phrases “humanized skeletal muscle,” “humanized cardiac muscle,” or “humanized muscle” refer to cells or tissue in a pig or other non-human
 30 animal that express one more human genes and/or proteins. In one embodiment, the pig cells or tissue that express one more human genes/proteins do not express the corresponding functional pig gene and/or protein.

A “coding region” of a gene consists of the nucleotide residues of the coding strand of the gene and the nucleotides of the non-coding strand of the gene which are
 35 homologous with or complementary to, respectively, the coding region of an mRNA molecule which is produced by transcription of the gene.

A “control” cell is a cell having the same cell type as a test cell. The control cell may, for example, be examined at precisely or nearly the same time the test cell is examined. The control cell may also, for example, be examined at a time distant from the time at which the test cell is examined, and the results of the examination of the control cell may be recorded so that the recorded results may be compared with results obtained by examination of a test cell.

As used herein, an “effective amount” or “therapeutically effective amount” means an amount sufficient to produce a selected effect, such as alleviating symptoms of a disease or disorder. In the context of administering compounds in the form of a combination, such as multiple compounds, the amount of each compound, when administered in combination with another compound(s), may be different from when that compound is administered alone. Thus, an effective amount of a combination of compounds refers collectively to the combination as a whole, although the actual amounts of each compound may vary. The term “more effective” means that the selected effect is alleviated to a greater extent by one treatment relative to the second treatment to which it is being compared.

“Encoding” refers to the inherent property of specific sequences of nucleotides in a polynucleotide, such as a gene, a cDNA, or an mRNA, to serve as templates for synthesis of other polymers and macromolecules in biological processes having either a defined sequence of nucleotides (i.e., rRNA, tRNA and mRNA) or a defined sequence of amino acids and the biological properties resulting therefrom. Thus, a gene encodes a protein if transcription and translation of mRNA corresponding to that gene produces the protein in a cell or other biological system. Both the coding strand, the nucleotide sequence of which is identical to the mRNA sequence and is usually provided in sequence listings, and the non-coding strand, used as the template for transcription of a gene or cDNA, can be referred to as encoding the protein or other product of that gene or cDNA.

A “fragment” or “segment” is a portion of an amino acid sequence, comprising at least one amino acid, or a portion of a nucleic acid sequence comprising at least one nucleotide. The terms “fragment” and “segment” are used interchangeably herein.

As used herein, a “functional” biological molecule is a biological molecule in a form in which it exhibits a property by which it is characterized. A functional enzyme, for example, is one which exhibits the characteristic catalytic activity by which the enzyme is characterized.

“Homologous” as used herein, refers to the subunit sequence similarity between two polymeric molecules, e.g., between two nucleic acid molecules, e.g., two DNA molecules or two RNA molecules, or between two polypeptide molecules. When a

subunit position in both of the two molecules is occupied by the same monomeric subunit, e.g., if a position in each of two DNA molecules is occupied by adenine, then they are homologous at that position. The homology between two sequences is a direct function of the number of matching or homologous positions, e.g., if half (e.g., five
 5 positions in a polymer ten subunits in length) of the positions in two compound sequences are homologous then the two sequences are 50% homologous, if 90% of the positions, e.g., 9 of 10, are matched or homologous, the two sequences share 90% homology. By way of example, the DNA sequences 3'ATTGCC5' and 3'TATGGC share 50% homology.

10 As used herein, "homology" is used synonymously with "identity."

The determination of percent identity between two nucleotide or amino acid sequences can be accomplished using a mathematical algorithm. For example, a mathematical algorithm useful for comparing two sequences is the algorithm of Karlin and Altschul (1990, Proc. Natl. Acad. Sci. USA 87:2264-2268), modified as in Karlin
 15 and Altschul (1993, Proc. Natl. Acad. Sci. USA 90:5873-5877). This algorithm is incorporated into the NBLAST and XBLAST programs of Altschul, et al. (1990, J. Mol. Biol. 215:403-410), and can be accessed, for example at the National Center for Biotechnology Information (NCBI) world wide web site having the universal resource locator using the BLAST tool at the NCBI website. BLAST nucleotide searches can be
 20 performed with the NBLAST program (designated "blastn" at the NCBI web site), using the following parameters: gap penalty = 5; gap extension penalty = 2; mismatch penalty = 3; match reward = 1; expectation value 10.0; and word size = 11 to obtain nucleotide sequences homologous to a nucleic acid described herein. BLAST protein searches can be performed with the XBLAST program (designated "blastn" at the NCBI web site) or
 25 the NCBI "blastp" program, using the following parameters: expectation value 10.0, BLOSUM62 scoring matrix to obtain amino acid sequences homologous to a protein molecule described herein. To obtain gapped alignments for comparison purposes, Gapped BLAST can be utilized as described in Altschul et al. (1997, Nucleic Acids Res. 25:3389-3402). Alternatively, PSI-Blast or PHI-Blast can be used to perform an
 30 iterated search which detects distant relationships between molecules (Id.) and relationships between molecules which share a common pattern. When utilizing BLAST, Gapped BLAST, PSI-Blast, and PHI-Blast programs, the default parameters of the respective programs (e.g., XBLAST and NBLAST) can be used.

The percent identity between two sequences can be determined using
 35 techniques similar to those described above, with or without allowing gaps. In calculating percent identity, typically exact matches are counted.

As used herein, an “instructional material” includes a publication, a recording, a diagram, or any other medium of expression which can be used to communicate the usefulness of the invention in the kit for effecting alleviation of the various diseases or disorders recited herein. Optionally, or alternately, the instructional material may describe one or more methods of alleviating the diseases or disorders in a cell or a tissue of a mammal. The instructional material of the kit of the invention may, for example, be affixed to a container which contains the identified invention, or portion thereof, or be shipped together with a container which contains the invention or portion thereof. Alternatively, the instructional material may be shipped separately from the container with the intention that the instructional material and the compound be used cooperatively by the recipient.

As used herein, the term “nucleic acid” encompasses RNA as well as single and double stranded DNA and cDNA. Furthermore, the terms, “nucleic acid,” “DNA,” “RNA” and similar terms also include nucleic acid analogs, i.e. analogs having other than a phosphodiester backbone. For example, the so called “peptide nucleic acids,” which are known in the art and have peptide bonds instead of phosphodiester bonds in the backbone, are considered within the scope of the present invention. By “nucleic acid” is meant any nucleic acid, whether composed of deoxyribonucleosides or ribonucleosides, and whether composed of phosphodiester linkages or modified linkages such as phosphotriester, phosphoramidate, siloxane, carbonate, carboxymethylester, acetamidate, carbamate, thioether, bridged phosphoramidate, bridged methylene phosphonate, bridged phosphoramidate, bridged phosphoramidate, bridged methylene phosphonate, phosphorothioate, methylphosphonate, phosphorodithioate, bridged phosphorothioate or sulfone linkages, and combinations of such linkages. The term nucleic acid also specifically includes nucleic acids composed of bases other than the five biologically occurring bases (adenine, guanine, thymine, cytosine, and uracil). Conventional notation is used herein to describe polynucleotide sequences: the left-hand end of a single-stranded polynucleotide sequence is the 5'-end; the left-hand direction of a double-stranded polynucleotide sequence is referred to as the 5'-direction. The direction of 5' to 3' addition of nucleotides to nascent RNA transcripts is referred to as the transcription direction. The DNA strand having the same sequence as an mRNA is referred to as the “coding strand”; sequences on the DNA strand which are located 5' to a reference point on the DNA are referred to as “upstream sequences”; sequences on the DNA strand which are 3' to a reference point on the DNA are referred to as “downstream sequences.”

The term “nucleic acid construct,” as used herein, encompasses DNA and RNA sequences encoding the particular gene or gene fragment desired, whether obtained by genomic or synthetic methods.

Unless otherwise specified, a “nucleotide sequence encoding an amino acid sequence” includes all nucleotide sequences that are degenerate versions of each other and that encode the same amino acid sequence. Nucleotide sequences that encode proteins and RNA may include introns.

The term “oligonucleotide” typically refers to short polynucleotides, generally, no greater than about 50 nucleotides. It will be understood that when a nucleotide sequence is represented by a DNA sequence (i.e., A, T, G, C), this also includes an RNA sequence (i.e., A, U, G, C) in which “U” replaces “T.”

Transcription Activator-Like Effector Nucleases (TALENs) are artificial restriction enzymes generated by fusing the TAL effector DNA binding domain to a DNA cleavage domain. These reagents enable efficient, programmable, and specific DNA cleavage for genome editing *in situ*. Transcription activator-like effectors (TALEs) are proteins that bind DNA in a sequence specific way. By fusing such a TALE to a nuclease (e.g., FokI endonuclease) a highly specific DNA “scissor” is made (these molecules can be engineered to bind any DNA sequence). The term TALEN, as used herein, is broad and includes a monomeric TALEN that can cleave double stranded DNA without assistance from another TALEN. The term TALEN is also used to refer to one or both members of a pair of TALENs that are engineered to work together to cleave DNA at the same site. TALENs that work together may be referred to as a left-TALEN and a right-TALEN, which references the handedness of DNA.

Once the TALEN genes have been assembled they are inserted into plasmids; the plasmids are then used to transfect the target cell where the gene products are expressed and enter the nucleus to access the genome. TALENs can be used to edit genomes by inducing double-strand breaks (DSB) and optionally inserting a cargo/preselected gene, which cells respond to with repair mechanisms. In this manner, they can be used to correct mutations in the genome which, for example, cause disease.

Genetic engineering, including gene editing, can be carried out by any method available to an art worker, for example, by the use of targeted endonucleases, and homology directed repair (HDR), TALEN, CRISPR (e.g., CAS9/CRISPR), recombinase fusion molecules, synthetic porcine artificial chromosomes, meganucleases, zinc finger or rAAV based systems for gene editing (e.g., to knockout desired target genes). Further, a variety of nucleic acids can be introduced into cells, for knockout purposes, for inactivation of a gene (such as interfering RNAs (shRNA, siRNA, dsRNA, RISC, miRNA) or express a gene.

Somatic cell nuclear transfer (SCNT) is a laboratory technique for creating a viable embryo from a body cell and an egg cell. The process of somatic cell nuclear transplant involves two different cells. The first being a female gamete, known as the ovum (egg/oocyte). The second being a somatic cell, referring to the cells of the human body. Skin cells, fat cells, and liver cells are only a few examples. The nucleus of the donor egg cell is removed and discarded, leaving it 'deprogrammed.' The nucleus of the somatic cell is also removed but is kept, the enucleated somatic cell is discarded. What is left is a lone somatic nucleus and an enucleated egg cell. These are then fused by squirting the somatic nucleus into the 'empty' ovum. After being inserted into the egg, the somatic cell nucleus is reprogrammed by its host egg cell. The ovum, now containing the somatic cell's nucleus, is stimulated with a shock and will begin to divide. The egg is now viable and capable of producing an adult organism containing all the necessary genetic information from just one parent. Development will ensue normally and after many mitotic divisions, this single cell forms a blastocyst (an early stage embryo with about 100 cells) with an identical genome to the original organism (i.e. a clone). Stem cells can then be obtained by the destruction of this clone embryo for use in therapeutic cloning or in the case of reproductive cloning the clone embryo is implanted into a host mother (pseudopregnant/surrogate) for further development and brought to term.

“Chimera” refers to is a single organism composed of genetically distinct cells.

A nullizygous organism carries two mutant or missing alleles for the same gene. The mutant/missing alleles are both complete loss-of-function or 'null' alleles, so homozygous null and nullizygous are synonymous.

A gene knockout (abbreviation: KO) is a genetic technique in which both of an organism's alleles are made inoperative ("knocked out" of the organism). Also known as knockout organisms or simply knockouts. The term also refers to the process of creating such an organism, as in "knocking out" a gene. The technique is essentially the opposite of a gene knockin.

The term gene is broad and refers to chromosomal DNA that is expressed to make a functional product. Genes have alleles. Gene editing may be mon-allelic or bi-allelic.

By describing two polynucleotides as “operably linked” is meant that a single-stranded or double-stranded nucleic acid moiety comprises the two polynucleotides arranged within the nucleic acid moiety in such a manner that at least one of the two polynucleotides is able to exert a physiological effect by which it is characterized upon the other. By way of example, a promoter operably linked to the coding region of a gene is able to promote transcription of the coding region.

“Recombinant polynucleotide” refers to a polynucleotide having sequences that are not naturally joined together. An amplified or assembled recombinant polynucleotide may be included in a suitable vector, and the vector can be used to transform a suitable host cell.

5 A recombinant polynucleotide may serve a non-coding function (e.g., promoter, origin of replication, ribosome-binding site, etc.) as well.

A host cell that comprises a recombinant polynucleotide is referred to as a “recombinant host cell.” A gene which is expressed in a recombinant host cell wherein the gene comprises a recombinant polynucleotide, produces a “recombinant
10 polypeptide.”

A “recombinant cell” is a cell that comprises a transgene. Such a cell may be a eukaryotic or a prokaryotic cell. Also, the transgenic cell encompasses, but is not limited to, an embryonic stem cell comprising the transgene, a cell obtained from a chimeric mammal derived from a transgenic embryonic stem cell where the cell
15 comprises the transgene, a cell obtained from a transgenic mammal, or fetal or placental tissue thereof, and a prokaryotic cell comprising the transgene.

The term “regulate” refers to either stimulating or inhibiting a function or activity of interest.

As used herein, a “subject in need thereof” is a patient, animal, mammal, or
20 human, who will benefit from the invention.

As used herein, a “substantially homologous amino acid sequences” includes those amino acid sequences which have at least about 95% homology, preferably at least about 96% homology, more preferably at least about 97% homology, even more preferably at least about 98% homology, and most preferably at least about 99% or
25 more homology to an amino acid sequence of a reference antibody chain. Amino acid sequence similarity or identity can be computed by using the BLASTP and TBLASTN programs which employ the BLAST (basic local alignment search tool) 2.0.14 algorithm. The default settings used for these programs are suitable for identifying substantially similar amino acid sequences for purposes of the present invention.

30 “Substantially homologous nucleic acid sequence” means a nucleic acid sequence corresponding to a reference nucleic acid sequence wherein the corresponding sequence encodes a peptide having substantially the same structure and function as the peptide encoded by the reference nucleic acid sequence; e.g., where only changes in amino acids not significantly affecting the peptide function occur. Preferably, the
35 substantially identical nucleic acid sequence encodes the peptide encoded by the reference nucleic acid sequence. The percentage of identity between the substantially similar nucleic acid sequence and the reference nucleic acid sequence is at least about

50%, 65%, 75%, 85%, 95%, 99% or more. Substantial identity of nucleic acid sequences can be determined by comparing the sequence identity of two sequences, for example by physical/chemical methods (i.e., hybridization) or by sequence alignment via computer algorithm. Suitable nucleic acid hybridization conditions to determine if a nucleotide sequence is substantially similar to a reference nucleotide sequence are: 7% sodium dodecyl sulfate SDS, 0.5 M NaPO₄, 1 mM EDTA at 50°C with washing in 2X standard saline citrate (SSC), 0.1% SDS at 50°C; preferably in 7% (SDS), 0.5 M NaPO₄, 1 mM EDTA at 50°C with washing in 1X SSC, 0.1% SDS at 50°C; preferably 7% SDS, 0.5 M NaPO₄, 1 mM EDTA at 50°C with washing in 0.5X SSC, 0.1% SDS at 50°C; and more preferably in 7% SDS, 0.5 M NaPO₄, 1 mM EDTA at 50°C with washing in 0.1X SSC, 0.1% SDS at 65°C. Suitable computer algorithms to determine substantial similarity between two nucleic acid sequences include, GCS program package (Devereux et al., 1984 Nucl. Acids Res. 12:387), and the BLASTN or FASTA programs (Altschul et al., 1990 Proc. Natl. Acad. Sci. USA. 1990 87:14:5509-13; Altschul et al., J. Mol. Biol. 1990 215:3:403-10; Altschul et al., 1997 Nucleic Acids Res. 25:3389-3402). The default settings provided with these programs are suitable for determining substantial similarity of nucleic acid sequences for purposes of the present invention.

A “vector” is a composition of matter which comprises an isolated nucleic acid and which can be used to deliver the isolated nucleic acid to the interior of a cell. Numerous vectors are known in the art including, but not limited to, linear polynucleotides, polynucleotides associated with ionic or amphiphilic compounds, plasmids, and viruses. Thus, the term “vector” includes an autonomously replicating plasmid or a virus. The term should also be construed to include non-plasmid and non-viral compounds which facilitate transfer or delivery of nucleic acid to cells, such as, for example, polylysine compounds, liposomes, and the like. Examples of viral vectors include, but are not limited to, adenoviral vectors, adeno-associated virus vectors, retroviral vectors, recombinant viral vectors, and the like. Examples of non-viral vectors include, but are not limited to, liposomes, polyamine derivatives of DNA and the like.

Methods involving conventional molecular biology techniques are described herein. Such techniques are generally known in the art and are described in detail in methodology treatises, such as Molecular Cloning: A Laboratory Manual, 2nd ed., vol. 1-3, ed. Sambrook et al., Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y., 1989; and Current Protocols in Molecular Biology, ed. Ausubel et al., Greene Publishing and Wiley-Interscience, New York, 1992 (with periodic updates). Methods for chemical synthesis of nucleic acids are discussed, for example, in Beaucage and

Carruthers, Tetra. Letts. 22: 1859-1862, 1981, and Matteucci et al., J. Am. Chem. Soc. 103:3185, 1981.

The terms "comprises," "comprising," and the like can have the meaning ascribed to them in U.S. Patent Law and can mean "includes," "including" and the like.

5 As used herein, "including" or "includes" or the like means including, without limitation.

Exogenic Organ/Tissue Production

The humanized large animal model is a resource for regenerative medicine and will serve as a platform for personalized humanized porcine models. This strategy will
10 transform the current clinical practice paradigms for chronic musculoskeletal diseases and transplantation. Ablation of porcine cardiac muscle is unique, because it not only aims to develop humanized cardiac muscle in a large animal model, but because it is a novel approach to circumvent immune rejection, and can be broadly applicable for exogenic organ development strategies.

15 Currently, the only definitive therapy for advanced endstage organ failure is transplantation. Millions of patients could benefit from such therapy, but are not eligible for transplantation due to limited donor organ availability. Therefore, there is a significant shortage of cadaveric or living-related donor organs. Furthermore, transplantation of organs requires lifelong immunosuppression, which also has
20 deleterious, life-limiting side effects. Described herein are humanized tissues generated in pigs that will serve as an unlimited source of organs for transplantation and provide a paradigm-shifting platform for the treatment of cardiovascular diseases (Fig. 6).

Intense interest has focused on exogenic transplantation and recent technological advances support the notion that these strategies can be successful. For
25 example, a rat pancreas was produced in a mouse by the process of blastocyst complementation (38). In these studies, blastocysts mutant for Pdx1, the master regulatory gene for pancreatic development, were injected with pluripotent stem cells from wild-type rats (rPSCs) (38). Transfer of the rPSC-injected blastocysts into surrogate mouse dams gave rise to mouse chimeras with functional pancreata composed
30 of rat cells. These mutant hosts provide a developmental "niche," for healthy donor stem cells to populate and generate a donor-derived organ. The blastocyst complementation strategy has also produced organs such as the kidney and liver in rodents, and recently the pancreas in pigs (39-41). This latter report using the porcine model supports the development of human patient-specific organs in pigs that can be subsequently used for
35 transplantation or advanced therapies (Fig. 6).

The humanized large animal model is a resource for regenerative medicine and will serve as a platform for personalized humanized porcine models. This strategy will

transform the current clinical practice paradigms for chronic musculoskeletal diseases and transplantation. Ablation of porcine heart tissue is unique, because it not only aims to develop humanized heart tissue in a large animal model, but because it is a novel approach to circumvent immune rejection, and can be broadly applicable for exogenic organ development strategies.

Using a gene-editing platform, various developmental genes can be mutated to generate organ and/or tissue deficient pigs, upon which blastocyst complementation can be deployed for the generation of exogenic organs and/or tissue. The efficiency of this system allows many genes to be tested empirically. The simultaneous modification of multiple regulatory genes permits the modulation of complex tissue ontogeny.

Muscle Diseases/Disorders

Cardiac tissue and cells include cardiac muscle cells or cardiomyocytes (also known as myocardiocytes or cardiac myocytes) are the muscle cells (myocytes) that make up the cardiac muscle. Cardiovascular disease or cardiac disease includes diseases of heart and blood vessels, many of which are related to atherosclerosis. Diseases/disorders include, but are not limited to, heart attack, stroke, heart failure, arrhythmia, and heart valve problems.

Generation of precision knockout (KO) pigs to generated human-pig chimeras for organ production

With the use of site-specific nucleases, efficiencies of introducing precise genetic alterations in large animal genomes have improved more than 100,000-fold. Highly efficient heterozygous and bi-allelic knockouts (KOs) in livestock at rates of 50% and 20%, respectively, was demonstrated using a TALEN based platform to inactivate genes by non-homologous end-joining (NHEJ) of double-stranded breaks cleaved by site-specific nucleases (27). Using the gene-editing platform, various developmental genes can be mutated to generate organ-deficient pigs, upon which blastocyst complementation can be deployed for the generation of exogenic organs. The efficiency of this system allows many genes to be tested empirically.

ETV2 knockout pig embryos lack the endothelial lineage

Previous studies have demonstrated that Nkx2-5 is an upstream regulator of the Etv2 gene and that Etv2 is a master regulator of the endothelial lineage in the mouse, as embryos lacking Etv2 are lethal at approximately E9.5 with an absence of vasculature (8, 10, 12, 13). To examine the role of ETV2 in the pig, the entire ETV2 coding sequence was removed using two TALEN pairs flanking the gene in porcine fibroblasts (Fig. 7A). The process was 15% efficient at homozygous gene removal; 79/528 of the genotyped clones were homozygous for the deletion of the ETV2 gene (Fig. 7B). ETV2 homozygous knockout fibroblast clones were used for nuclear cloning (Somatic Cell

Nuclear Transfer; SCNT) to generate ETV2 null embryos, which were transferred to surrogate sows. The cloning efficiency was 29%, which was higher than the average success rate of 20%. Embryos were harvested and analyzed at E18.0 (Fig. 8). At this stage, Wt embryos were vascularized with a well-developed vascular plexus in the allantois (Fig. 8A, C). In contrast, growth was significantly retarded in ETV2 KOs, (Fig. 7B), and these embryos lacked the endocardial/endothelial lineages (Fig. 8D, F, H). ETV2 KO embryos lacked cardinal veins, dorsal aortae, and the endocardium, that are clearly developed in the Wt embryos (Fig. 8E-H). The results reflect similarities in mouse and pig phenotypes and suggest that the function of ETV2 is conserved between these species. Further, these data demonstrate that one can direct multiple mutations into the porcine genome to support growth of chimeric organs that will be humanized in more than one cell type.

Nkx2-5, HandII and Tbx5

Nkx2-5, HandII and Tbx5 were mutated to generate heart muscle lineage deficient pig embryos (Nkx2-5/HandII/Tbx5 null porcine embryos). Performing multiplex gene edits for Nkx2-5/HandII/Tbx5 created a permissive niche that is repopulated with cardiac cells using human cells with pluripotent capacity, to yield humanized heart/cardiac tissue and/or cardiac muscle. See details in Example 2.

The humanized large animal model will be an important resource for regenerative medicine and will serve as a platform for making personalized organs. This strategy can transform the current clinical practice paradigms for muscle diseases and transplantation. To date, exogenic transplantation of organs has been performed between mouse and rat (27, 29); and pig and pig (31), and no successful development of humanized organs in large animal models have been reported. Incorporated herein by reference is U.S. Provisional Application Serial No. 62/247,092; 62/247096; and 62/247,122.

The following example is intended to further illustrate certain particularly preferred embodiments of the invention and is not intended to limit the scope of the invention in any way.

EXAMPLES

Example 1: Nkx2-5, HandII and Tbx5 as regulators of cardiogenesis

Cardiac development is a complex highly-orchestrated event that includes the specification, proliferation, migration and differentiation of cardiac progenitors that become electrically coupled and ultimately form a functional syncytium (Fig. 1). These stages of cardiogenesis are governed by transcriptional networks, which have been shown, using gene disruption technology, to be required for heart formation and

viability (6, 8, 9, 22-26) (Table1).

Table 1: Phenotypes of cardiac gene mutation			
Genes mutated	Phenotypes in the heart		
	Lethal stage	Morphological features of the heart	Down-regulated transcription factors
<i>Nkx2-5</i>	E9.5	Heart tube forms, but does not loop. No demarcation of atria and ventricles.	<i>Hand1, Meis2C</i>
<i>Tbx5</i>	E10.5	Hypoplasia of the left ventricle and sinoatrial structures (primitive atria and inflow tract). Heart does not loop.	<i>Nkx2-5, Gata4</i>
<i>Hand2</i>	E10.5	Hypoplasia of the right ventricle and aortic arch defects.	<i>Gata4</i>
<i>Nkx2-5+Hand2</i>	E8.5-9.5	Single cardiac chamber with complete ventricular dysgenesis.	<i>Hand1</i>

Nkx2-5 is the vertebrate homolog of the *Drosophila* homeodomain protein, Tinman (Csx). The Tinman mutation results in the absence of heart formation in the fly (35).

5 Nkx2-5 is one of the earliest transcription factors expressed in the cardiac lineage. Targeted disruption of *Nkx2-5* results in perturbed heart morphogenesis, severe growth retardation and embryonic lethality at approximately E9.5 (22, 24). One of the *Nkx2-5* interacting factors is the T-box transcription factor, *Tbx5*, which together form a complex and transactivates cardiac gene expression (36). Global deletion of *Tbx5* in the

10 mouse results in perturbed cardiac morphogenesis (severe atrial and ventricular hypoplasia) and embryonic lethality by E10.5 (25). Even haploinsufficient mice (*Tbx5*^{+/-}) display severe congenital heart and forelimb malformations and have been shown to cause the defects in patients with Holt-Oram Syndrome (25). HandII (dHand) is a bHLH transcription factor that has also been shown to be need for cardiac

15 morphogenesis. *HandII* mutant embryos are lethal during early embryogenesis and have severe right ventricular hypoplasia and aortic arch defects (23). Moreover, mice lacking both *Nkx2-5* and *HandII* demonstrate ventricular agenesis and have only a single atrial chamber (Fig. 2) (26).

Multiplex knockout of porcine *NKX2-5*, *HANDII* and *TBX5* genes

20 To define the *Nkx2-5* transcriptional regulatory cascade in cardiac progenitor cells, engineered knockout and transgenic mouse models were utilized to define the molecular networks that direct the specification of the cardiac lineage from stem cell populations (8, 9, 37). To define *Nkx2-5* mediated networks during cardiogenesis, the molecular signature of the CPC population in the developing *Nkx2-5* null hearts (9) was

25 examined. The 6 kb *Nkx2-5* enhancer-EYFP transgenic mouse model was combinatorially mated into the *Nkx2-5* null background to direct EYFP expression in *Nkx2-5* null CPCs. Using FACS, Wt and *Nkx2-5* null CPCs from stage (age) matched individual embryos were isolated, RNA was isolated and amplified and the respective

molecular programs using whole genome analysis were interrogated. This strategy defined downstream Nkx2-5 target genes and uncovered roles for Nkx2-5 in cardiogenesis, endothelial/endocardial lineage specification (induction of Etv2) and the repression of blood formation (Fig. 5F). The studies also identified a molecular signature for the early CPC population that included Nkx2-5, HandlI and Tbx5 (37).

Multiplex homology-dependent recombination (HDR) in pigs

As previously described (see above), methodologies to introduce bi-allelic knockouts (KOs) into porcine fibroblasts using the TALEN-specified HDR technique (28) were developed. These emerging technologies were further utilized to perform multiplex gene KOs (i.e. to engineer an ETV2 knockout along with NKX2-5/HANDII/TBX5 mutations and other organ-specific factors). To verify this technology for multiple bi-allelic gene editing, pairs of TALENs were used that each resulted in more than 20% HDR/site, and simultaneously co-transfected these pairs in three combinations, with each combination targeting five separate genes in the pig genome (28).

A combination of TALEN stimulated HDR and mutation by NHEJ (discussed herein) was used to generate *NKX2-5/HANDII/TBX5* mutant porcine embryonic fibroblasts. Each gene was targeted either within or immediately prior to their conserved transcription factor/DNA binding domains (Fig. 3A). This strategy is favored over targeting the gene near the transcription start site to reduce the chance of producing a functional peptide by initiation at a downstream AUG. For *TBX5* and *NKX2-5*, a homology template was provided to generate a novel in-frame stop codon, restriction site for RFLP screening, and an additional five base insertion after the stop codon to prevent a functional read-through protein. The *HANDII* TALENs were about 10% efficient, and therefore the experiments were carried out without a homology template to avoid interference with *TBX5* and *NKX2-5* HDR, a phenomenon observed using multiplex HDR in pig fibroblasts (unpublished data). Triple mutants were identified using a three-tiered approach. First, colonies were screened for double knockout of *TBX5* and *NKX2-5* by RFLP assay (Fig. 3B). In the first round of 480 colonies, thirty-three (7%) were found to be double knockouts. Among the double knockouts, four were identified (1% overall) that also were mutant for in *HANDII* (Fig. 3C). The ability to reliably produce triple null pig fibroblast cell lines in a single shot is unique and a transformative technology.

Absence of a heart in triple knockout pig embryos

The experiments have targeted a number of transcription factors (i.e. *MESPI*, *GATA4*, *NKX2-5*, *HANDII*, *TBX5*, etc.) that result in perturbed cardiogenesis and provides new models for the study and treatment of congenital heart disease.

Demonstrated herein, as proof-of-concept, successful targeting and generation of clones homozygous for the deletion of *NKX2-5/HAND1/TBX5* genes. Triple knockout fibroblast clones were used for nuclear cloning (SCNT) to generate *NKX2-5/HAND1/TBX5* null porcine embryos, which were transferred to surrogate sows.

- 5 Embryos were harvested and analyzed at E18, which is equivalent to E11 of the mouse. At E18, the triple knockout porcine embryos have vasculature, skeletal muscle and blood, but lack a heart (minimal GATA4 immunohistochemically positive cardiomyocytes) (see Figure 4) compared to the wildtype control porcine embryo.

Example 2 - Human stem cells integrate into the inner cell mass (ICM) of porcine parthenotes (embryos electrically activated to develop without fertilization)

- 10 Human stem cell/progenitor cell populations can contribute and participate in porcine parthenote chimeras. The capacity of human inducible pluripotent stem cells (hiPSCs), human mesenchymal stem cells (hMSCs), human pluripotent stem cells and human cardiac progenitors (hCPCs) to contribute to porcine parthenote development
- 15 will be compared. Data using porcine parthenogenetic blastocysts (30) support the belief that hiPSCs are integrated into the inner cell mass of the parthenotes. The experiments will examine hiPSC lines, hMSC lines, human pluripotent stem cells and hCPCs and their capacity to successfully produce human-porcine chimeras *in vitro* and *in vivo* using porcine parthenogenetic embryos. These studies will examine the
- 20 proliferative capacity of the human stem cell populations, apoptosis and developmental progression for the *in vitro* analysis. The *in vivo* analysis will utilize immunohistochemistry with human specific antisera and in situ hybridization of post-implantation parthenotes.

- The capacity of hiPSC to integrate into the porcine blastocysts and participate in
- 25 embryonic development was evaluated. Porcine parthenogenetic blastocysts were generated using electrical stimulation of oocytes (42). Six days following activation 9-12 DiI- or EdU (24 hr)- labeled hiPSC were injected into the blastocoel cavity. Blastocysts were allowed to recover two days in culture and then imaged. Labeled hiPSCs were observed in the ICM of 90% of the porcine blastocysts (Fig. 9A, B,
- 30 representative images are shown). Comparison of DiI distribution with immunohistochemistry using human nuclear antigen-specific antibody (HNA) reveals that HNA antibody detects injected human stem cells (Fig. 9A, arrows). Blastocysts injected with EdU labeled hiPSC were further pulsed with BrdU for 1 hour before harvest to detect proliferating cells. Double labeling with EdU reveals that injected
- 35 human stem cells continued to proliferate after 48 hrs of injection (Fig. 9B, arrows). These results demonstrate the incorporation of human stem cells into the ICM of

porcine blastocysts, and the developmental progression of the chimeric blastocysts to the hatching stage in preparation for implantation into the uterus.

These results support the rationale and feasibility of the proposed strategy and provide a rapid assay to examine whether human stem cell populations are compatible and/or contribute to the ICM development. Furthermore, implantation of parthenogenetic blastocysts provides a high-throughput method to examine integration and differentiation of human stem cells into developing embryos. A significant advantage of this strategy is that porcine oocytes are abundantly available as a bi-product of food production, and parthenogenetic embryos can be generated in large quantities on a regular basis. It should be noted that parthenogenetic embryos do not survive past 8 weeks, and therefore negates the concern of inadvertently giving birth to undesired human-porcine chimeras.

Human stem cell populations proliferate and contribute to the formation of human-porcine parthenote chimeras. Human mesenchymal stem cells (hMSCs) (46) and cardiac progenitor cells (hCPCs) (47) will be more restricted in their capacity to contribute to embryonic lineages in the developing pig. Furthermore, the hiPSCs and porcine stem cell populations may equally contribute to embryonic lineages.

Human stem/progenitor cell populations will rescue the NKX2-5/HANDII/TBX5 mutant porcine embryo. hiPSCs will be progenitors to every cardiac cell in the NKX2-5/HANDII/TBX5 mutant pre-term embryo.

Utilizing TALEN-mediated techniques (27, 28), an ETV2 mutant pig embryo was generated that is nonviable and lacks an endothelial lineage. Using TALEN-mediated techniques to generate NKX2-5/HANDII/TBX5 mutant fibroblasts and the data demonstrates that these mutant pig embryos lack a heart. The data further support the notion that human stem cells (human cord blood stem cells and human iPSCs) can integrate into the ICM of porcine parthenotes. In human-porcine complementation studies, the engraftment of human stem cells in E17 human stem cell-porcine chimeras will be examined.

Example 3

Materials and Methods

TALEN design and production

Candidate TALEN target DNA sequences and RVD sequences were identified using the online tool "TAL EFFECTOR NUCLEOTIDE TARGETER 2.0". Plasmids for TALEN DNA transfection or *in vitro* TALEN mRNA transcription were then constructed by following the Golden Gate Assembly protocol using RCIscript-GOLDYTALEN (Addgene ID 38143) as final destination vector (Carlson 2012). Assembled RCIscript vectors prepared using the QIAPREP SPIN MINIPREP kit

(Qiagen) were linearized by *SacI* to be used as templates for in vitro TALEN mRNA transcription using the mMESSAGE mMACHINE® T3 Kit (Ambion) as indicated previously (Carlson, 2009). Resulting mRNA was DNase treated prior to purification using the MEGACLEAR REACTION CLEANUP kit (Applied Biosciences) or RNeasy
5 kit, (Qiagen).

Tissue Culture and Transfection

Pig fibroblasts were maintained at 37 or 30 degrees Celsius (as indicated) at 5% CO₂ in DMEM supplemented with 10% fetal bovine serum, 100 I.U./mL penicillin and streptomycin, 2mM L-Glutamine and 10mM Hepes. The Neon Transfection system
10 (Life Technologies) was used to deliver TALENs and HDR oligos. Low passage Ossabaw or Landrace pig fibroblasts at 70-100% confluency were split 1:2 and harvested the next day at 70-80% confluency. Approximately 600,000 cells were resuspended in "R" Buffer (Life Technologies) with mRNA TALENs and HDR oligos and electroporated in 100uL tips using the following parameters: input voltage: 1800V;
15 pulse width: 20 ms; pulse number: 1. 0.1-4 ug of TALEN mRNA and 0.1-0.4 nmol of HDR oligos for the specific gene(s) of interest were included for each transfection. Transfected cells were cultured for 2 or 3 days at 30 degrees Celsius, and then analyzed for gene editing efficiency and plated for colonies.

Dilution cloning

20 Two or three days post transfection, 50 to 250 cells were seeded onto 10 cm dishes and cultured until individual colonies reached circa 5mm in diameter. 8 mL of a 1:4 (vol/vol) mixture of TrypLE and DMEM media (Life Technologies) was added and colonies were aspirated, transferred into wells of a 48-well dish and a replica 96 well dish and cultured under the same conditions. Colonies reaching confluence were
25 collected and for cryopreservation and sample preparation for genotyping.

Sample preparation

Transfected cell populations at day 3 and 10 were collected from a well of a 6-well dish and 10-30% were resuspended in 50 µl of 1X PCR compatible lysis buffer: 10 mM Tris-Cl pH 8.0, 2 mM EDTA, 0.45% Tryton X-100(vol/vol), 0.45% Tween-
30 20(vol/vol) freshly supplemented with 200 µg/ml Proteinase K. The lysates were processed in a thermal cycler using the following program: 55°C for 60 minutes, 95°C for 15 minutes.

Analysis of gene-edits

PCR flanking the intended sites was conducted using AccuStart™ Taq DNA
35 Polymerase HiFi (Quanta Biosciences) with 1 µl of the cell lysate according to the manufacturer's recommendations. The frequency of mutation in a population was analysed with the SURVEYOR MUTATION DETECTION Kit (Transgenomic)

according to the manufacturer's recommendations using 10 ul of the PCR product as described above. SURVEYOR reactions were resolved on a 10% TBE polyacrylamide gels and visualized by ethidium bromide staining. Densitometry measurements of the bands were performed using ImageJ; and mutation rate of SURVEYOR reactions was calculated as described in (Guschin et al. 2010). Individual colonies were screened for the presence of an HDR allele using primers. PCR products underwent restriction fragment length polymorphism analysis (RFLP) by digesting the resulting PCR amplicons with HindIII to determine whether one, both, or none of the alleles were cut and therefor contained the HDR allele. Products were resolved on agarose gels.

10 PIG sequences

Nkx2-5: ENSSSCG00000016984

Tbx5: ENSSSCG00000009867

Hand2: ENSSSCG00000009703

Pig Gene: NKX2-5 Gene ID: ENSSSCG00000016984

15 Description: NK2 homeobox 5 [Source:HGNC Symbol;Acc:HGNC:2488]

Synonyms: CSX, CSX1, NKX2.5, NKX2E, NKX4-1

Location: Chromosome 16: 55,400,561-55,403,626 forward strand.

INSDC coordinates: chromosome:Sscrofa10.2:CM000827.4:55400561:55403626:1

About this gene: This gene has 1 transcript (splice variant), 37 orthologues, 15

20 paralogues and is a member of 1 Ensembl protein family

Pig NKX2-5 Genomic sequence ID: CU928102

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 ID NO:1)

Code :

- Exons/ Introns
- Translated sequence
- 20 • **Flanking sequence**
- Intron sequence
- *UTR*

Pig NKX2-5 mRNA sequence: ID ENSST00000018494

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Pig Gene: HAND2 ENSSCG00000009703 (Ensemble)

Description; heart and neural crest derivatives expressed 2 [Source:HGNC
Symbol;Acc: HGNC:4808]

20 Synonyms; bHLHa26, dHand, Hed, Thing2

Location; Chromosome 14: 17,528,447-17,531,529 reverse strand.

INSDC coordinates;

chromosome:Sscrofa10.2:CM000825.4:17528447:17531529:1

About this gene: This gene has 1 transcript (splice variant), 54 orthologues, 9
25 paralogues and is a member of 1 Ensembl protein family.

Pig HAND2 genomic sequence ID: CU468996

Pig HAND2-201 mRNA ID: ENSSTCT00000010638 (Ensemble) XM_005670479
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Uniprot ID: F1RJ02-1

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(SEQ ID NO:6)

Pig Gene: TBX5 Gene ID: ENSSCG00000009867

Pig TBX5 genomic sequence ID: CU468413

Description: T-box 5 [Source:HGNC Symbol;Acc:HGNC:11604]

Synonyms: HOS

5 Location: Chromosome 14: 40,211,210-40,259,321 forward strand.

INSDC coordinates: chromosome:Sscrofa10.2:CM000825.4:40211210:40259321:1

About this gene: This gene has 1 transcript (splice variant), 61 orthologues, 8
paralogues and is a member of 1 Ensembl protein family.

Pig Tbx5 gene ID :ENSSCG00000009867

10 Pig TBX5 mRNA predicted sequence

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Pig TBX5 protein ID: FIRKD2 (Ensembl, predicted)

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Homo sapiens NK2 transcription factor related, locus 5 (Drosophila), mRNA (cDNA
 25 clone MGC:34495 IMAGE:5225103), complete cds

Human NKX2-5 Gene information: GenBank: BC025711.1

LOCUS BC025711 1632 bp mRNA

linear PRI 15-JUL-2006 DEFINITION Homo sapiens NK2

transcription factor related, locus 5

30 (Drosophila), mRNA (cDNA clone MGC:34495 IMAGE:5225103),
 complete cds. ACCESSION BC025711 VERSION

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Protein sequence information

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Human NKX2-5 protein sequence

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Human NKX2-5 mRNA sequence

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Homo sapiens heart and neural crest derivatives expressed 2 (HAND2) mRNA,
 complete cds

GenBank: FJ226608.1

50 Human HAND2 gene information

LOCUS FJ226608 2351 bp mRNA linear PRI 15-APR-2009

DEFINITION Homo sapiens heart and neural crest derivatives expressed 2 (HAND2)

mRNA, complete cds. ACCESSION FJ226608 VERSION FJ226608.1

GI:209170693

Human HAND2 mRNA information

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Human HAND2 protein information

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10 Homo sapiens T-box 5, mRNA (cDNA clone MGC:35581 IMAGE:5204163), complete
 cds

GenBank: BC027942.1

Human TBX5 gene information:

LOCUS BC027942 3748 bp mRNA

15 linear PRI 15--JUL--2006 DEFINITION Homo sapiens T-box 5,
 mRNA (cDNA clone MGC:35581 IMAGE:5204163),
 complete cds. ACCESSION BC027942 VERSION BC027942.1
 GI:20379838

Human TBX5 mRNA information:

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Human TBX5 protein information

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Bibliography

1. Garry, DJ, Martin, CM. *Circ Res*. 2004;95(9):852-4.
- 10 2. Hoffman, JL. *Pediatr Cardiol*. 1995;16(3):103-13.
3. Kang, HK, et al. *American journal of industrial medicine*. 2000;38(4):447-54.
4. Kramarow, EA, Pastor, PN. *NCHS data brief*. 2012(101):1-8.
5. Rasmussen, TL, et al. *Circulation*. 2011;123(16):1771-9.
6. Garry, DJ, Olson, EN. *Cell*. 2006;127(6):1101-4.
- 15 7. Latif, S, et al. *Trends Cardiovasc Med*. 2006;16(7):234-40.
8. Ferdous, A, et al. *Proc Natl Acad Sci U S A*. 2009;106(3):814-9. PMID: 2630085.
9. Caprioli, A, et al. *Circulation*. 2011;123(15):1633-41. PMID: 3110259.
10. Rasmussen, TL, et al. *Development*. 2011;138(21):4801-12. PMID: 3190388.
- 20 11. Borges, L, et al. *Blood*. 2012;119(23):5417-28.
12. Koyano-Nakagawa, N, et al. *Stem Cells*. 2012;30(8):1611-23. PMID: 3651838.
13. Rasmussen, TL, et al. *PLoS One*. 2012;7(11):e50103. PMID: 3501484.
14. Behrens, et al. *Stem Cells and Development*. 2013;22(15):2211-20. PMID: 3715789.
- 25 15. Behrens, AN, et al. *Etv2 transactivates Sox7 and regulates endothelial development*. Submitted to *Developmental Biology*. 2013.
16. Borges, L, et al. *Levels of endoglin distinctively control TGFb/BMP signaling at different stages of yolk sac hematopoiesis*. Submitted to *Stem Cells Revised manuscript under review*. 2013.
- 30 17. Borges, L, et al. *Stem Cells*. 2013;31(9):1893-901. PMID: 3795927.
18. Chan, SS, et al. *Cell Stem Cell*. 2013;12(5):587-601. PMID: 3646300.
19. Rasmussen, TL, et al. *Genesis*. 2013;51(7):471-80.
20. Behrens, AN, et al. *Stem Cells Dev*. 2014;23(17):2004-13. PMID: 4142794.
- 35 21. Shi, X, et al. *Dev Biol*. 2014;389(2):208-18. PMID: 4099474.

22. Lyons, I, et al. *Genes Dev.* 1995;9(13):1654-66.
23. Srivastava, D, et al. *Nat Genet.* 1997;16(2):154-60.
24. Tanaka, M, et al. *Development.* 1999;126(6):1269-80.
25. Bruneau, BG, et al. *Cell.* 2001;106(6):709-21.
- 5 26. Yamagishi, H, et al. *Dev Biol.* 2001;239(2):190-203.
27. Carlson, DF, et al. *Proc Natl Acad Sci U S A.* 2012;109(43):17382-7. PMCID: 3491456.
28. Tan, W, et al. *Proc Natl Acad Sci U S A.* 2013.
29. Xin, J, et al. *PLoS One.* 2013;8(12):e84250. PMCID: 3866186.
- 10 30. Kure-bayashi, S, et al. *Theriogenology.* 2000;53(5):1105-19.
31. Naseem, RH, et al. *Physiol Genomics.* 2007;30(1):44-52.
32. Martin, CM, et al. *Circ Res.* 2008;102(9):1075-81.
33. Sadek, H, et al. *Proc Natl Acad Sci U S A.* 2008;105(16):6063-8. PMCID: 2329693.
- 15 34. Roger, VL, et al. *Circulation.* 2012;125(1):188-97.
35. Bodmer, R. *Development.* 1993;118(3):719-29.
36. Hiroi, Y, et al. *Nat Genet.* 2001;28(3):276-80.
37. Masino, AM, et al. *Circ Res.* 2004;95(4):389-97.
38. Kobayashi, T, et al. *Cell.* 2010;142(5):787-99.
- 20 39. Usui, J, et al. *Am J Pathol.* 2012;180(6):2417-26.
40. Bort, R, et al. *Dev Biol.* 2006;290(1):44-56.
41. Matsunari, H, et al. *Proc Natl Acad Sci U S A.* 2013;110(12):4557-62. PMCID: 3607052.
42. Kure-Bayashi, S, et al. *Theriogenology.* 1996;46(6):1027-36.
- 25 43. Adamo, L, Garcia-Cardena, G. *Dev Biol.* 2012;362(1):1-10.
44. Rhee, JM, Iannaccone, PM. *Dev Biol.* 2012;365(1):1-13. PMCID: 3322272.
45. Heinz, M, et al. *Exp Hematol.* 2002;30(7):809-15.
46. Crisan, M, et al. *Cell Stem Cell.* 2008;3(3):301-13.
47. Makkar, RR, et al. *Lancet.* 2012;379(9819):895-904.
- 30 48. Nakano, K, et al. *PLoS One.* 2013;8(4):e61900. PMCID: 3633951.
49. King, TJ, et al. *Reproduction.* 2002;123(4):507-15.
50. Zhu, J, et al. *Cloning Stem Cells.* 2003;5(4):355-65.

51. Brustle, O, et al. Nat Biotechnol. 1998;16(11):1040-4.
52. Messina, E, et al. Circ Res. 2004;95(9):911-21.
- Bodmer, R. (1993 Development 118(3): 719-729.
- Bruneau, B. G., et al. Cell 106(6): 709-721.
- 5 Caprioli, A., et al. Circulation 123(15): 1633-1641.
- Ferdous, A., et al. Proc Natl Acad Sci U S A 106(3): 814-819.
- Garry, D. J. and E. N. Olson (2006). Cell 127(6): 1101-1104.
- Lyons, I., et al. Genes Dev 9(13): 1654-1666.
- Srivastava, D., et al. Nat Genet 16(2): 154-160.
- 10 Tanaka, M., et al. Development 126(6): 1269-1280.
- Yamagishi, H., et al. Dev Biol 239(2): 190-203.

All publications, patents, and patent applications, Genbank sequences, websites and other published materials referred to throughout the disclosure herein are herein

15 incorporated by reference to the same extent as if each individual publication, patent, or patent application, Genbank sequences, websites and other published materials was specifically and individually indicated to be incorporated by reference. In the event that the definition of a term incorporated by reference conflicts with a term defined herein, this specification shall control.

20

WHAT IS CLAIMED IS:

1. A non-human animal cell, morula or blastocyst wherein the genome carries a mutation in both alleles of the NKX2-5 gene, HANDII gene, TBX5 gene or a combination thereof such that the non-human animal cell or blastocyst lacks functional NKX2-5 protein, HANDII protein, TBX5 protein or a combination thereof.
2. The non-human animal cell, morula or blastocyst of claim 1, wherein the mutation is a deletion of the NKX2-5 gene, HANDII gene, TBX5 gene or a combination thereof.
3. The non-human animal cell, morula or blastocyst of claim 1 or 2, wherein the non-human animal cell or blastocyst is a porcine, bovine, equine or goat.
4. A chimeric non-human animal, morula or blastocyst expressing human NKX2-5, HANDII, TBX5 or a combination thereof and lacking expression of non-human animal NKX2-5, HANDII, TBX5 or a combination thereof.
5. The chimeric non-human animal of claim 4, wherein the non-human animal produces humanized cardiac cells and/or tissue.
6. A chimeric pig expressing exogenous pig NKX2-5, HANDII, TBX5 or a combination thereof and lacking expression of endogenous pig NKX2-5, HANDII, TBX5 or a combination thereof (a pig-pig chimera).
7. The chimeric non-human animal of claims 4 or 5, wherein the non-human animal is a porcine, bovine, equine or goat.
8. A method for producing a chimeric non-human animal expressing a human NKX2-5 gene, HANDII gene, TBX5 gene or a combination thereof comprising:
 - a) generating a NKX2-5, HANDII, TBX5 or a combination thereof null non-human animal cell, wherein both copies of the non-human NKX2-5 gene, HANDII gene, TBX5 gene or a combination thereof gene carry a mutation that prevents production of functional NKX2-5 protein, HANDII protein, TBX5 protein or combination thereof;
 - b) creating a NKX2-5, HANDII, TBX5 or a combination thereof null non-human morula blastocyst by somatic cell nuclear transfer comprising fusing a nucleus from said NKX2-5, HANDI, TBX5 or a combination thereof null non-human cell of a) into an enucleated non-human oocyte and activating said oocyte to divide so as to form

a NKX2-5, HANDII, TBX5 or a combination thereof null non-human morula or blastocyst;

c) introducing human stem cells into the non-human NKX2-5, HANDII, TBX5 or a combination thereof null morula or blastocyst of b); and

5 d) implanting said morula or blastocyst from c) into a pseudopregnant surrogate non-human animal to generate a chimeric non-human animal expressing human NKX2-5, HANDII, TBX5 or a combination thereof.

9. A method for producing a chimeric pig expressing an exogenous NKX2-5 gene, HANDII gene, TBX5 gene or a combination thereof comprising:

a) generating a NKX2-5, HANDII, TBX5 or a combination thereof null pig cell, wherein both copies of the endogenous pig MYF5 gene, MYOD gene, MRF4 gene or a combination thereof gene carry a mutation that prevents production of functional endogenous pig MYF5 protein, MYOD protein, MRF4 protein or combination thereof;

15 b) creating a NKX2-5, HANDII, TBX5 or a combination thereof null pig morula or blastocyst by somatic cell nuclear transfer comprising fusing a nucleus from said NKX2-5, HANDII, TBX5 or a combination thereof null pig cell of a) into an enucleated pig oocyte and activating said oocyte to divide so as to form a NKX2-5, HANDII, TBX5 or a combination thereof null pig morula or blastocyst;

20 c) introducing pig stem cells into the pig NKX2-5, HANDII, TBX5 or a combination thereof null morula or blastocyst of b); and

d) implanting said morula or blastocyst from c) into a pseudopregnant surrogate pig to generate a chimeric pig expressing exogenous pig NKX2-5, HANDII, TBX5 or a combination thereof.

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10. A method of producing human or humanized cardiac cells in a non-human animal comprising:

a) generating a NKX2-5, HANDII, TBX5 or a combination thereof null non-human cell, wherein both alleles of the non-human NKX2-5 gene, HANDII gene, TBX5 gene or a combination thereof carry a mutation that prevents production of functional the non-human NKX2-5 protein, HANDII protein, TBX5 protein or combination thereof;

b) creating a NKX2-5, HANDII, TBX5 or a combination thereof null non-human morula or blastocyst by somatic cell nuclear transfer comprising fusing a nucleus from said MYF5, MYOD, MRF4 or a combination thereof null non-human cell of a) into an enucleated non-human animal oocyte and activating said oocyte to divide so as

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to form a NKX2-5, HAND1, TBX5 or a combination thereof null non-human animal blastocyst;

c) introducing human stem cells into the NKX2-5, HAND1, TBX5 or a combination thereof null non-human animal blastocyst or morula of b); and

5 d) implanting said blastocyst or morula from c) into a pseudopregnant surrogate non-human animal so as to generate a non-human animal expressing human or humanized cardiac cells.

11. The method of claims 8 or 10, wherein the non-human animal is a porcine, bovine, equine or goat.

10 12. The method of claims 8, 9, or 10, wherein the human stem cell is a tissue specific stem cell, pluripotent stem cell, multipotent adult stem cell, induced pluripotent stem cell or umbilical cord blood stem cell (UCBSC).

13. The method of claims 8, 9 or 10, wherein the induced pluripotent cell is formed from a fibroblast cell.

15 14. A non-human animal produced by the method of any one of claims 8-13.

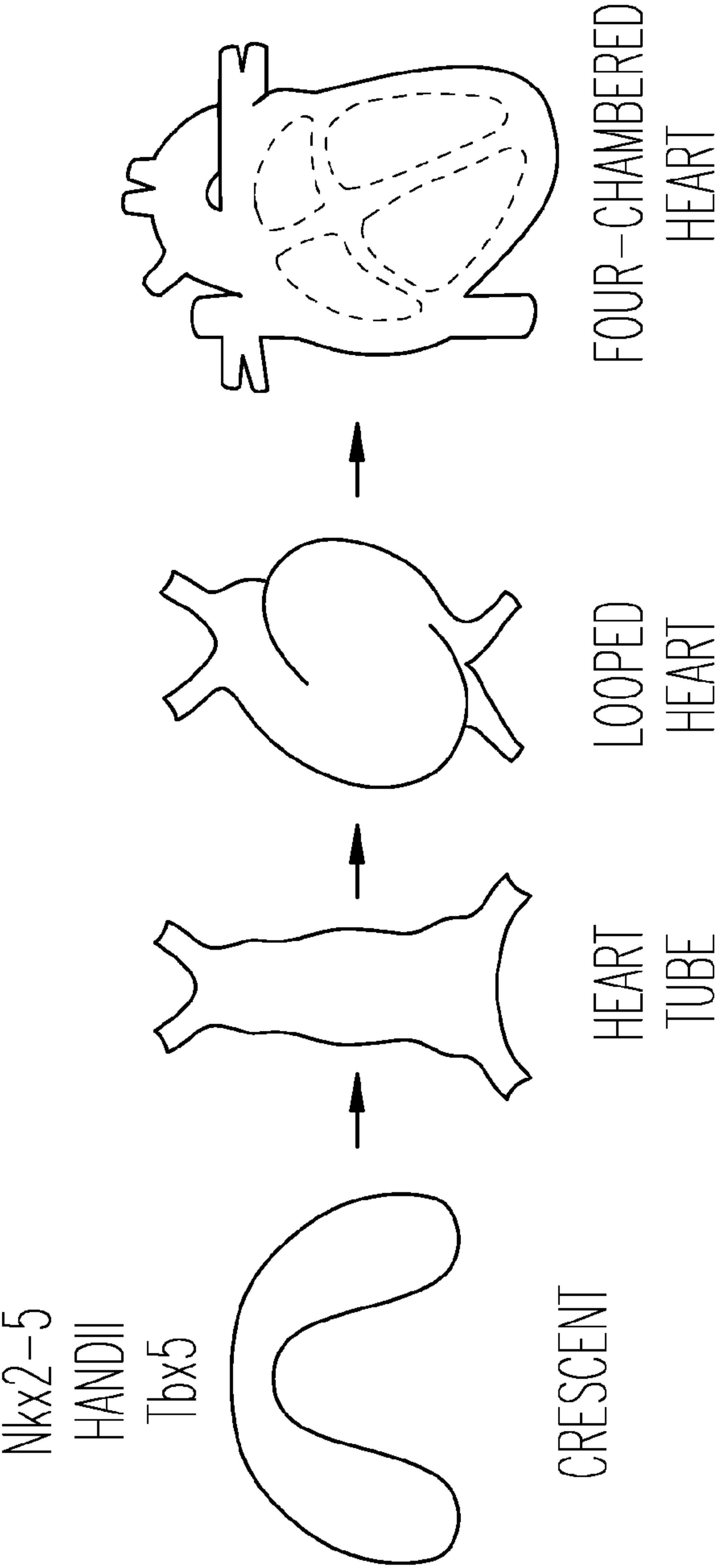


Fig. 1

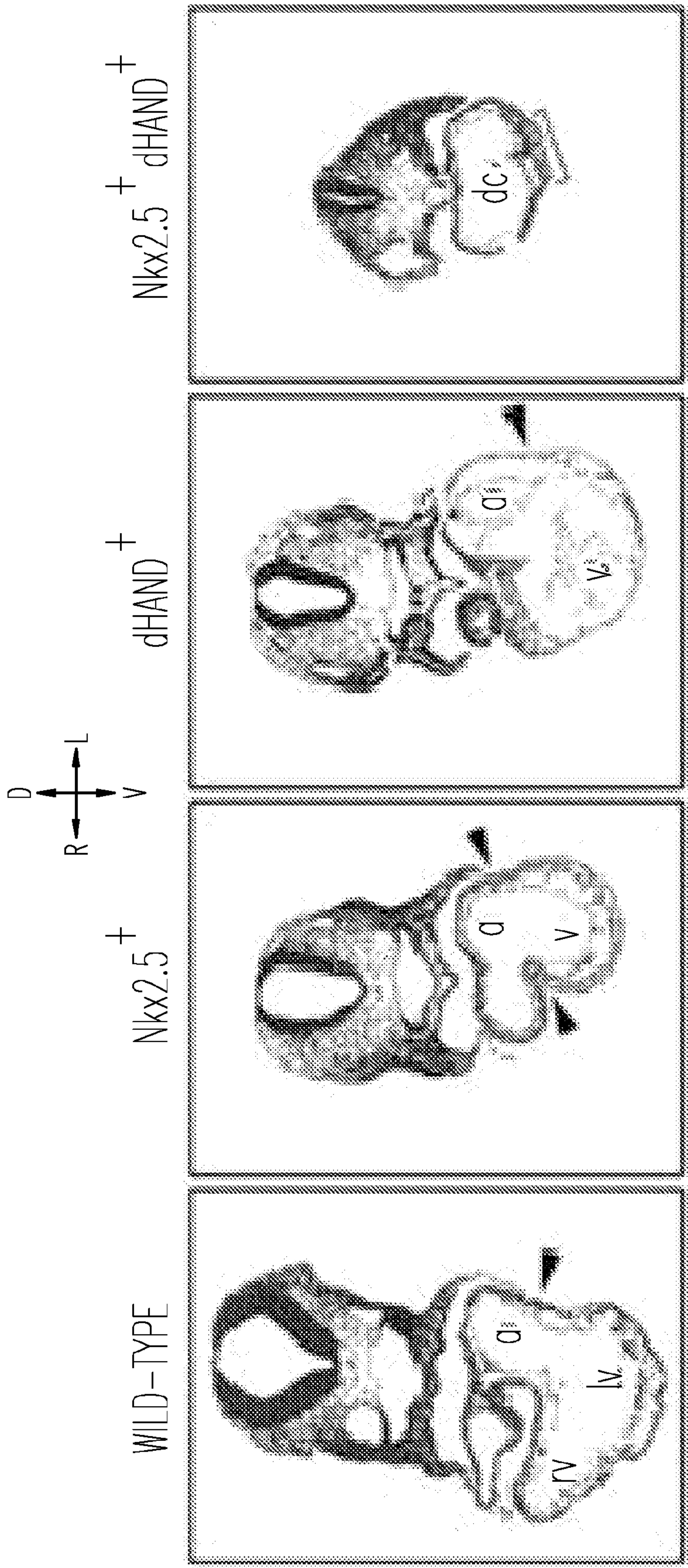


Fig. 2

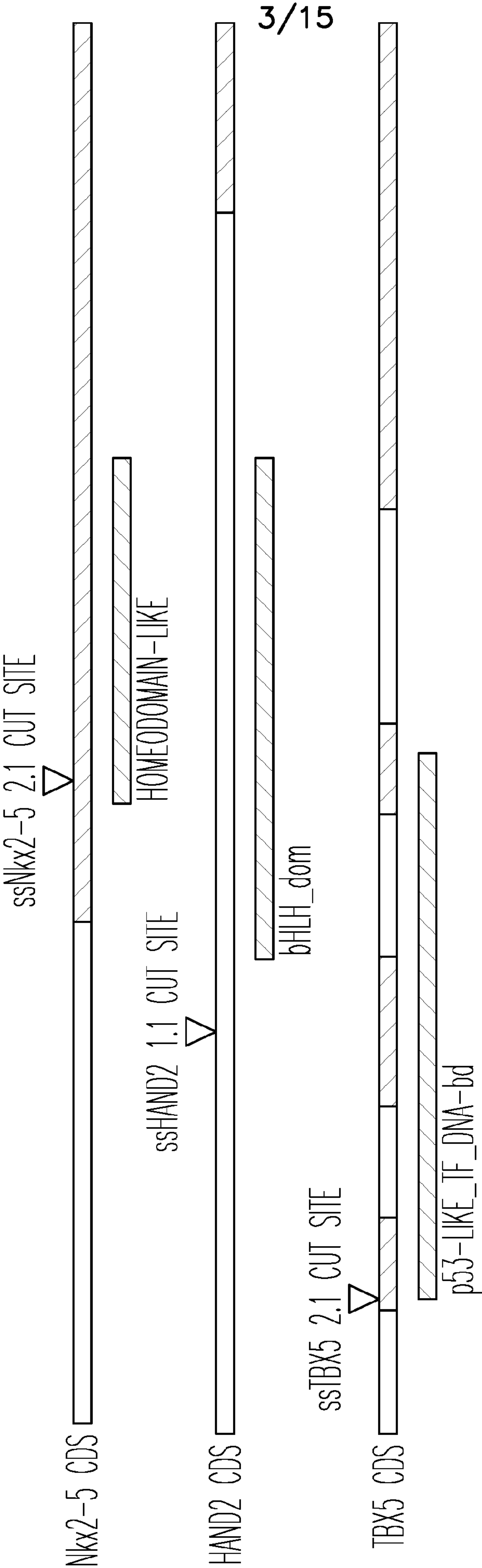


Fig. 3A

Fig. 3B

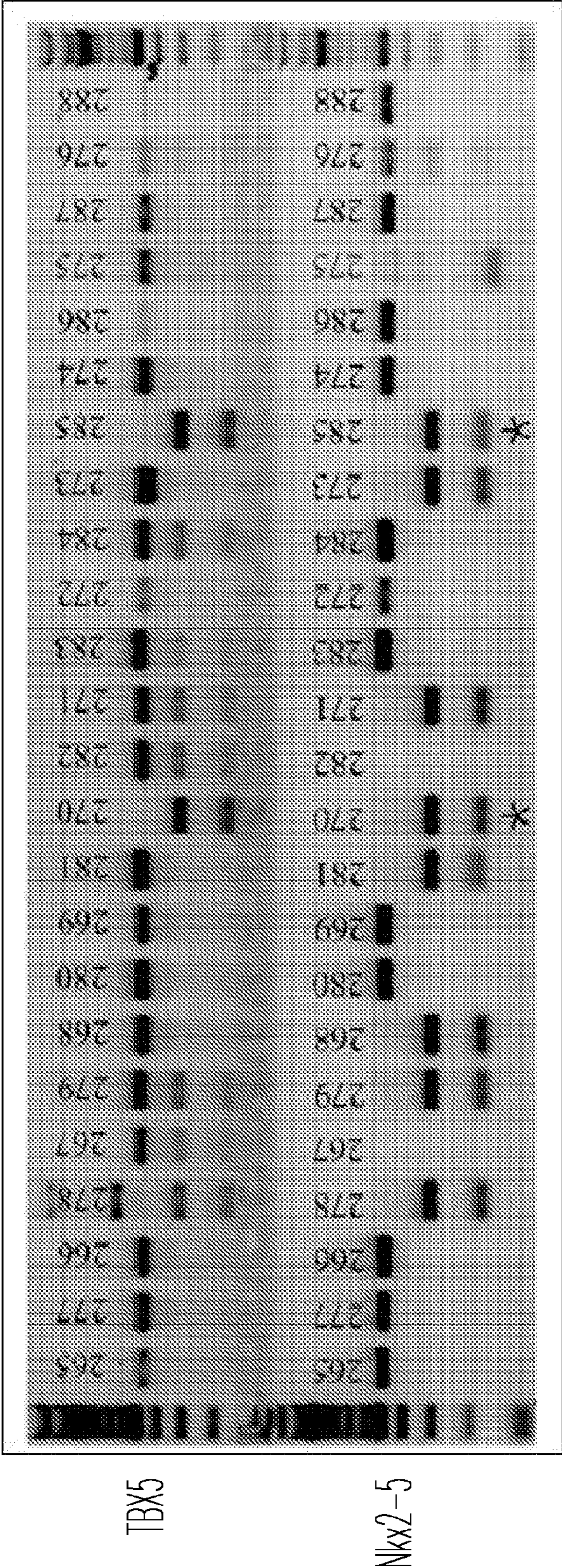


Fig. 3C

TALEN Pair	Number of Homozygous KOs (% of total)	Number of Nkx2-5 and TBX5 Double KOs (% of total)		Number of Triple Gene Mutants (% total)	
ssNkx2-5 2.1	102 (21%)				
ssHand2 1.1	N/A			4 (1%)	
ssTBX5 2.1	65 (14%)				

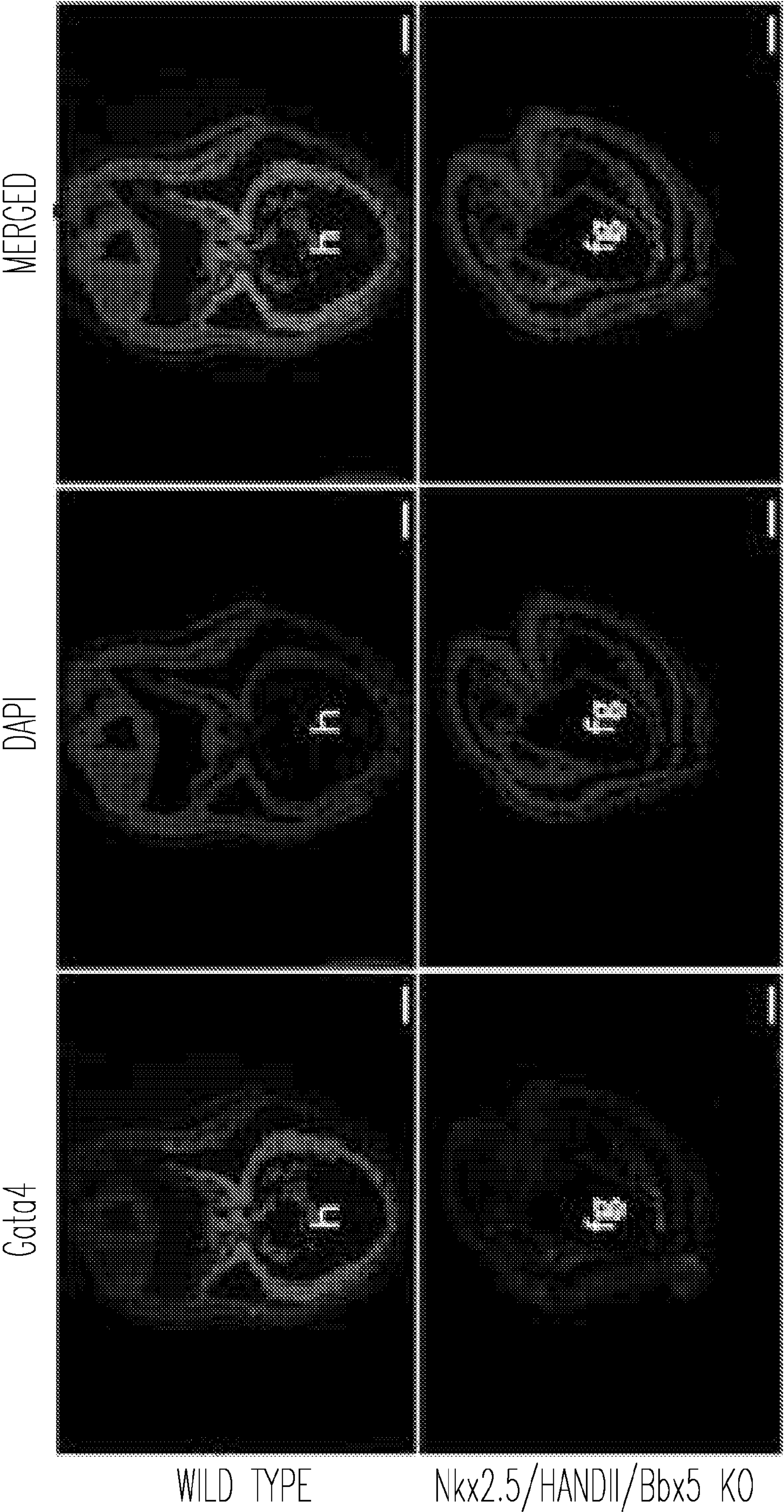


Fig. 4

Nkx 2.5 6kb ENHANCER	Hsp68	EYFP
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Fig. 5A

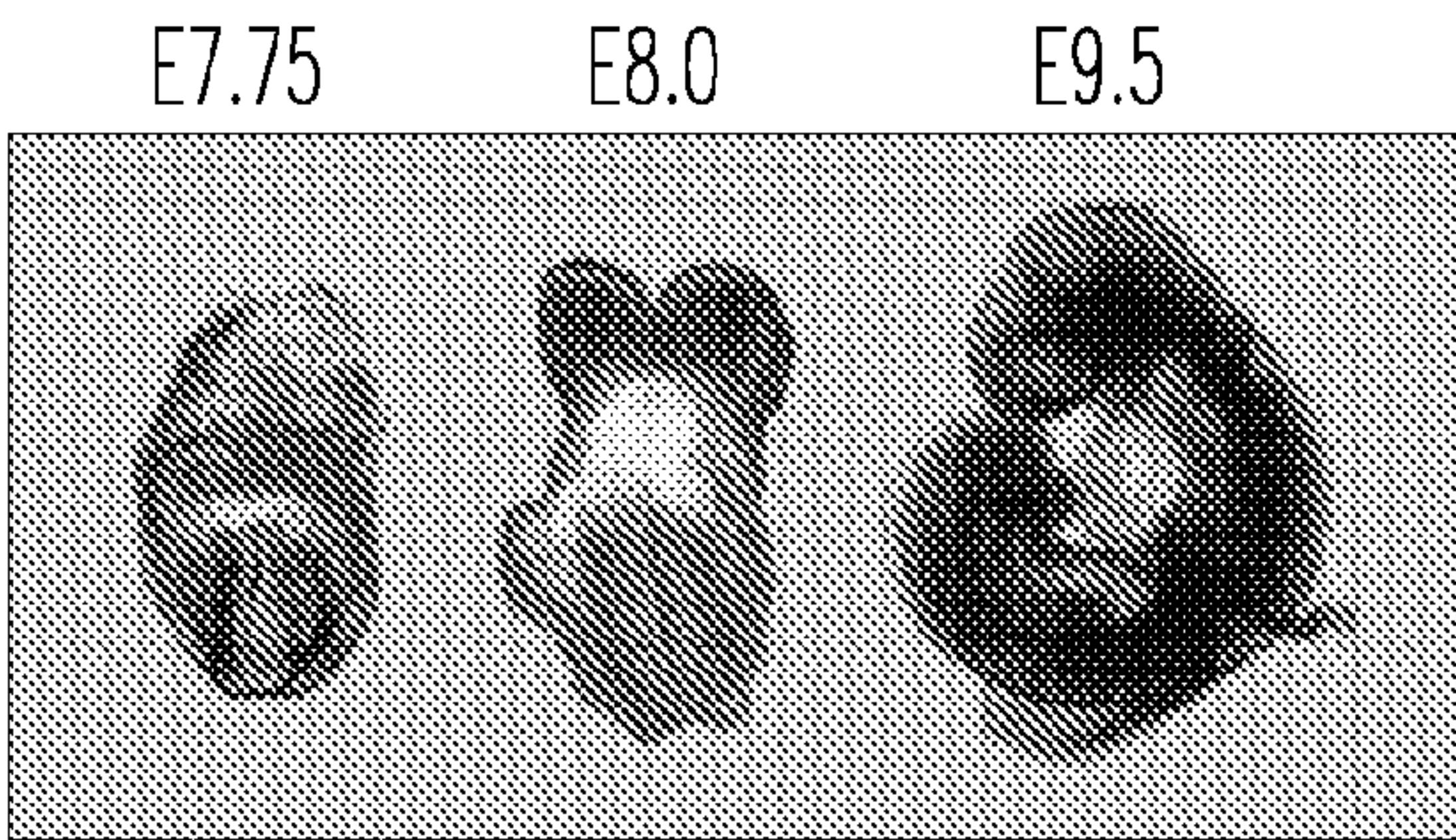


Fig. 5B

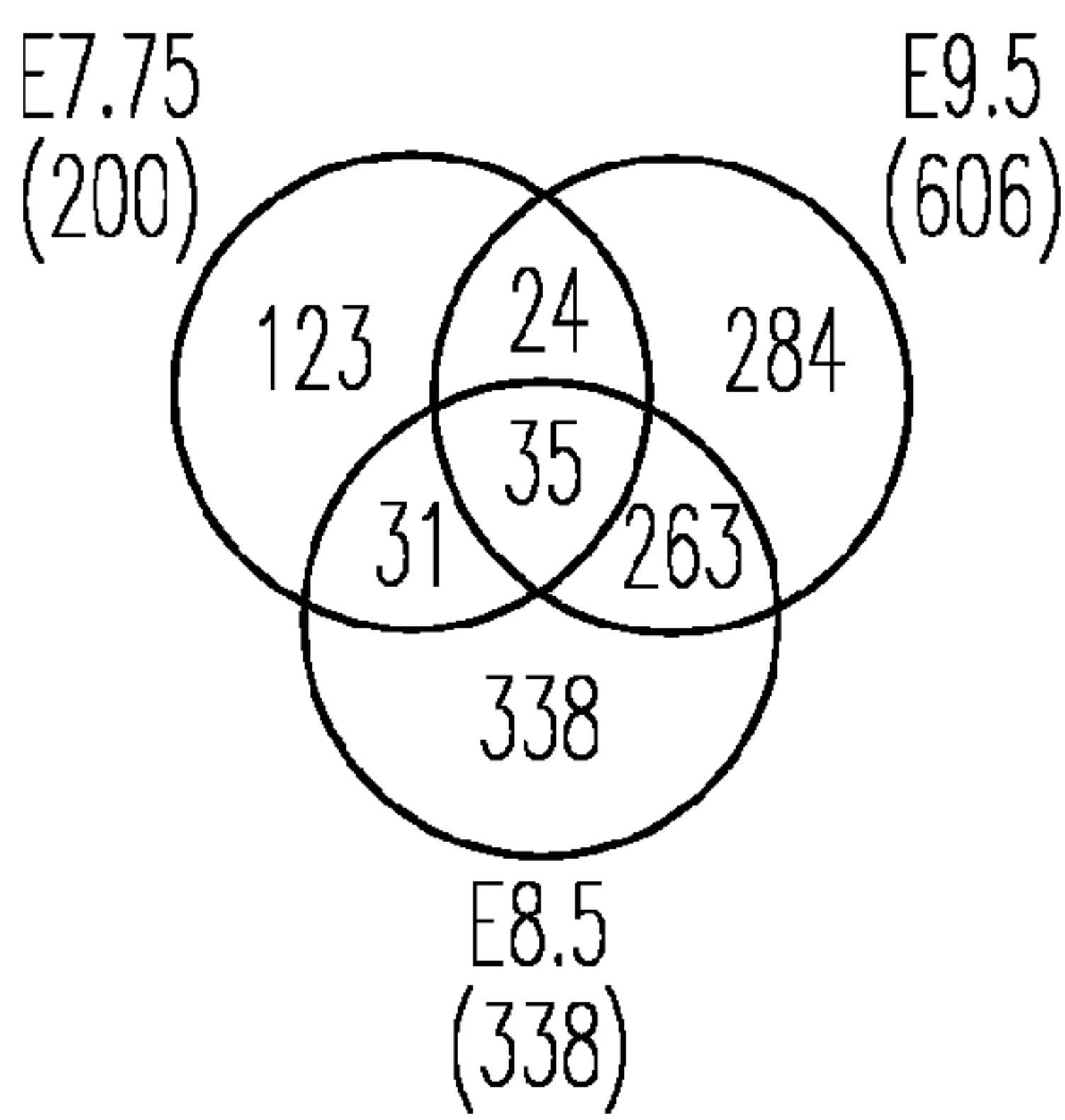


Fig. 5C

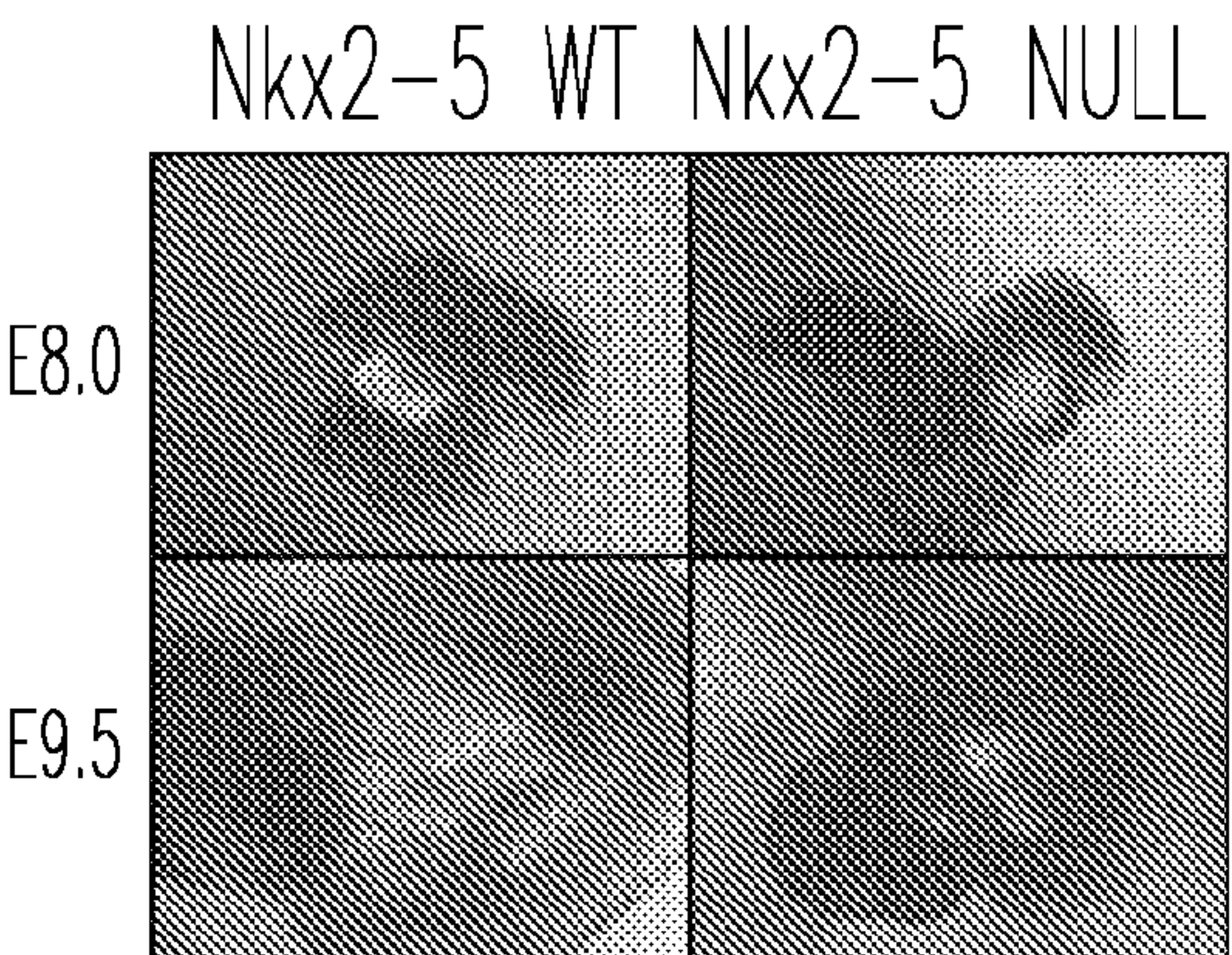


Fig. 5D

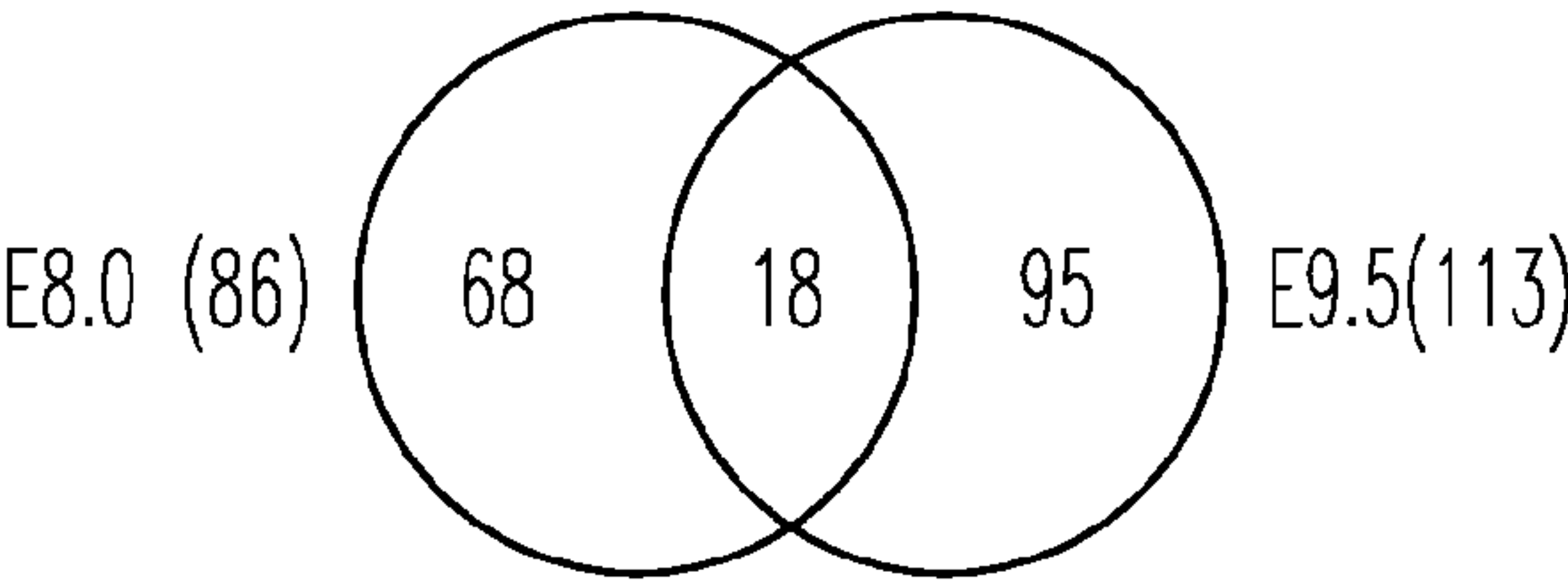


Fig. 5E

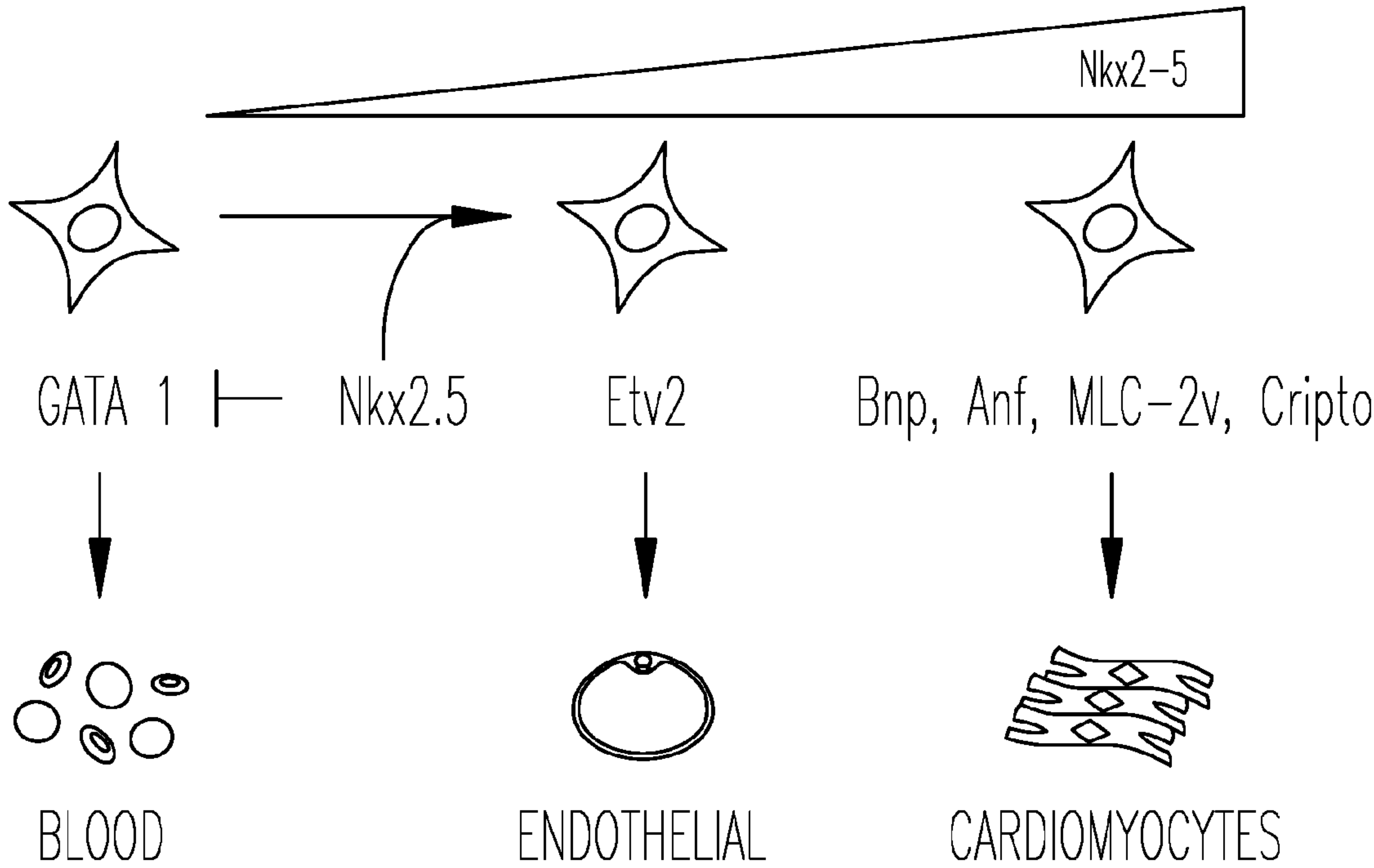


Fig. 5F

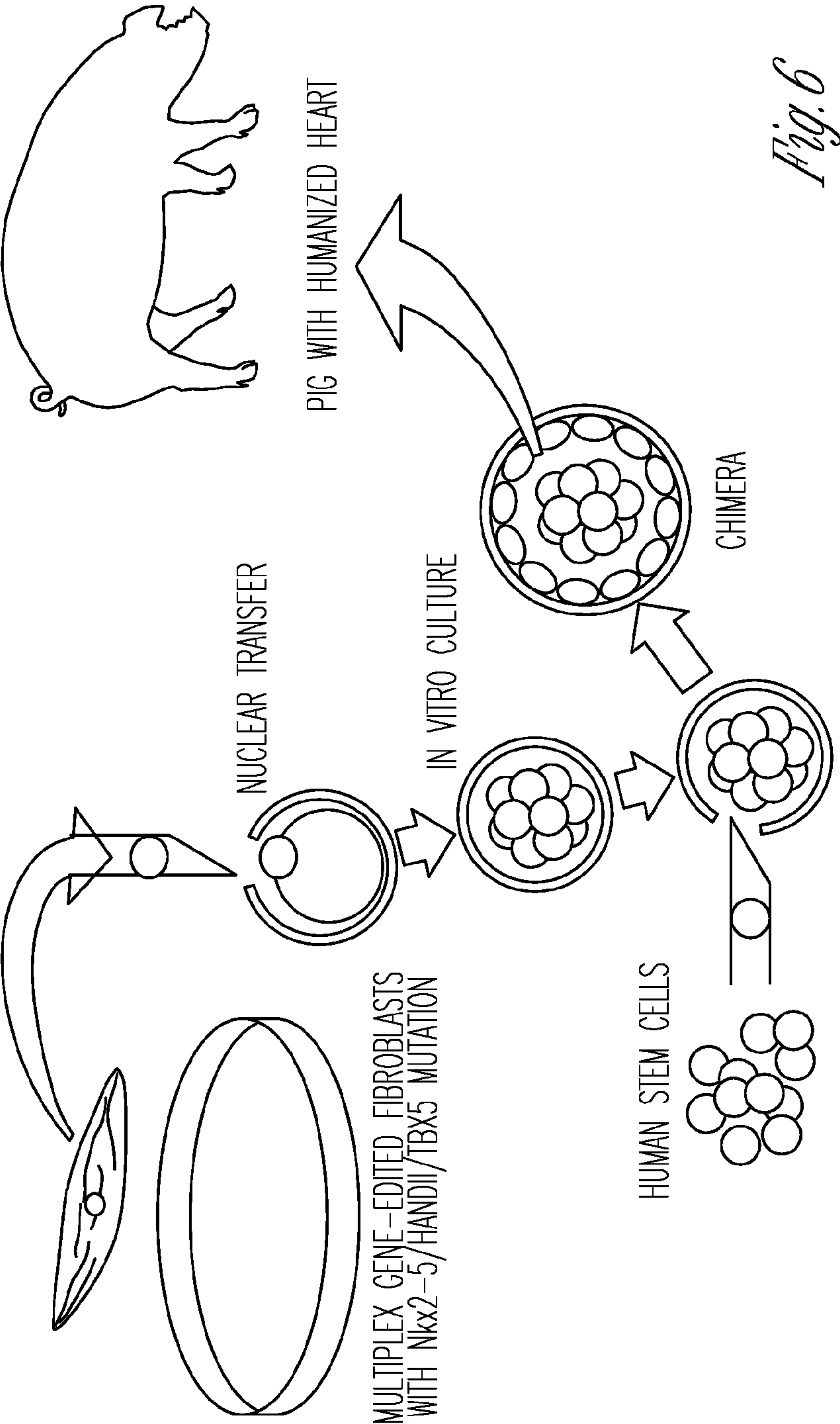


Fig. 6

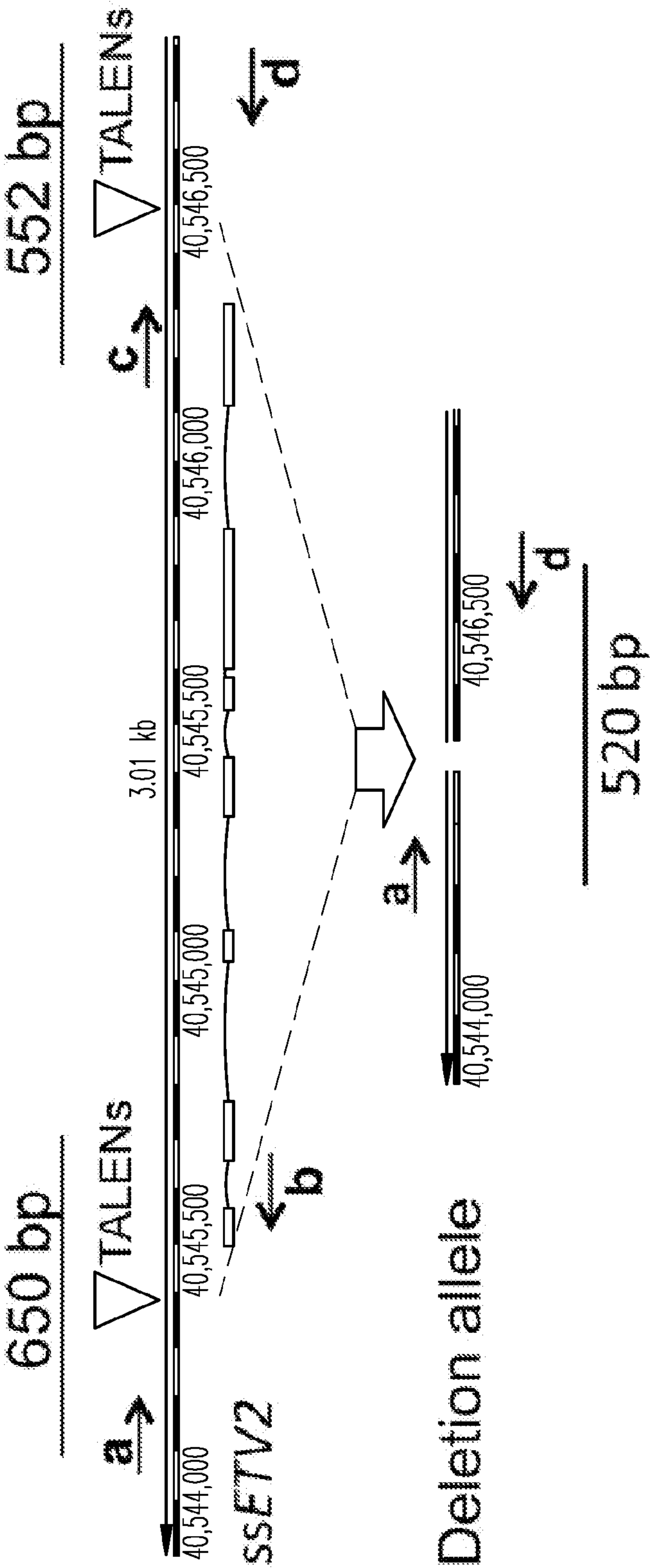
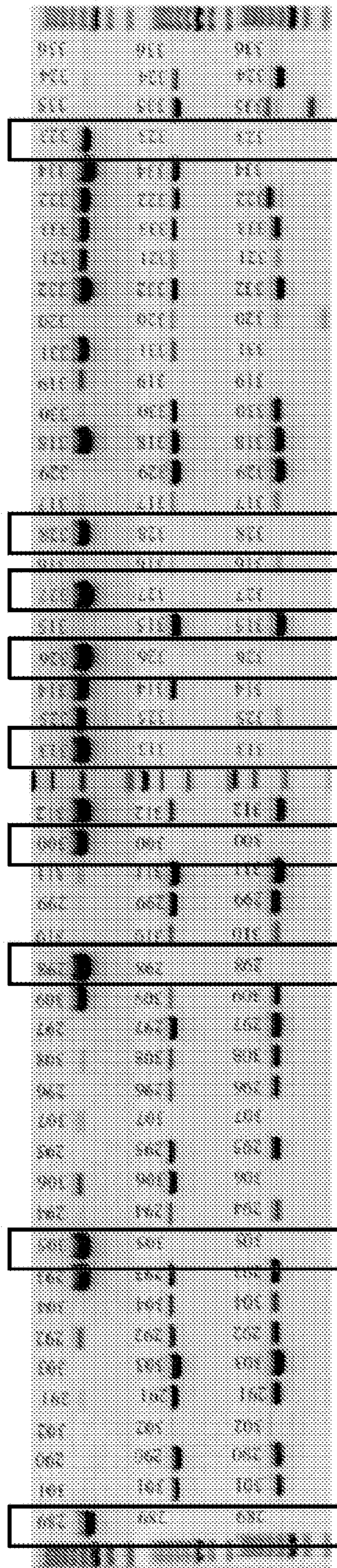


Fig. 7A

10/15



79/528 (15%) = homozygous deletion

Fig. 7B

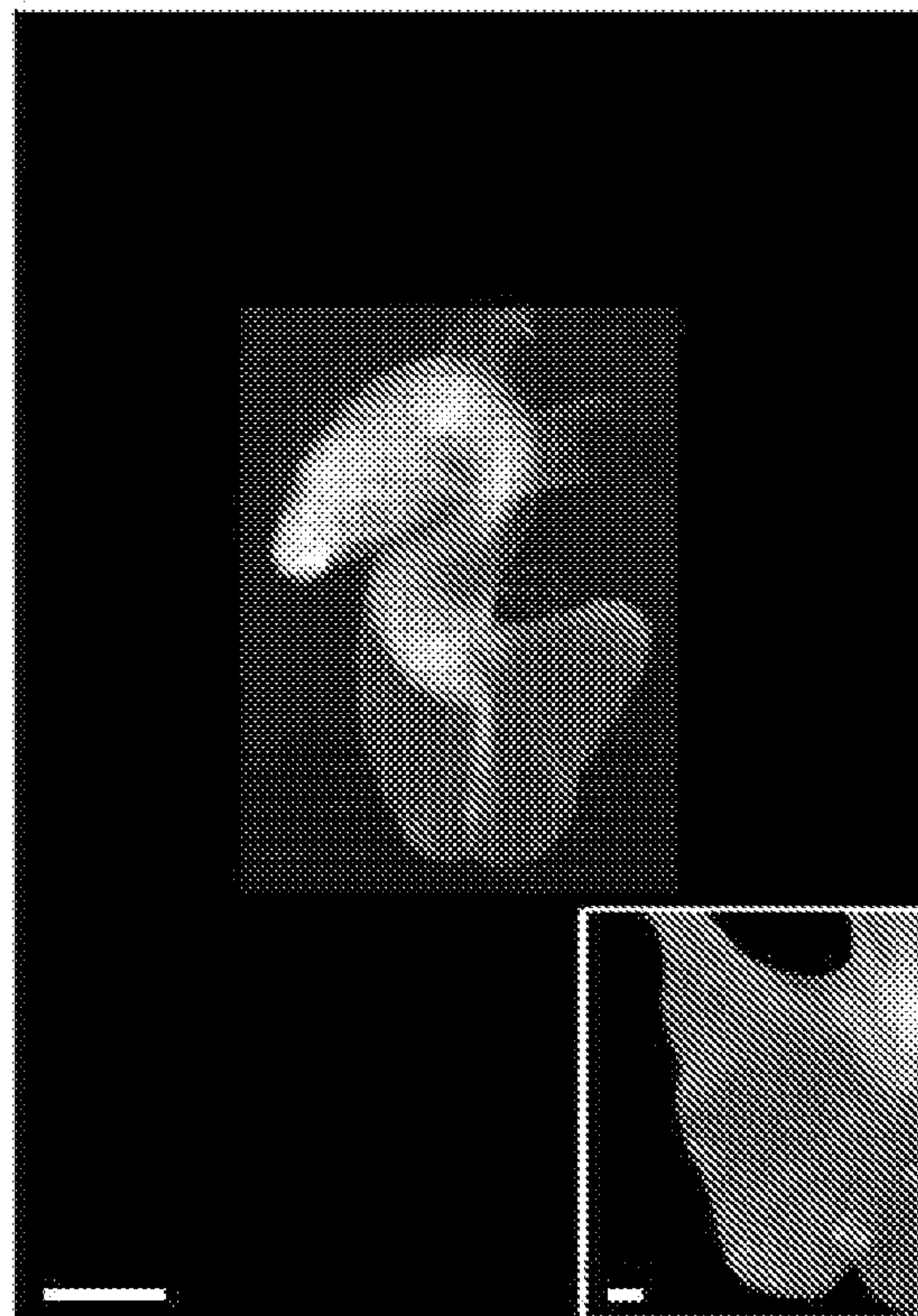
a-d

a-b

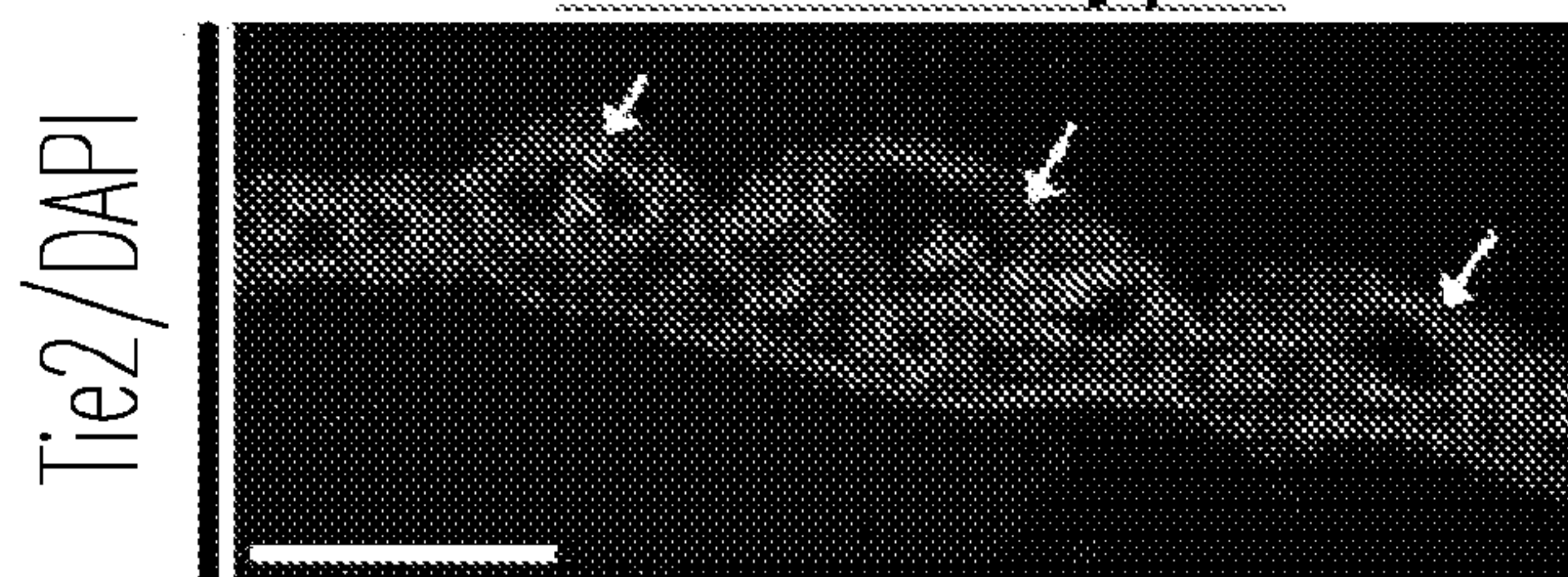
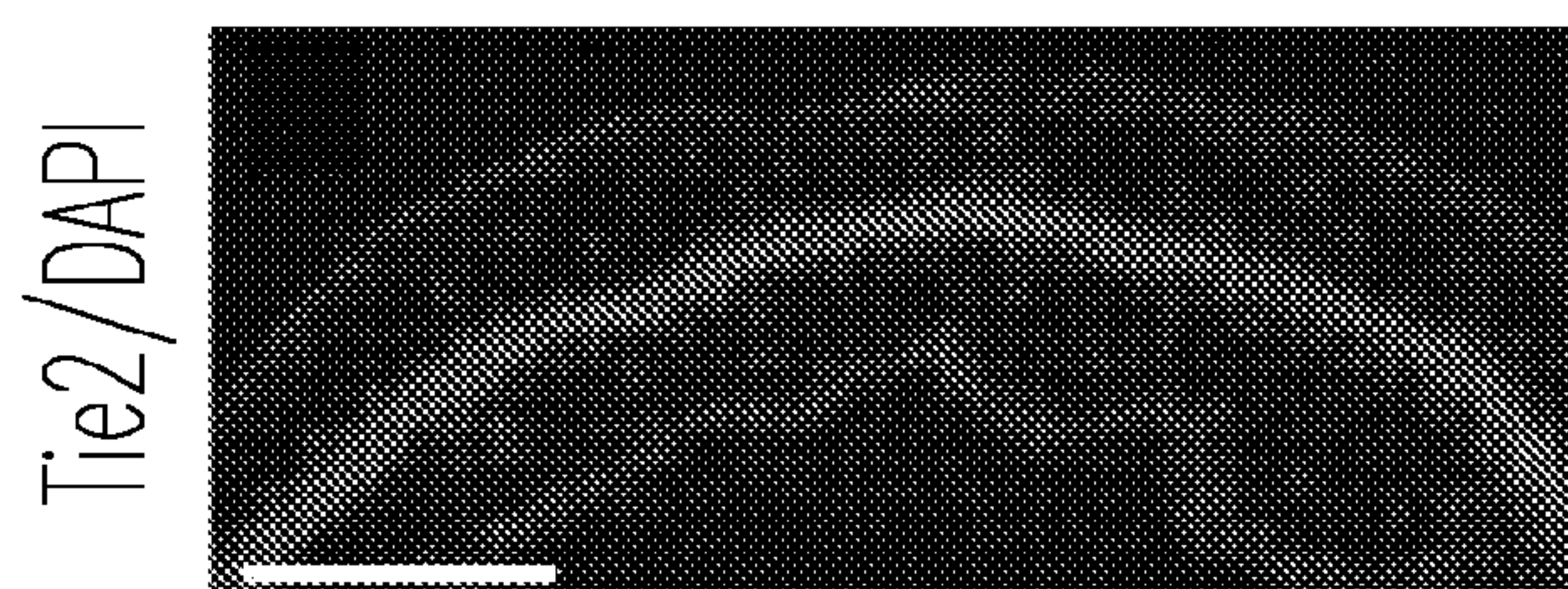
c-d

11/15

E18 Wild type

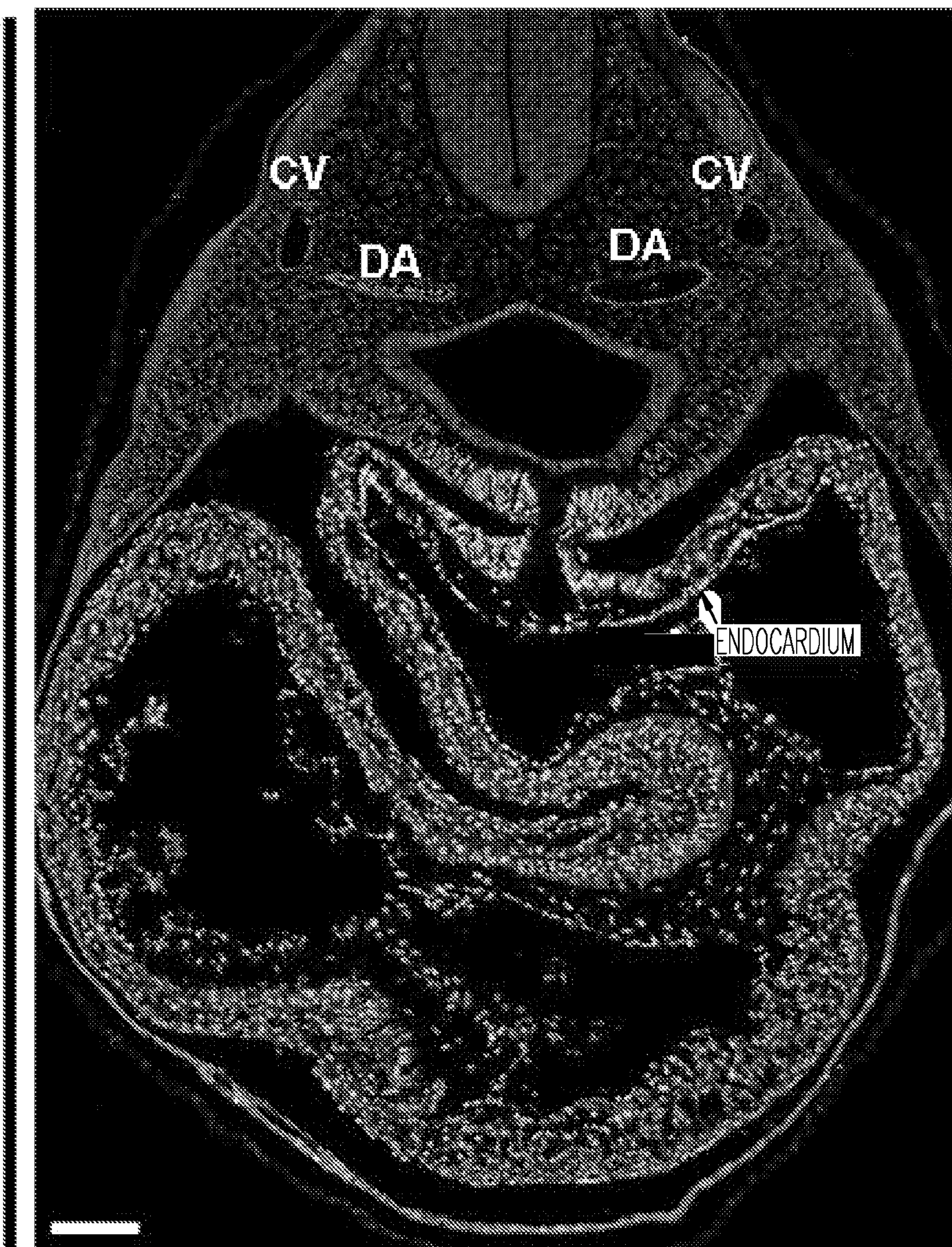
*Fig. 8A*E18 *Etv2* KO*Fig. 8B*

E18 Wild type

*Fig. 8C*E18 *Etv2* KO*Fig. 8D*

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Tie2/GATA4/DAPI

*Fig. 8E*

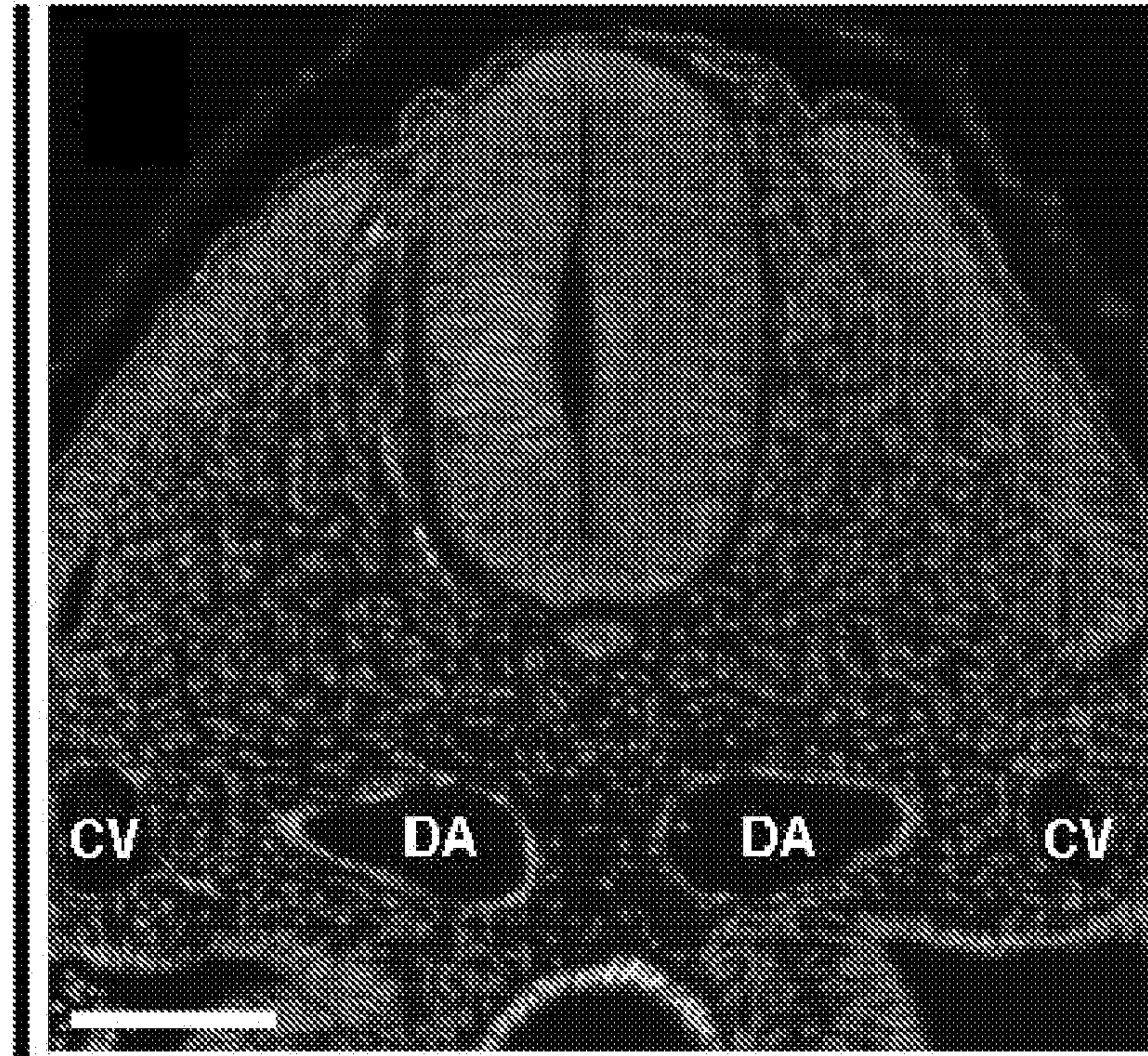
13/15

Tie2/GATA4/DAPI

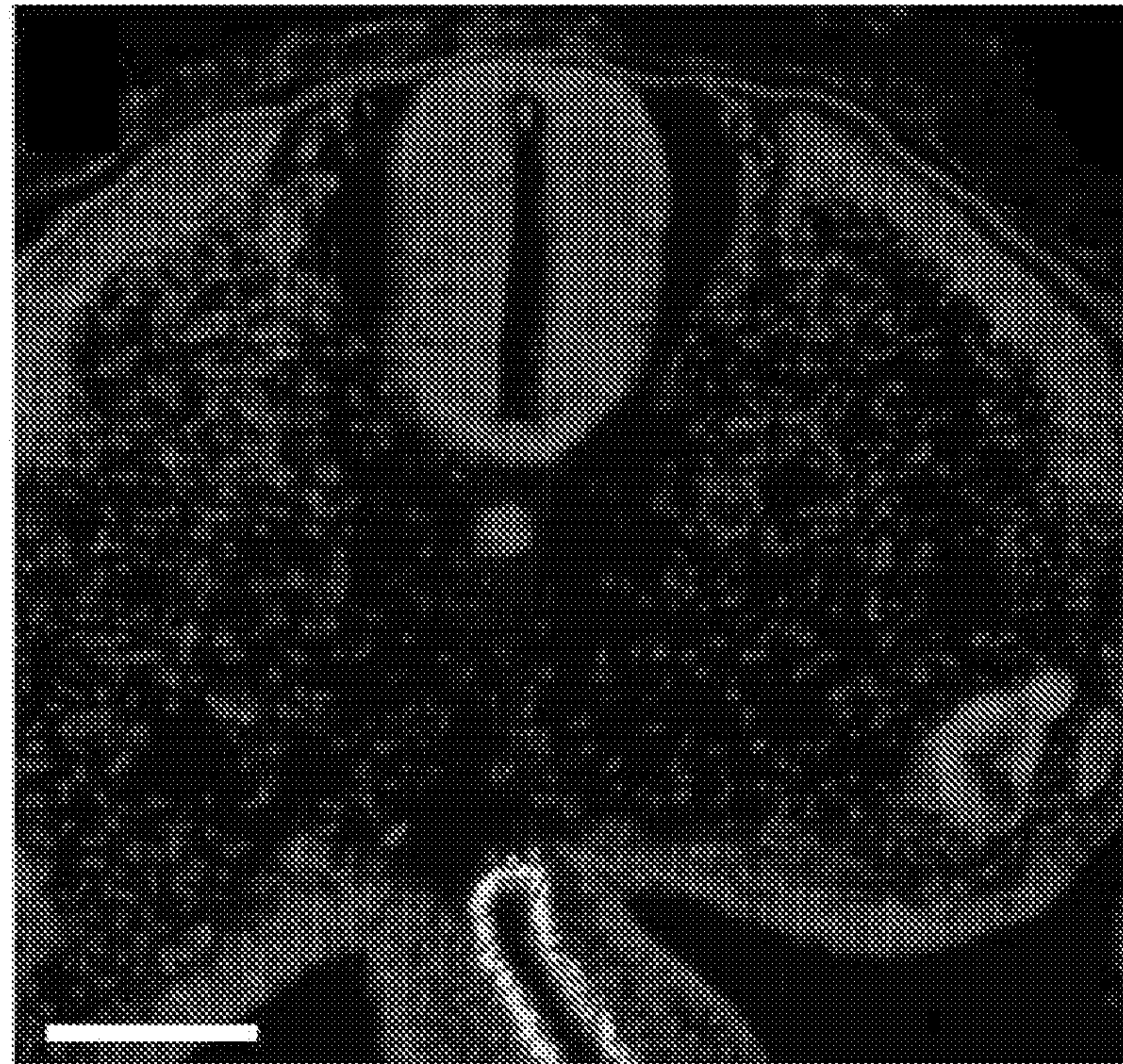
*Fig. 8F*

14/15

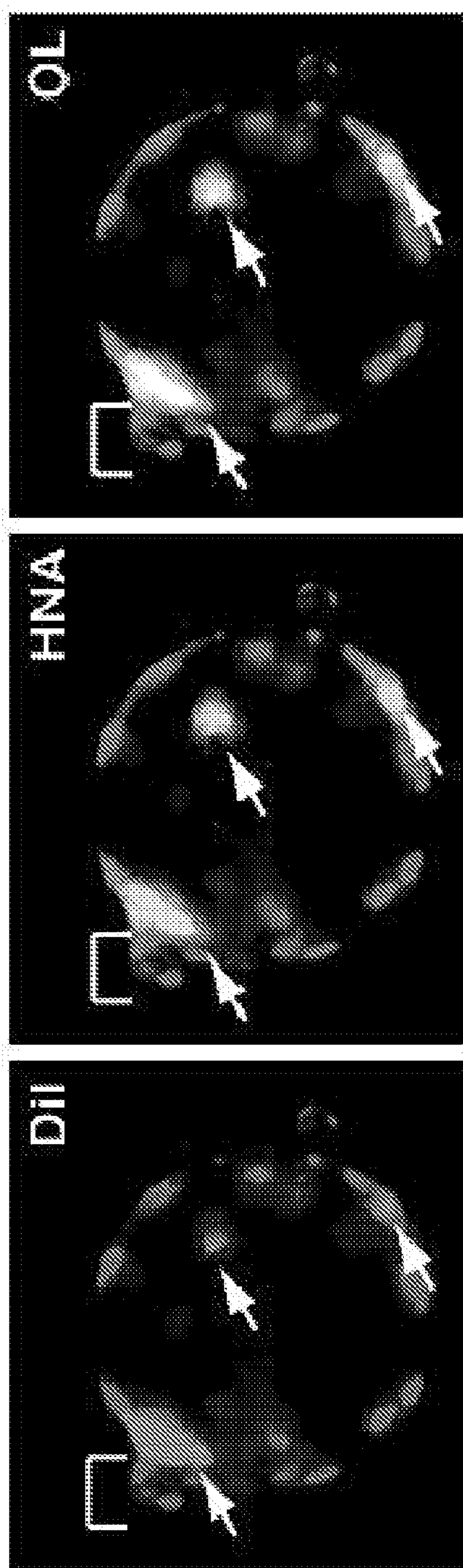
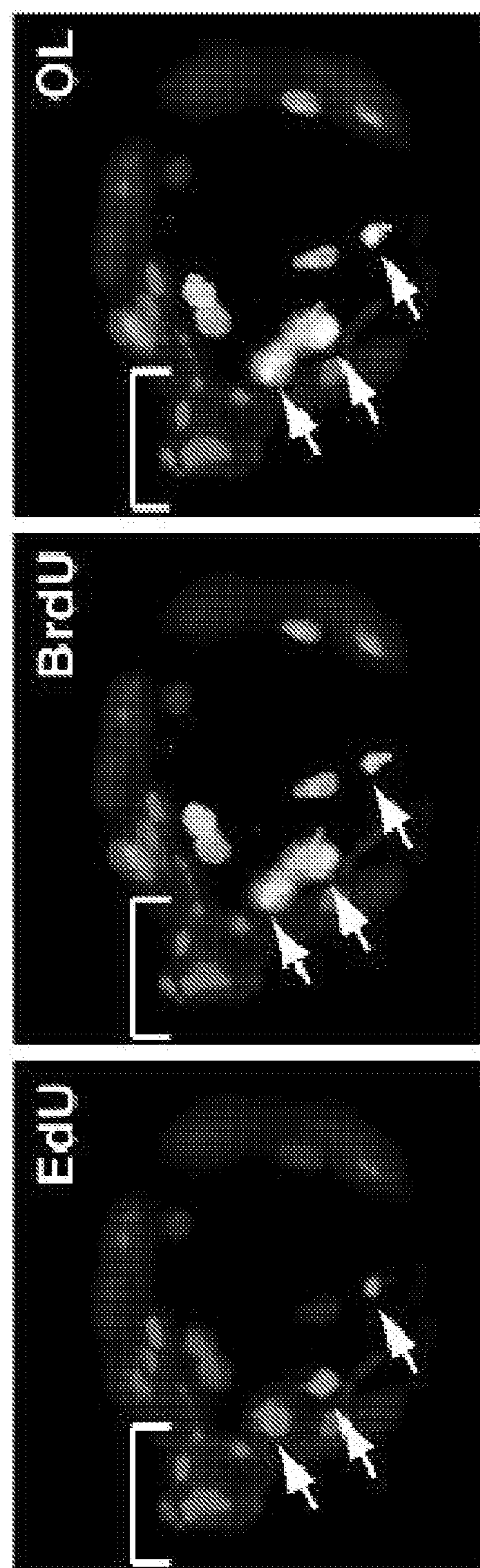
Tie2/GATA4/DAPI

*Fig. 8G*

Tie2/GATA4/DAPI

*Fig. 8H*

15/15

*Fig. 9A**Fig. 9B*

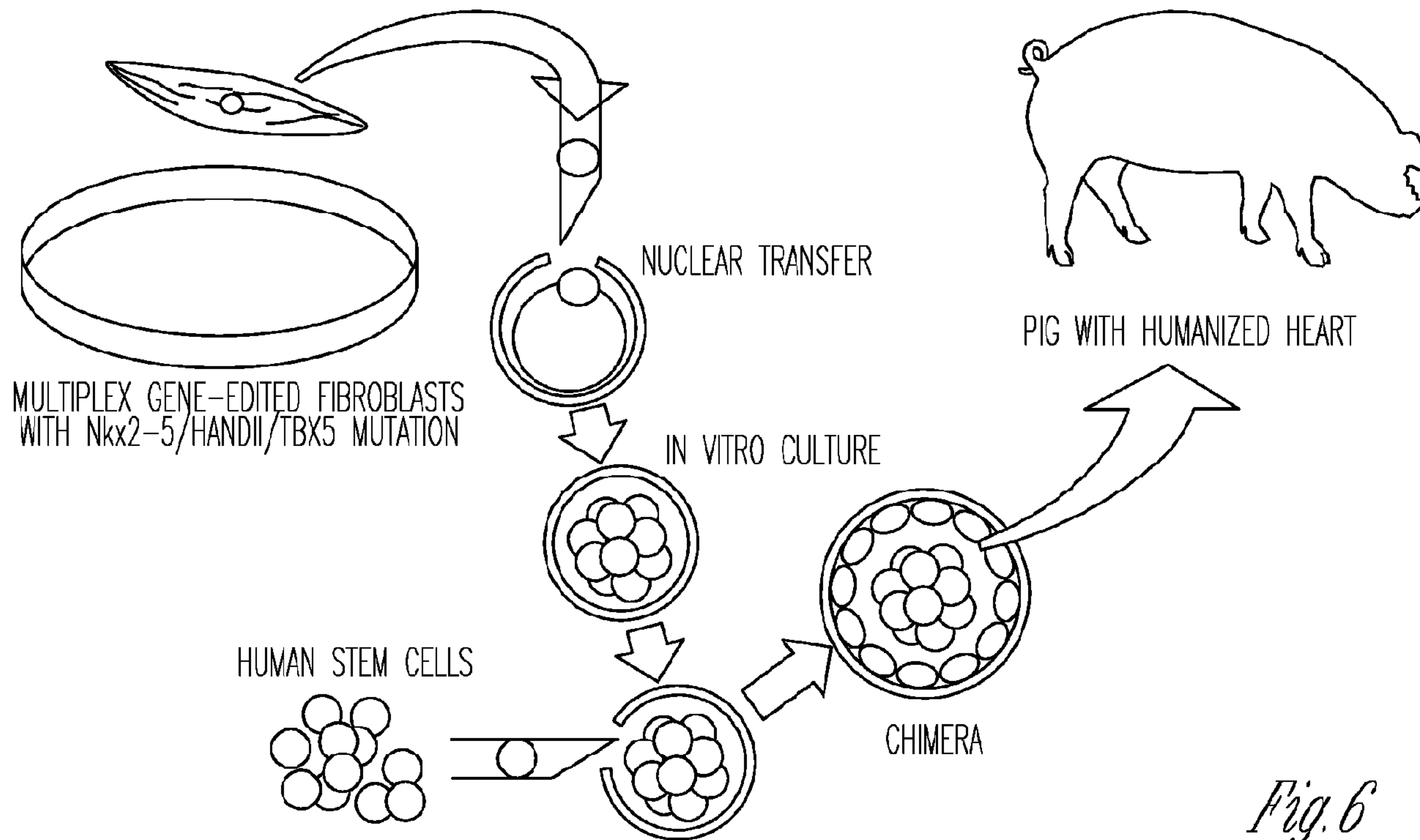


Fig. 6