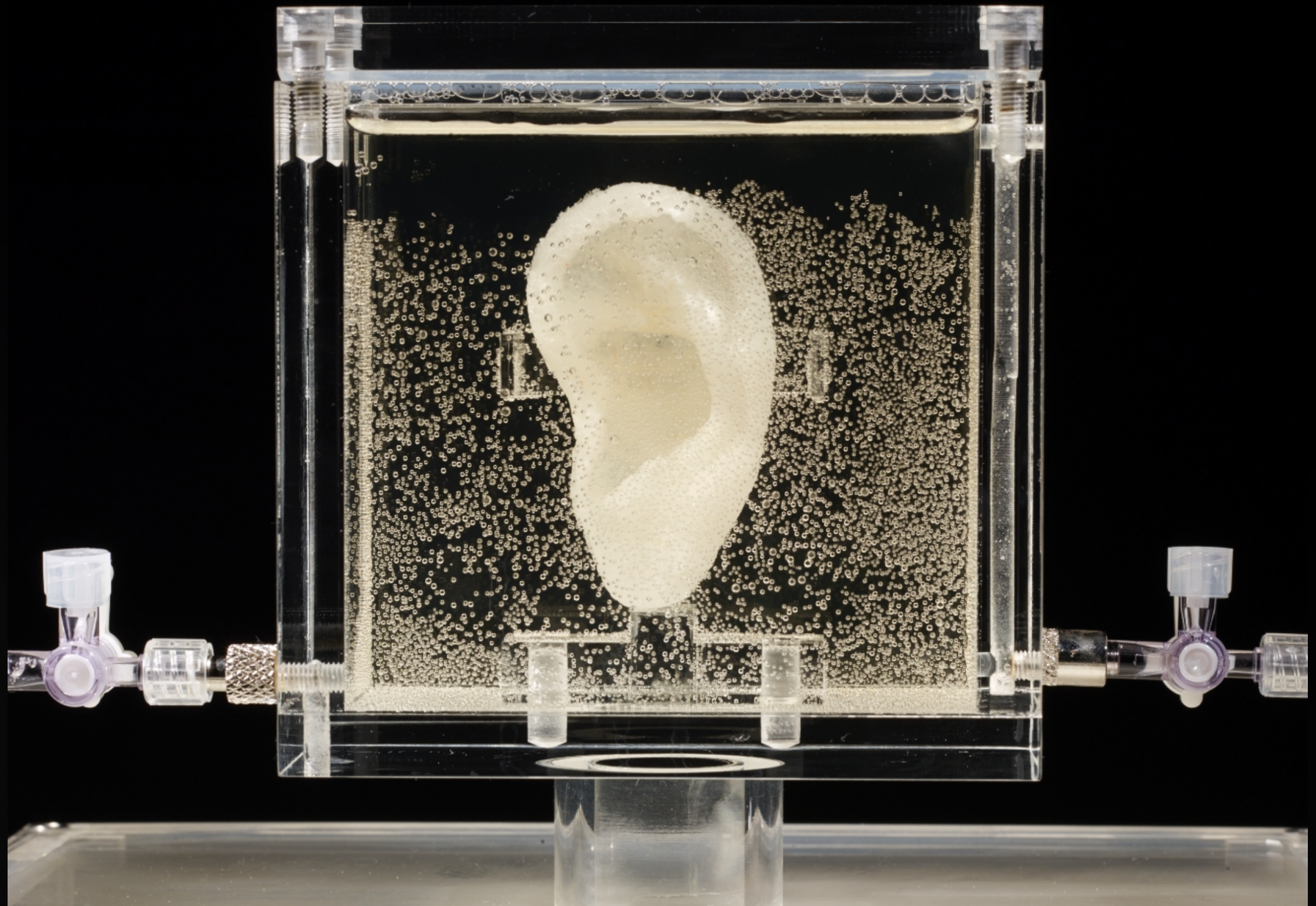
SUGA BABE

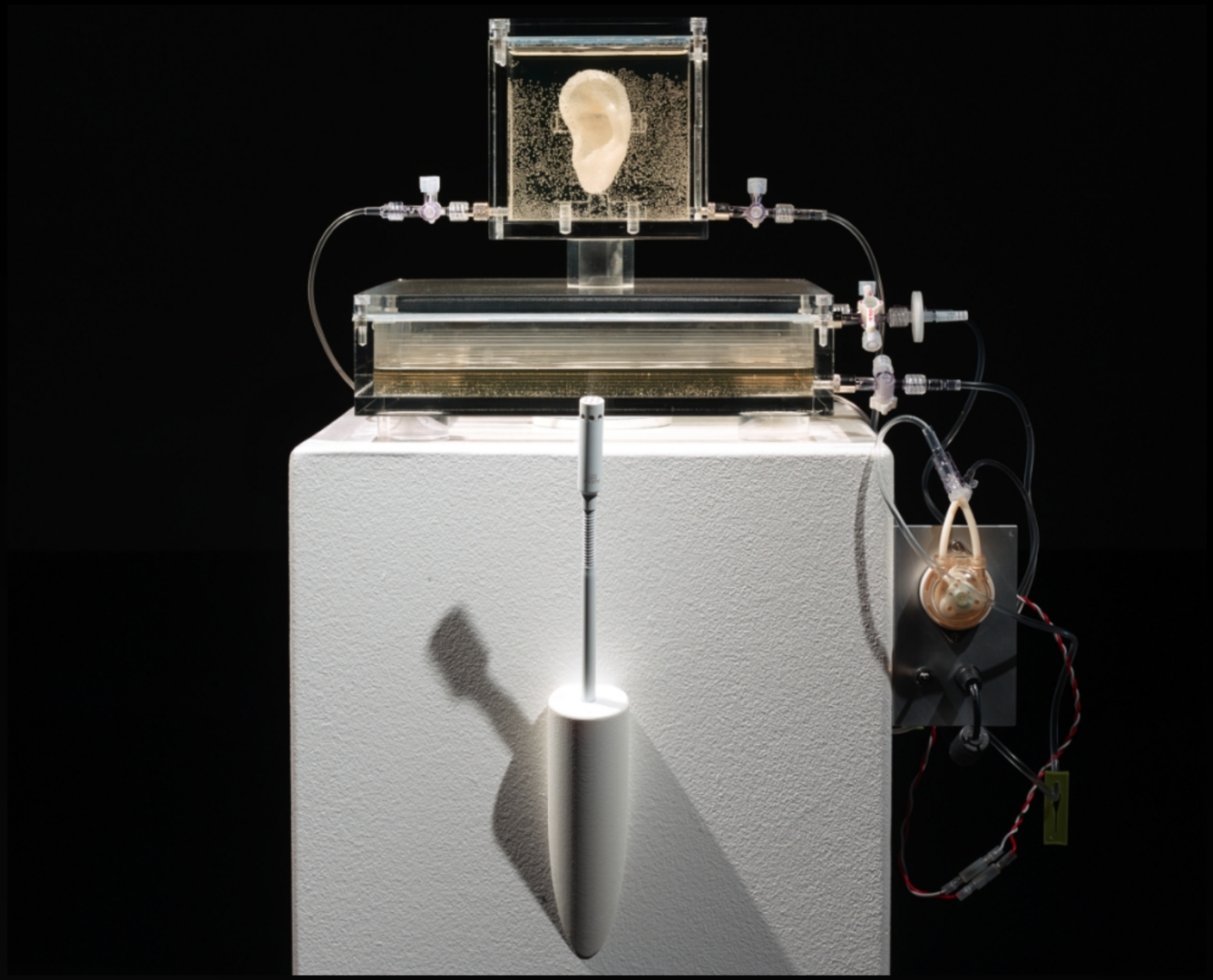
An Art Science Project

by

Diemut Strebe

Scientists:
Robert Langer, MIT, *Yulia Rybakova*, Jason (Yen-Chun) *Lu and Luke Hyunsik Rhym*, all MIT,
Mary B Goldring, Hospital for Special Surgery and Weill Cornell Medical College,
C. and J. Vacanti, Harvard, *Ian Wilmut,* MRC Edinburgh,
Vincent Castella/Christian Gehrig, University Center of LegalMedicine, Lausanne-Geneva,
George Church, Harvard, Tessa Hadlock, *Fouzi Benboujja*, both Mass Eye and Ear Institute,
Peter Cariani, Boston University, *Bertrand Delgutte*, Harvard, *Mass Eye and Ear* Institute,
Farshid Guilak, Washington University Center of Regenerative Medicine.





***SUGABABE*/2014-2021**

Living genetically engineered, reprogrammed and immortalized chondrocytes, seeded on biodegradable scaffold, maintained in glass containers infused with plasma using a pump system.
Pedestal equipped with a computer system, microphone, amplifier and speakers.

Sugababe is a living replica of Vincent van Gogh‘s left ear, created in collaboration with a team of scientists from several institutions including MIT, Harvard and CURML.
In *Sugababe*, the *Theseus paradox*—a thought experiment based on Plutarch’s *Ship of Theseus,* which questions whether an object that has all its component parts replaced remains the same object - has been applied to the molecular level by replacing various natural components with engineered ones: We replaced natural DNA present in a living cell line from a van Gogh male descendant with foreign DNA of a living female descendant and natural DNA with modified variations, namely those genes and other components that are supposed to influence and enhance artistic creativity.
The involved technology such as gene scissors CRISPR Cas9 and mRNA technology is probing the re-creation of a historical person and options to enhance our natural physical dispositions. The principles of such technologies allow us to alter, control and re-design our own “hardware.”

Sugababe explores the potential and implications of such cutting edge bio-technology and questions the mystification of art and the artist by the public and in art theory.

Download Concept

***SUGABABE*/2014-2021**

Living genetically engineered, reprogrammed and immortalized chondrocytes, seeded on biodegradable scaffold, maintained in glass containers infused with plasma using a pump system. Pedestal equipped with a computer system, microphone, amplifier and speakers.

Earchamber: 12.2 x 12 x 7 cm reservoir: 8 x 25 x 25 cm pedestal: 122 x 30.5 x 30.5 cm // Exhibition view ZKM | Center for Art and Media Karlsruhe, 2014

The artwork has been also on view in Ron Feldman’s Gallery in New York City in 2015 and at The Mori Art Museum, Tokyo in 2019/20

The Scientific Part

The Realization Process

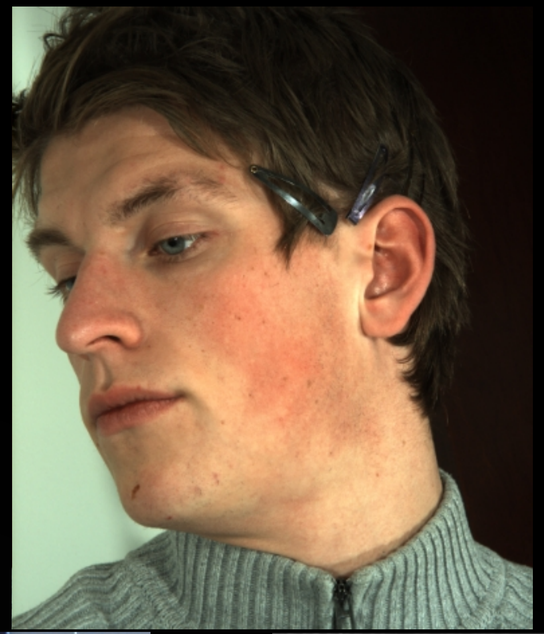
ENTER

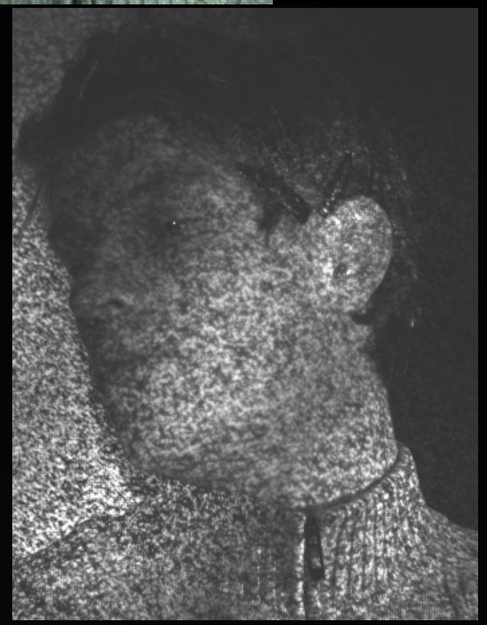
Further in brief presentation

The Recreation of the Shape

The newly grown ear is reconstructed in shape based on a photo from Vincent Van Gogh, the only image showing his left ear.
We then took 3D facial scans from a male living descendant: Lieuwe Van Gogh. He flew over twice to Boston to donate his cells and to support the reconstruction the shape.
We were able to build computer models from 3D impressions, which we took from Lieuwe ‘s ear, to create the basic 3 D model . We then refined the shape by and merging 2 D and 3D information to finally match the photo.

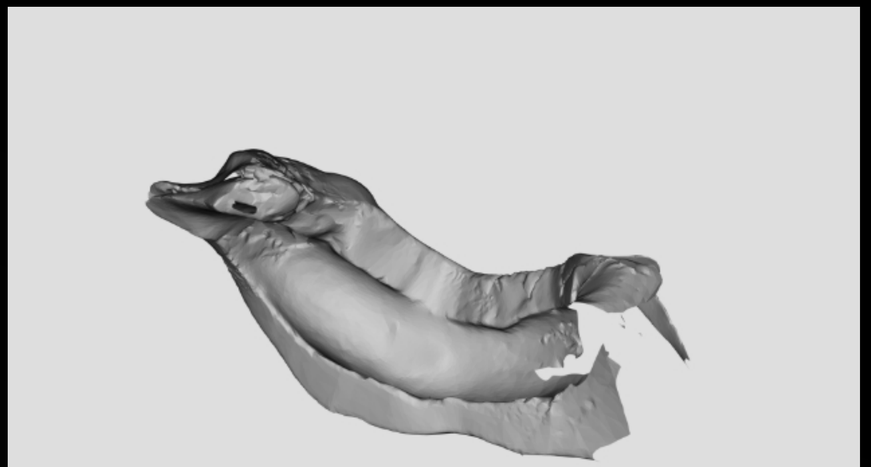
The only photo that shows Vincent van Gogh’s left ear. The date of this portrait is 1873 and the dimensions are 11 x 6.3 cm.
We recalculated the angle at which the photo was taken, factoring in the supposed focal length of a camera lens from the late 1800s,
and extrapolated those measurements into a 3-D printed mold in the shape of Vincent van Gogh’s ear.

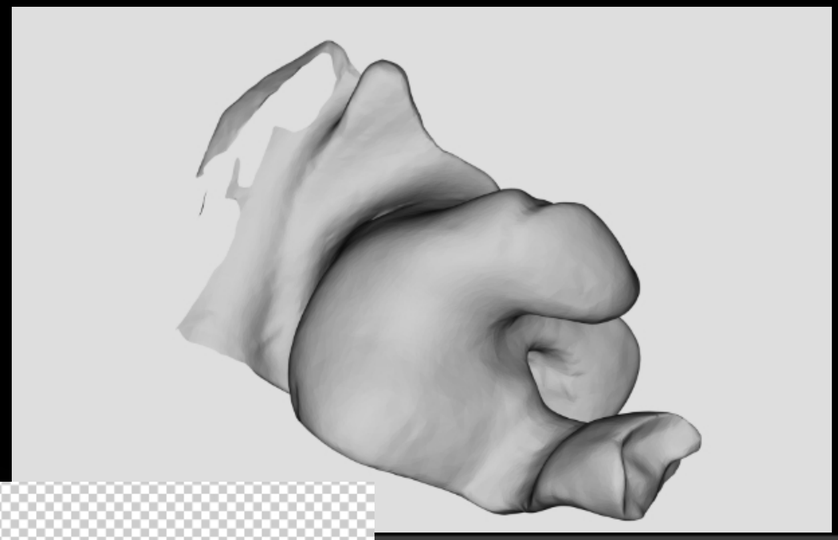


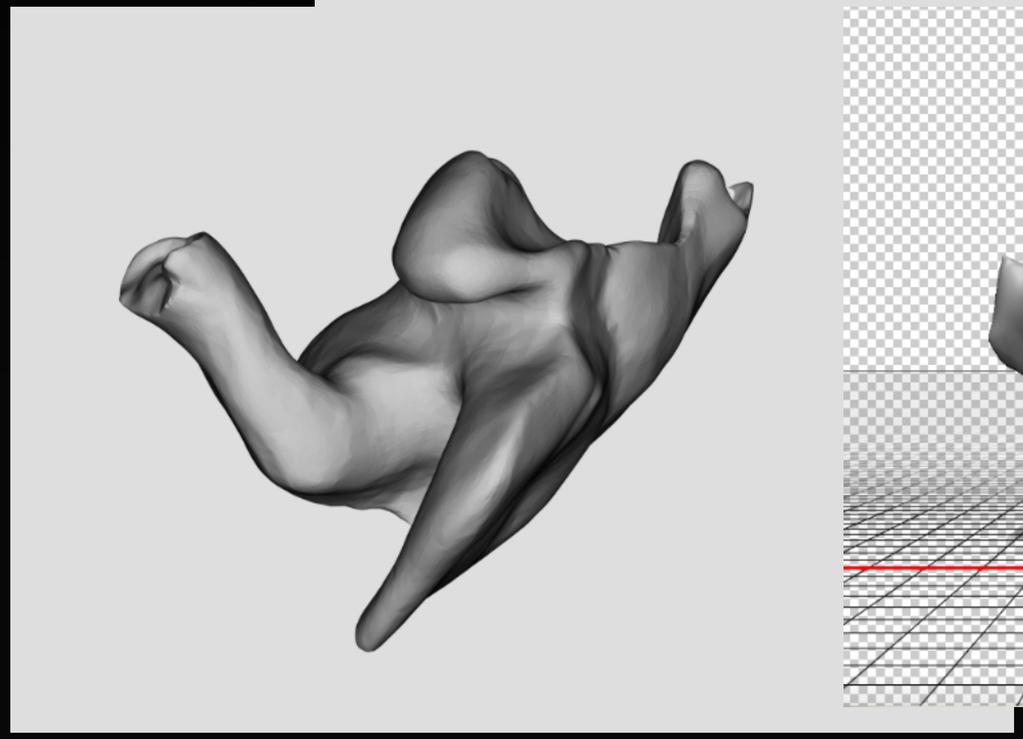


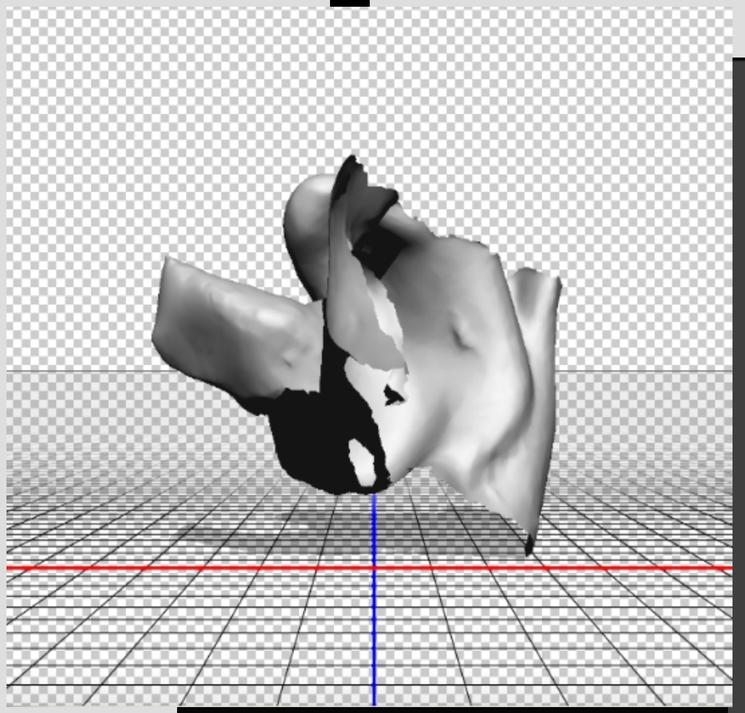
Lieuwe Van Gogh’s Scans
and Steps to Create the 3D Structure

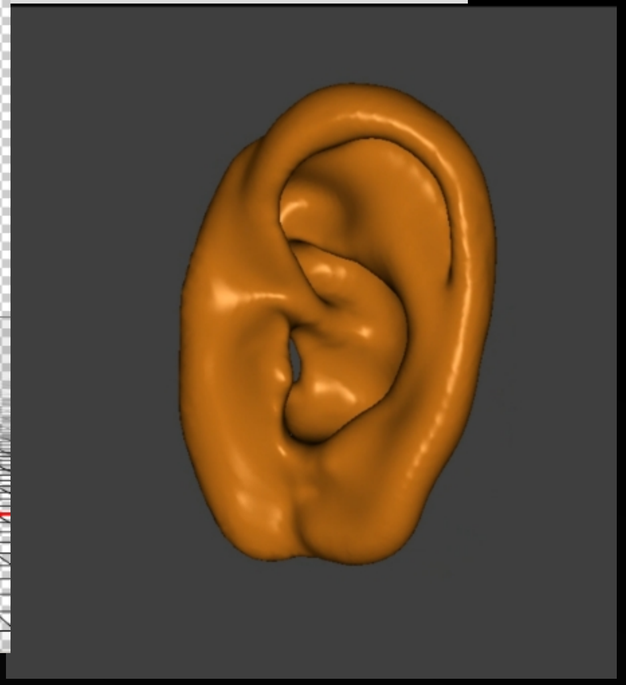
A - 3DMD facial scanner, as above
B - silicone impressions
C - digitized and assembled



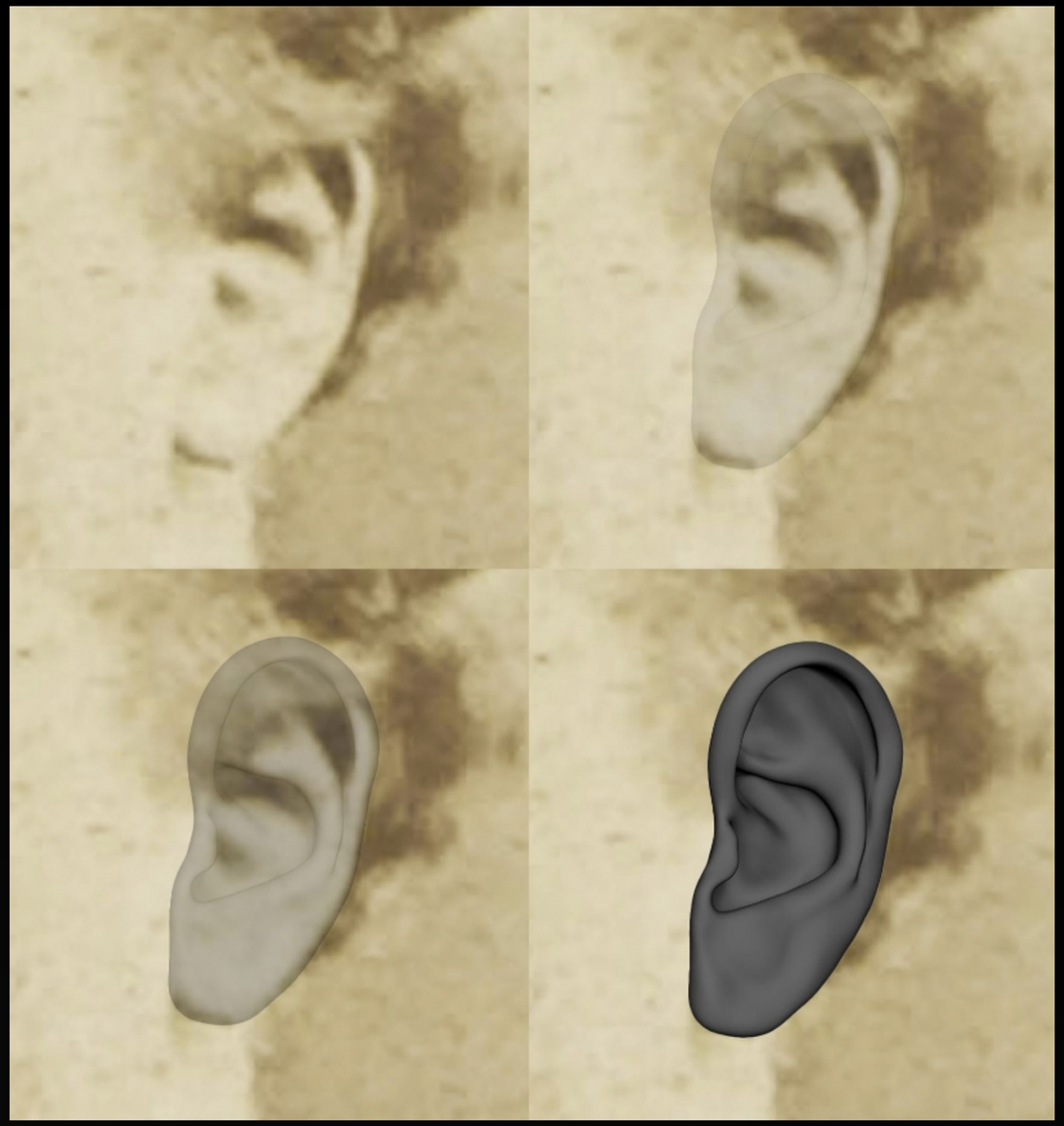








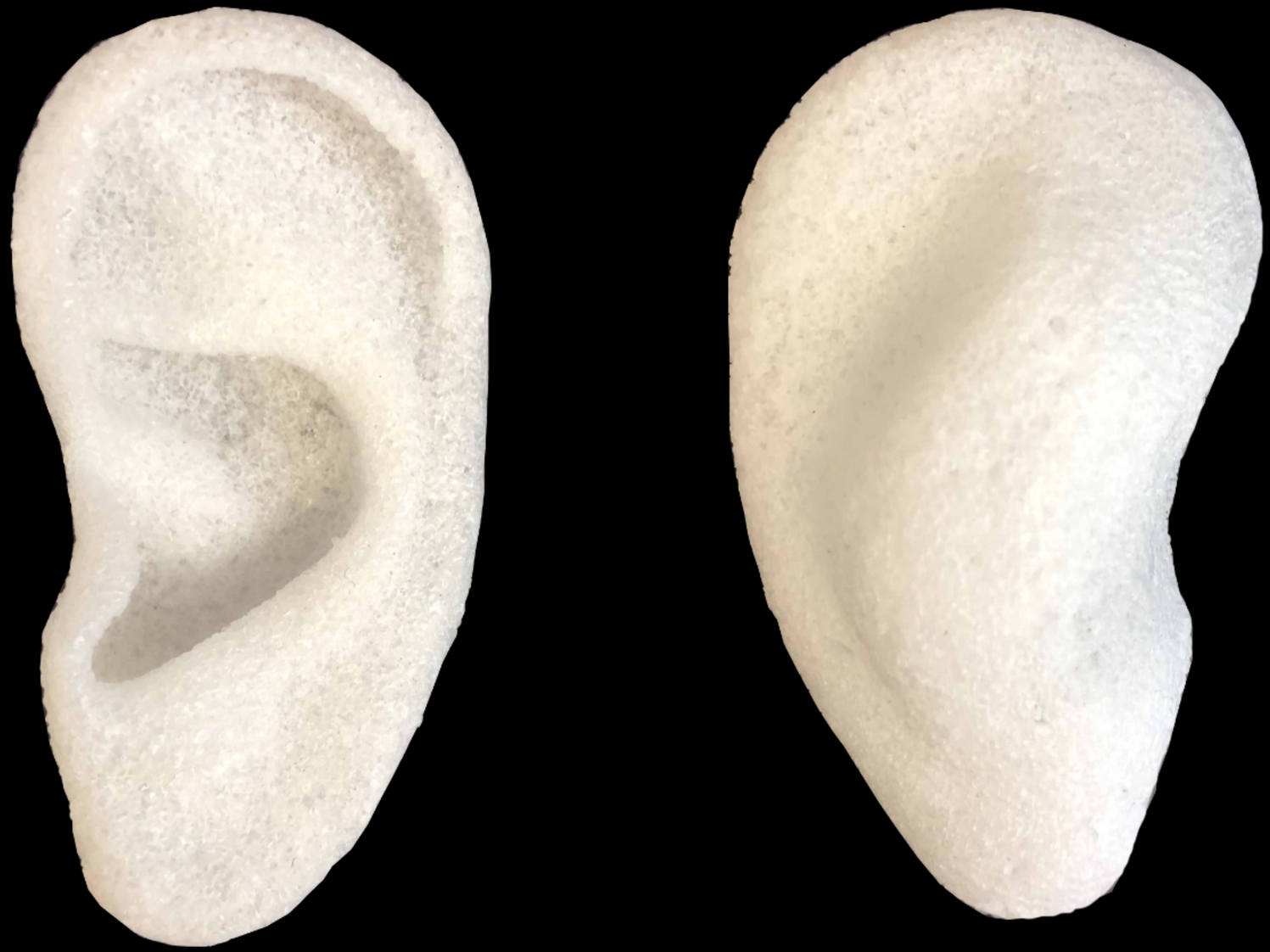
Silicon impressions were taken from Lieuwe Van Gogh, digitized and assembled to create a 3D file



We merged 2D and 3D information to match the shape of the historical image

The Role of Sugar in Sugababe

Before creating the biodegradable polymer scaffold to be seeded with the new Van Gogh cell line we made sugar-ears. They are quite complicated to generate in the molding process since we have to capture all negative and positive shapes of the ear. This step is required in order to block the space that once the sugar is washed out makes room for the cells to be seeded on the scaffold.
The porous, “airy” structure allows thecells to migrate and diffuse to then form tissue. The title of the artwork refers to the use of sugar to make the polymer. It also refers to a modern variation of the Theseus Paradox since the British Band Sugababes could be seen as a contemporary version of the theme.



Once the sugar is washed out the scaffold made from poly(e-caprolactone) (PCL dissolved in chloroform) a very porous airy structure is left on which we seeded the cells to grow the ear.

Cell - Reprogramming and Modifying Part Sugababe

We use 3 different approaches as a proof of principle to achieve DNA replacement of natural DNA present in Lieuwe Van Gogh's cell line to be replaced with Vincent's DNA obtained from the following:

A - Historical DNA/Forensic Research

B - DNA in living descendants
(mtDNA Rosine Weenink, female descendant in 4th generation from Vincent 's mother in Lieuwe van Gogh's cell line)

C - CRISPR-Cas9 and mRNA enhancement of creativity

A - Historical samples acquired from an original source / Forensic research

We started the acquisition of genetic samples for the cell - reprogramming part of the project with some research on historical sources in a Swiss forensic institute (CURML) on an original envelope from Vincent van Gogh from a letter he sent in 1883 to a friend. We examined the stamp and flaps hoping to find original historical DNA from Vincent van Gogh:
Stamp and envelope flap were likely licked and sealed by the postman rather than from van Gogh himself. The mtDNA recovered from the envelope did not match the van Gogh maternal lineage. We had previously generated 2 genetically matching reference samples acquired from living descendants to validate the outcome.

Historical Envelope

DNA -Extraction from an original letter from Vincent van Gogh at CURML, Lausanne, Switzerland on 3 September 2012.

This research has been made possible by the courtesy of Custodia Foundation, Paris, Ger Luijten and Mariska de Jonge and CURML, Lausanne, Switzerland, Vincent Castella and Christian Gehrig.

http://diemutstrebe.altervista.org/

Historical Letter
Envelope from Vincent van Gogh

Location:
Fondation Custodia Paris,
inv. no. i 1970-A-172, 173

Date:
Date of postmark:
Friday, 23 February 1883.
This tallies with the heading:
'Vrijdag morgen'.

B - DNA in living descendants :

Through participation living descendants of Vincent Van Gogh’s parents we were able to recover a significant part of Vincent’s genome.
We are using a living cell line from Lieuwe van Gogh, 4th generation descendant from Vincent (who shares the Y chromosome and 1/16th of his genome with Vincent) .
We then replaced Lieuwe van Gogh’s mtDNA, - which he inherited from his mother- with the mtDNA of the female descendant, Rosine Weenink , who is descending directly in an uninterrupted line from Vincent’s mother. Through heritage Rosine’s mtDNA is identical to that of Vincent.
Through support of the descendants we were able, to create a new cell-line using cell fusion technique containing significant parts of Vincent’s genome through DNA replacement.
If replacement is applied consequently one could in principle recreate a historical person.

Self-Portrait with Bandaged Ear, 2012
Digital C-print mounted on Dibond 125cm x 160cmHigh resolution photo

Selfportarit with Bandaged Ear

Lieuwe van Gogh

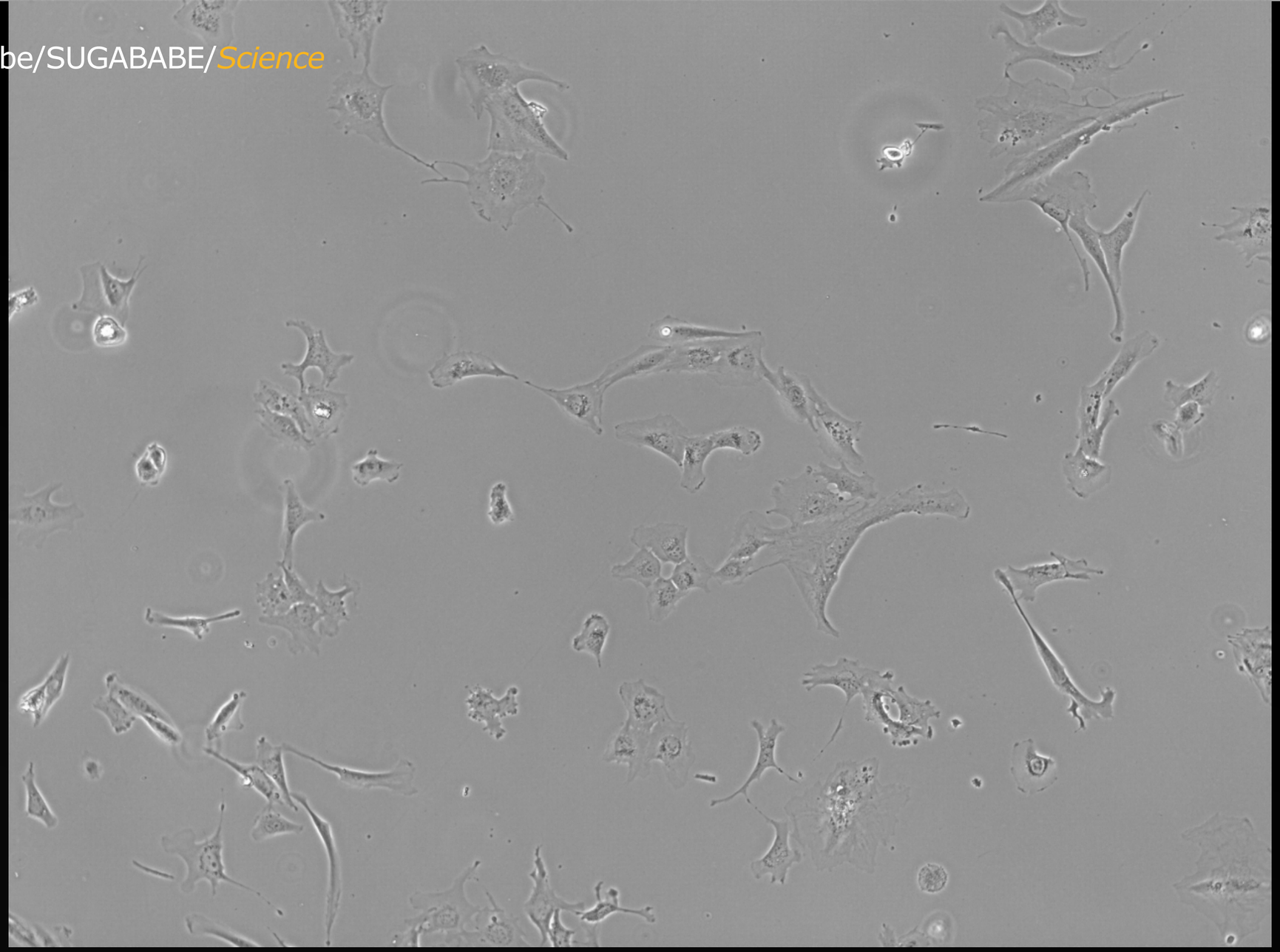
Rosine Weenink

We collected cellular and genetic samples from living descendants:
right: Rosine Weenink, descendant in 4th generation descending in an uninterrupted female line from Vincent's mother. Through her we retrieved the mitochondrial DNA of Vincent and replaced Lieuwe's natural mtDNA with her's.
mid: Lieuwe van Gogh
left: Selfportrait with Bandaged Ear, Vincent Van Gogh

C - Reprogramming and Modifications / CRISPR-Cas9 and mRNA technology

Replacement by using the 'molecular scissors' CRISPR-Cas9 and mRNA technology to modify genes correlated with creativity to explore enhancement of creativity artificially.

The 3rd part, which aims to enhance creativity artificially with specific alterations in Lieuwe van Gogh's genome, is based on 2 papers that correlate elevated creativity to genetically determined levels of neurotransmitter dopamine and serotonine in specific brain regions.
While obviously none of the genetic changes involved in the enzymatic and genetic control of neurotransmitters is here functionally expressed in the ear chondrocytes, this artistic/biological (model) work mimics cutting-edge scientific approaches to control the flow of information in a cellular system at the molecular level via CRISPR-Cas9 and mRNA/lipid particle technology.
It seems to be within the "artistic license" of the art/science project to speculate whether Vincent's artistic genius might have resided in his ear, as Samson's strength depended upon his uncut hair.



Immortalized, modified and reprogrammed chondrocytes from Lieuwe Van Gogh with the same mitochondrial DNA as Vincent Van Gogh are growing in tissue culture flask for Sugababe. (view 1)

Scientific Description of the Work Involved in Creation of Sugababe

-Tissue Engineering of van Gogh Ear Cartilage, Genetics and Cell Reprogramming-

The realization of the art/science project Sugababe, the recreation of Vincent van Gogh left ear, has stretched over the course of many years until 2021, when we completed its development as envisioned.
Here we provide a scientific description of the art project.

Lieuwe van Gogh is a 4th generation descendent of Vincent's brother Theo, sharing the Y- chromosome in a direct male line and thus having one16th of the genome of Vincent. Lieuwe's chondrocytes were obtained from ear biopsies in 2011 and 2012 by Tessa Hadlock at the Massachusetts Eye and Ear Infirmary in Boston, MA USA.

For the first Sugababe exhibit mounted both in Germany and in New York at the Ron Feldman Gallery, L. Van Gogh's (LvG) ear chondrocytes were isolated, grown in primary culture, and sub-cultured to sufficient numbers for seeding into an engineered Polycaprolactone scaffold in the shape of van Vincent van Gogh's ear, which was displayed in a perfusion chamber. For subsequent Sugababe exhibits the LvG ear chondrocytes were immortalized by transducing them with a lentiviral vector producing the oncogene, SV40 large T antigen (AddGene).
More recently, the mitochondrial DNA (mtDNA) in Lieuwe's immortalized ear chondrocytes was substituted with mtDNA from Rosine Weenink. Rosine is a 3rd generation female descendant from Vincent Van Gogh's mother, descending in an uninterrupted line and sharing the mtDNA with Vincent. This was acccomplished by first destroying the resident mitochondria in Lieuwe's chondrocytes by treatment with Rhodamine 6 G (R6G), a potent irreversible inhibitor of mitochondria function. These mtDNA-depleted chondrocytes were then fused with Rosine Weenink's red blood cells, which lack nuclei and, therefore, do not carry genomic DNA (gDNA), thereby avoiding contamination of Lieuwe's gDNA with Rosine's gDNA. The fused, or cybrid, cells were cultured in a special medium that permitted selection of chondrocytes containing the incorporated functional mitochondria from Rosine's red blood cells. These cybrid chondrocytes with DNA from both male and female descendents were expanded to sufficient numbers for seeding in the ear scaffolds, growth, and maintenance in the perfusion chamber for Sugababe as displayed in 2019/20 in Tokyo in the Mori Art Museum.

A crucial perspective from the outset of the project has been to question the myth of the artistic genius, as described in art theory over the last 200 years and as persisting in prevailing public opinion. We wished to extend the philosophical discussion to the scientific context by considering the underlying genetic disposition for creativity.
We, therefore, looked into the genes associated with creativity.
Several researchers have found a positive correlation between creativity and genes associated with dopamine, a key neurotransmitter participating in motivation, focus, learning, and memory (Flaherty, 2005; Heilman et al., 2003; Takeuchi et al., 2010; de Manzano et al., 2010; Reuter et al., 2006; Mayseless et al., 2013; Zabelina et al., 2016). They suggest that individuals having higher dopamine levels in the brain exhibit more creativity. Interestingly, high dopamine levels may also be connected to mental illness such as bipolar disorder or schizophrenia, which are the so-called "demons" underlying personalities of a number of creative figures (Kyaga et al., 2011 , Power et al., 2015). Although no single study has been able to prove, beyond a doubt, that there are connections between genetics and creativity, we hypothesized that it might be possible to "tweak creativity" via modifications of genes participating in dopamine production and regulation.
Certain small changes, called single nucleotide polymorphisms or SNPs, in genes expressing proteins involved in dopamine metabolism can affect the dopaminergic system via regulation of dopamine production and degradation. Recent findings claim that interactions between genetic polymorphisms related to dopamine metabolism in the frontal brain and striatum can be used to predict creativity (Zabelina et al., 2016). Catechol-O-methyl transferase (COMT) is the most important mechanism for dopamine degradation in the prefrontal cortex. Single nucleotide substitution of G to A in the COMT gene results in the amino acid change of Valine128 to Methionine and decreased enzymatic activity, leading to higher dopamine concentration. This affects cognition and behavior and plays a role in neuropsychiatric disorders. Dopamine transporter 1 (DAT) is another gene important for dopamine metabolism. It is responsible for removing DA from the neural synapse. When DAT activity is low, the synapse floods with dopamine, which increases dopaminergic signaling. DAT contains a variable number of tandem repeat sequences in the 3′ untranslated region of the gene, consisting of 9 or 10 repeats of short nucleotide sequences. The number of the repeats affects enzymatic activity of the protein. The gene containing 10 tandom-repeats was associated with low enzymatic activity and subsequently a higher level of dopamine available in the synapses. Functionally, the gene with 10 tandom-repeats is related to low learning abilities and attention-deficit/hyperactivity disorders. Tests for creative achievements in the artistic domain suggest a strong correlation between creativity and high DAT level in the striatum together with high activity of COMT enzyme in the prefrontal cortex.
To investigate if Lieuwe van Gogh has any of these polymorphisms, we isolated DNA from his cells and submitted it for deep sequencing. Sequencing was performed by VERITAS Genetics. We found that Lieuwe's DNA contains the aforementioned polymorphism in the DAT gene, but not in the COMT gene. Therefore, we decided to introduce the COMT gene polymorphism into Lieuwe's immortalized ear chondrocytes using the CRISPR gene modification technique.
Another neurotransmitter serotonin, also known as "hormone of expectation of reward ", has been implicated in creativity, potentially via indirect activation of the DAT system (Reuter et al., 2006; Runco et al., 2011). The rate of serotonin synthesis is regulated by tryptophan hydroxylase (TPH1) enzyme. Thus, the increased TPH1 activity would result in increased serotonin levels, thereby augmenting creative potential. Accordingly, we decided to induce TPH1 expression by delivering TPH1 mRNA to Lieuwe's chondrocytes. After synthesizing mRNA in vitro (TriLink Biotech), we used lipid nanoparticles to encapsulate the mRNA for a delivery system. Additionally, the cationic lipid-like materials mimic the biological membrane to enhance the efficiency of membrane fusion and the endosomal escape in the cytoplasm. The ribosome in the cells will then translate the delivered mRNA to increase the TPH1 protein level.

While obviously none of the genetic changes involved in the enzymatic and genetic control of neurotransmitters is functionally expressed in the ear chondrocytes, this artistic/biological model mimics cutting-edge scientific approaches to control the flow of information in a cellular system at the molecular level via CRISPR Cas9 and mRNA/lipid particle technology.
It seems to be within the "artistic license" of the art/science project to speculate whether Vincent's artistic genius might have resided in his ear, as Samson's strength depended upon his uncut hair.

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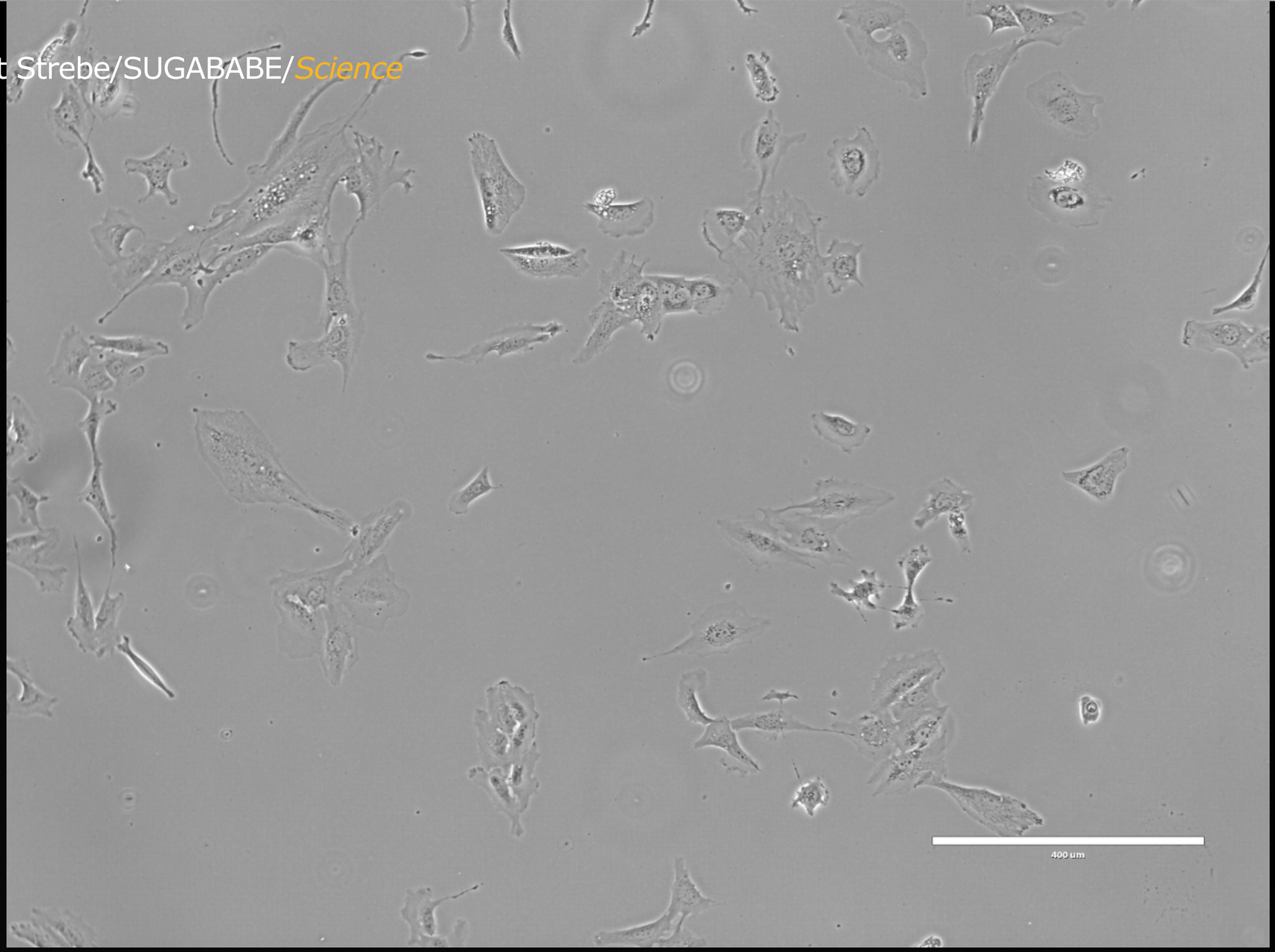
Diemut Strebe/SUGABABE/*Science*



Immortalized, modified and reprogrammed chondrocytes from Lieuwe Van Gogh with the same mitochondrial DNA as Vincent Van Gogh are growing in tissue culture flask for Sugababe. (View 2)

Sound Installation:

One can speak to the ear through a microphone system.
The input sound is connected to a computer processor, using a software program to generate simulated nerve impulses from the sound signal in real time. They mimic sounds recorded from an electrode inserted into the auditory nerve, when firing.

During the opening at ZKM Karlsruhe, Germany in May 2014, Noam Chomsky was the first person to speak to the ear.

To the left is Lieuwe van Gogh.

Please click in the black surface to start the film if not starting on its own

Van Gogh’s missing ear is nothing less than the key story, the very essence of the romantic myth of art and artist, the still tremendously vivid idea of the artist as a genius. **Sugababe** could be seen as a recreation of the common myth, formally and conceptually attached to the iconic story as its dialectic opposite.

Nowadays and very explicitly since the last 200 years a common stereotype about the artist’s personality is that of the irrational, suffering creator on the verge of self- destruction and ingenious creation, receiving his extraordinary creativity and inspirations almost as a divine afflatus and “epiphany”.

Diemut Strebe/SUGABABE/*Artist*

I am a German-American US based artist, working with different international institutions, mostly with MIT faculty.
At MIT I have been Artist in Residence from 2017-2019.

My works link art and science to address contemporary issues, often incorporating themes related to philosophy and literature.
I explore the crossover between science and art through media such as living biological materials, nanomaterials, algorithms & numbers, experimental setups and installations. This practice includes scientific concepts, methods and tools, engaging with science directly. The collaborations with scientists take place for example in the fields of human and plant -genetics, quantum- and astrophysics, AI, math and various types of engineering.
The heterogeneous appearance of my works, results from the variety of topics and strands in science I deal with.

Focused on the advanced science of our era, I feel compelled to reaffirm the Romantic paradigm of “the new” as well as the role of avant-garde art relating to radical experiments of Classical Modern Art throughout the medium and its combination with the arts.

Luke Rhym
Is a PhD candidate al MIT in Daniel Anderson's lab working on the development of lipid nanoparticles for the delivery of therapeutic mRNA.
Whit a focus on delivering system for targeted gene editing.

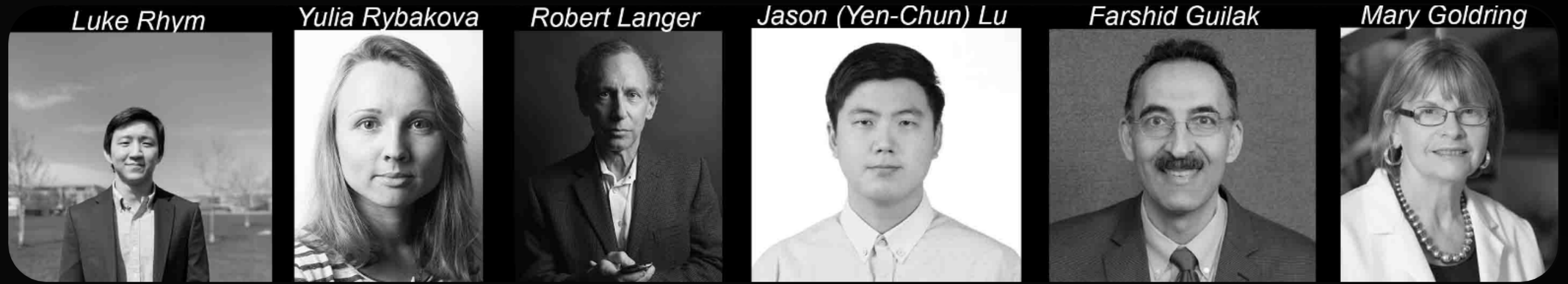
Yulia Rybakova
Is a former postdoctoral scientist at Professor Anderson's Lab at MIT. Currently she is a Research Scientist at SiPhox Inc. Although cell biologist by training Yulia is an avid Science Art admirer, spending her free time working on art projects.

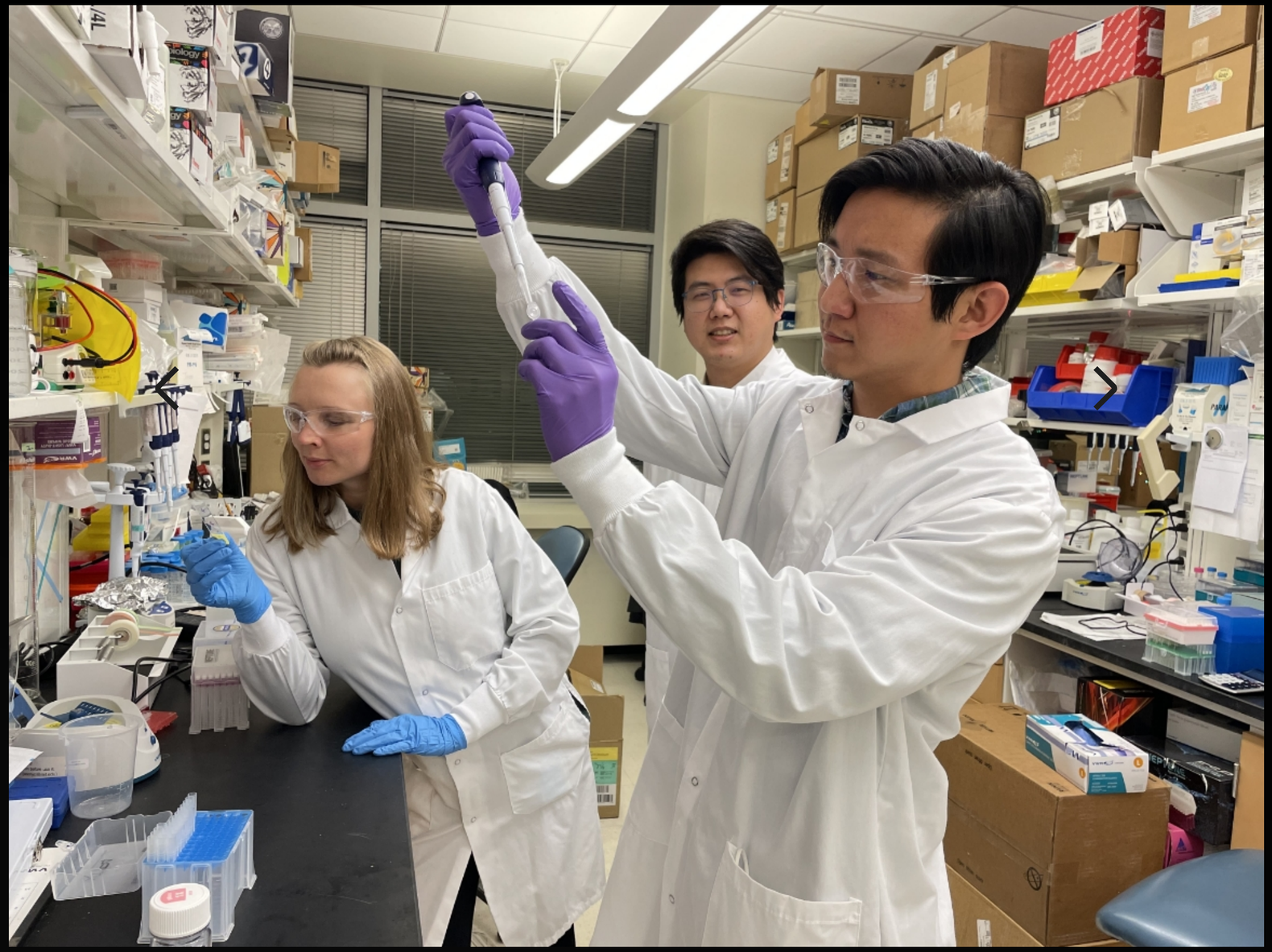
Robert Langer
MIT Institute Professor and a cofounder of Moderna is working on timed and targeted drug delivery systems, nanotechnology, and tissue-engineering; he is the most cited engineer in history.

Jason (Yen-Chun) Lu
Ph. D., is a Research Fellow at Boston Children's Hospital/Research Affiliate at MIT in Prof. Robert Langer's and Prof. Daniel Anderson's groups working on cell therapy in metabolism disorder disease and gene therapy in RNA therapeutics.

Farshid Guilak
Is a biomedical engineer at Washington University in St. Louis, specializing in the development of genetically-engineered stem cells to treat arthritis.

Mary B. Goldring
PhD, Senior Scientist Emerita at the Hospital for Special Surgery, New York. NY and Professor of Cell and Developmental Biology, Weill Cornell Medical College, has expertise in the development of Immortalized chondrocyte cell lines and in pre-clinical models for studying osteoarthritis disease mechanisms.





Yulia Rybakova, Jason (Yen-Chun) Lu and Luke Hyunsik Rhym at MIT in Robert Langer's working on *Sugababe*

A special thank you to all the scientist I worked with in the *Sugababe Project.*
A few scientists I would like to thank in particular:

These are Robert Langer, Charles Vacanti, Noam Chomsky, Mary Goldring, Luke Rhym, Jason Lu and Yulia Rybakova.

Selected Press/Sugababe

Wall street Journal
https://blogs.wsj.com/photojournal/2014/06/04/vincent-van-goghs-3-d-printed-ear-on-display/

New York Times
https://artsbeat.blogs.nytimes.com/2014/06/04/a-rather-unusual-van-gogh-work-at-a-german-museum/

CNN
http://www.cnn.com/2015/11/13/health/van-gogh-ear-art-science/

Arnet
https://news.artnet.com/market/vincent-van-gogh-ear-replica-358550

The Guardian
https://www.theguardian.com/artanddesign/2014/jun/03/vincent-van-gogh-ear-replica-german-museum

Smithsonian
https://www.smithsonianmag.com/smart-news/this-ear-made-with-van-gogh-dna-180957230/

BBC
https://www.youtube.com/watch?v=FSyS6EsuNvY

Architectural Digest
https://www.architecturaldigest.com/story/vincent-van-gogh-ear-diemut-strebe-ronald-feldman-fine-arts-new-york-city

Washington Post
https://www.washingtonpost.com/news/morning-mix/wp/2014/06/04/photo-living-replica-of-van-goghs-ear/

Sankei
https://www.sankei.com/life/news/191212/lif1912120001-n1.html

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