Mapping and Quantification of Vascular Branching in Plants, Animals and Humans by VESGEN Software

Humans face daunting challenges in the successful exploration and colonization of space, including adverse alterations in gravity and radiation. The Earth-determined biology of plants, animals and humans is significantly modified in such extraterrestrial environments. One physiological requirement shared by larger plants and animals with humans is a complex, highly branching vascular system that is dynamically responsive to cellular metabolism, immunological protection and specialized cellular/tissue function. VESsel GENeration (VESGEN) Analysis has been developed as a mature beta version, pre-release research software for mapping and quantification of the fractal-based complexity of vascular branching. Alterations in vascular branching pattern can provide informative read-outs of altered vascular regulation. Originally developed for biomedical applications in angiogenesis, VESGEN 2D has provided novel insights into the cytokine, transgenic and therapeutic regulation of angiogenesis, lymphangiogenesis and other microvascular remodeling phenomena. Vascular trees, networks and tree-network composites are mapped and quantified. Applications include disease progression from clinical ophthalmic images of the human retina; experimental regulation of vascular remodeling in the mouse retina; avian and mouse coronary vasculature, and other experimental models in vivo. We envision that altered branching in the leaves of plants studied on ISS such as Arabidopsis thaliana can also be analyzed.

(Supported by NASA GRC IR&D04-54 and 2010 TTP Fund, NIH EY-01759 & NSF Center of Excellence UWEB, University of Washington Engineered Biomaterials)
VESGEN
Innovative Research Discovery Tool

Mapping and Quantification of Vascular Branching in Plants, Animals and Humans by VESGEN Software

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Glenn Research Center
VESGEN Patent Pending
at Lewis Field
Vascular Alterations, Immunosuppression & Bone Loss: NASA-defined risk categories for human space exploration
VESGEN 2D
APPLICATIONS

Vascular Trees
Human Retina
Avian CAM, Yolksac and Murine/Avian Coronary Vessels
Plant Leaf Venation such as in Arabidopsis thaliana?

Vascular Networks
Mouse Postnatal Retina and Intestinal Inflammation
CAM Lymphatic Vessels

Vascular Tree-Network Composites
Normal and Abnormal Embryonic Coronary Vessels

Glenn Research Center
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at Lewis Field
Panel to specify vessel type

Main panel ➔
- Image specification
- Algorithm selection
- Process initiation

VESGEN Patent Pending
Mapping and Quantification of Microvascular Remodeling and Angiogenesis by **VESGEN**
VESGEN Hypothesis: 'Signature' Vascular Patterns

The form of an object is a 'diagram of forces'
- D'Arcy Thompson

FGF-2 as a Simple Stimulator
(Fibroblast Growth Factor-2)

Arterio Scler Thromb Vasc Biol 20 2000

VEGF as a Complexity Factor
(Vascular Endothelial Growth Factor-2)

Microvascular Research 72(3) 2006

TGF-β1 as a Simple Inhibitor
But Complex Potentiator
(Transforming Growth Factor-β1)

Microvascular Research 59(2) 2000
**Long-Term Hypothesis**

Vascular pattern provides an integrative read-out of dominant molecular regulators in complex signaling pathways of angiogenesis and microvascular remodeling.

**VESsel GENeration (VESGEN) Analysis Software**

- Vessel Number Density, $N_v$
- Vessel Length Density, $L_v$
- Vessel Diameter, $D_v$
- Fractal Dimension, $D_f$
- Branchpoint + Endpoint Densities, $Br_v+E_v$
Clinical Steroid (TA) Treatment in CAM Vascular Tree

On Rarity and Richness

Two researchers take a stab at explaining why oceans have far fewer species than terrestrial habitats.

...
Vein pattern development in adult leaves of *Arabidopsis thaliana*


VESGEN
Research Tool for Mapping and Quantification of Vascular Branching Pattern in Genetically Engineered A. thalia on ISS

Vascular Pattern by Branching Generation
Grouping of Generations: LARGE and SMALL
Avascular Spaces of Branching Networks

Results
Fractal Dimension
$D_f = 1.32$
Area, Length,
Branchpoint Densities
$A_v(LARGE) = 0.195$
$A_v(SMALL) = 0.013$
Average Vessel
Diameter ($\mu$m)
$D_v(LARGE) = 11.8 \mu$m
$D_v(SMALL) = 7.0 \mu$m

Conclusions
Less mature branching

Day 2

Day 8

Day 2

Generation, $G_x$

Increased vascular complexity—especially density of smaller vessels

$D_f = 1.47$

$A_v(LARGE) = 0.159$
$A_v(SMALL) = 0.276$

$D_v(LARGE) = 93.1 \mu$m
$D_v(SMALL) = 66.8 \mu$m
VASCULAR NETWORKS IN TRANSGENIC MOUSE RETINA

Fluorescence Microscopy

VESGEN Network Output
Distance Mapping
Colorized Skeleton

Mouse Retina

Control (P15)

TA-Treated

with J Sears & Q Ebrahem (Cole Eye Institute), from Vickerman et al, Anatomical Record A 292(3), 2009
VESGEN Patent Pending
CORONARY VESSEL NETWORK-TO-TREE TRANSITIONS

Vickerman et al, VESGEN Review, Anatomical Record A 292(3), 2009