Estimation of local conduction velocity in a high-resolution three-dimensional triangular mesh using the average nodal gradients algorithm on triangular grids

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COI Disclosure

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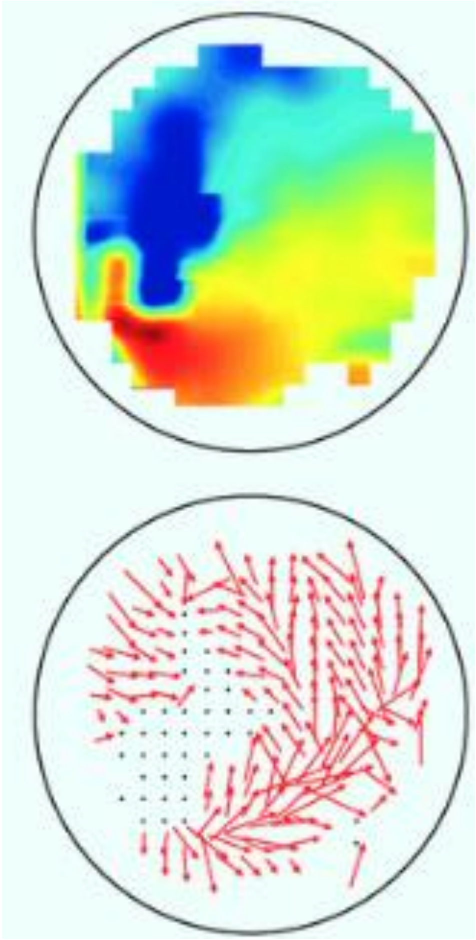
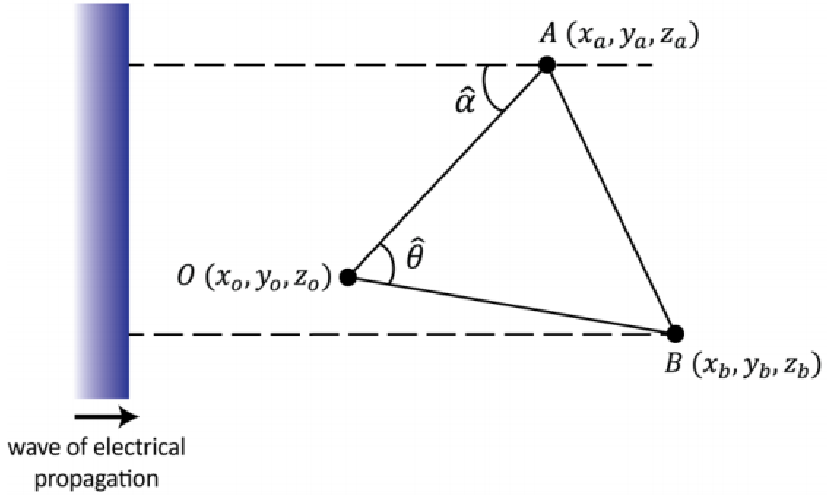
Introduction

- Estimating cardiac conduction velocity (CV) is important to identify the functional and physical aspects of electrophysiological pathology.
- However, the widely used triangular method for calculating CV encounters incomputable problems due to spatial limitations in differential geometry calculations and the relationship between triangles and the propagation direction of local activation time (LAT).
- To address these challenges, we propose a simple and robust method for accurate CV estimation using the average nodal gradients.



Limitation of triangulation method related to topology

A



$$(1)\ \hat{\alpha} = arctan\left(\frac{\frac{t_{OB}\cdot|OA|}{t_{OA}\cdot|OB|} - \cos\hat{\theta}}{\sin\hat{\theta}}\right)$$

$$(2)\ v_{el} = \frac{|OA|}{t_{OA}}\cos\hat{\alpha}$$

$$(3)\ \vec{j} = \left(\vec{A} + \frac{\vec{B}-\vec{A}}{|AB|}\right)\cdot|OA|\cdot\frac{\sin(\hat{\alpha})}{\sin\left(\pi-\hat{\alpha}-\arcsin\left(sin\hat{\theta}\cdot\frac{|OB|}{|AB|}\right)\right)}$$

$$(4)\ \vec{v} = \frac{\vec{j}-\vec{o}}{|\vec{j}-\vec{o}|}v_{el}$$

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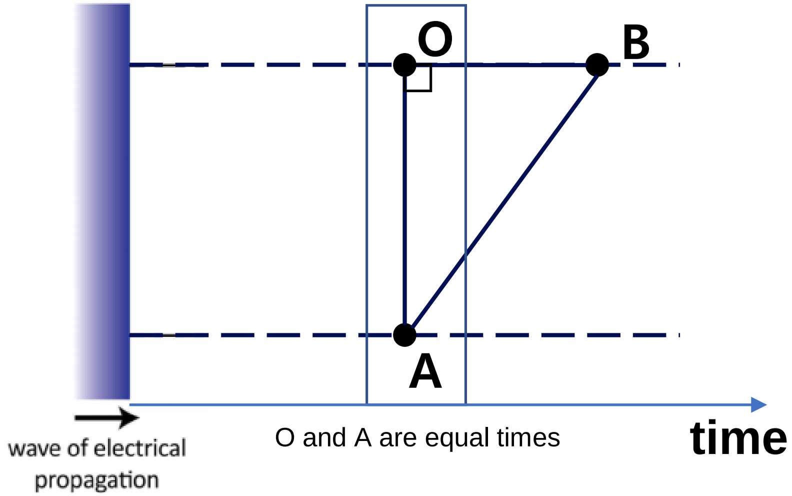
B



If A or B in O is perpendicular to the direction of electrical propagation,
the difference of activation time (t_{OA}) becomes zero.

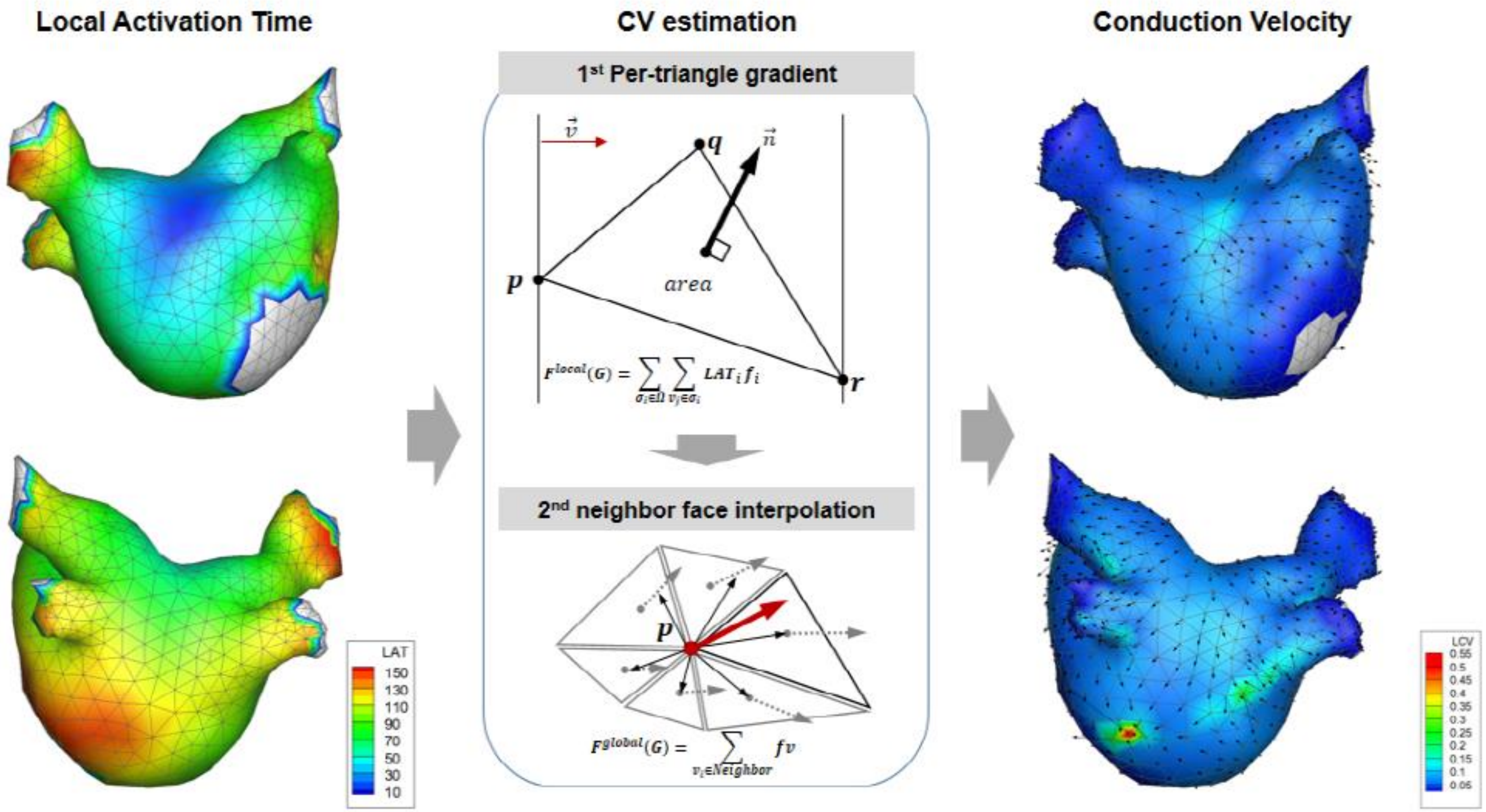
Methods

- Our algorithm improves accuracy and preserves the topology of a 3D triangular mesh by considering the average nodal gradients on adjacent triangles.

- To validate its accuracy, we compared it with the linear integral of a geodesic path in the LAT maps of **50 atrial fibrillation patients.**

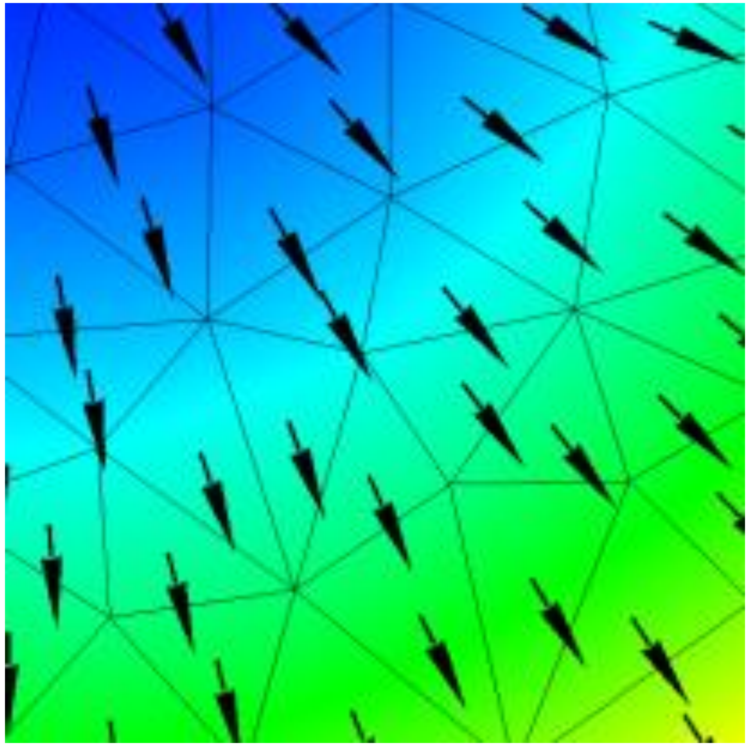
- We also assessed if the algorithm increased the number of measurable triangles for different types and sizes of triangular mesh structures.

CV estimation process



Per-Cell gradient estimation

Each triangle



$$s = \frac{\|v_i - v_j\| + \|v_i - v_j\| + \|v_i - v_j\|}{2},$$

$$A_t = \sqrt{s(s - \|v_i - v_j\|)(s - \|v_i - v_k\|)(s - \|v_j - v_k\|)},$$

$$N_t = |(v_j - v_i) \times (v_k - v_i)|.$$

At is the area of a triangle, and it can be calculated using Heron’s eq.

$$\nabla \mathrm{u(t)} = (LAT_i - LAT_j)\frac{N_t \times (vi - vk)}{2A_t} + (LAT_k - LAT_i)\frac{N_t \times (v_j - v_i)}{2A_t},$$

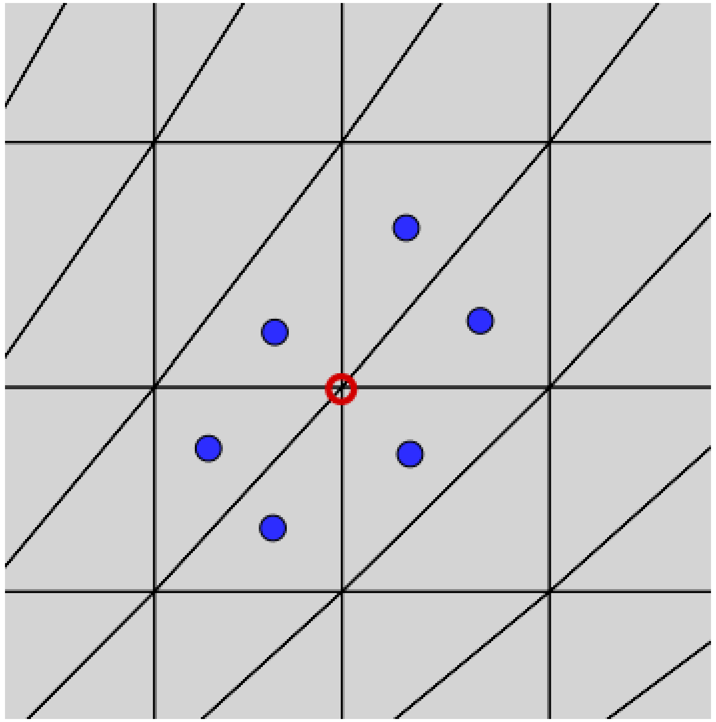
∇ u is the gradient in the triangle.

IJK are the three vertices of the triangle, and the gradient can be computed

even when aligned perpendicular to the propagation.

Average Nodal gradients

Nodal gradients



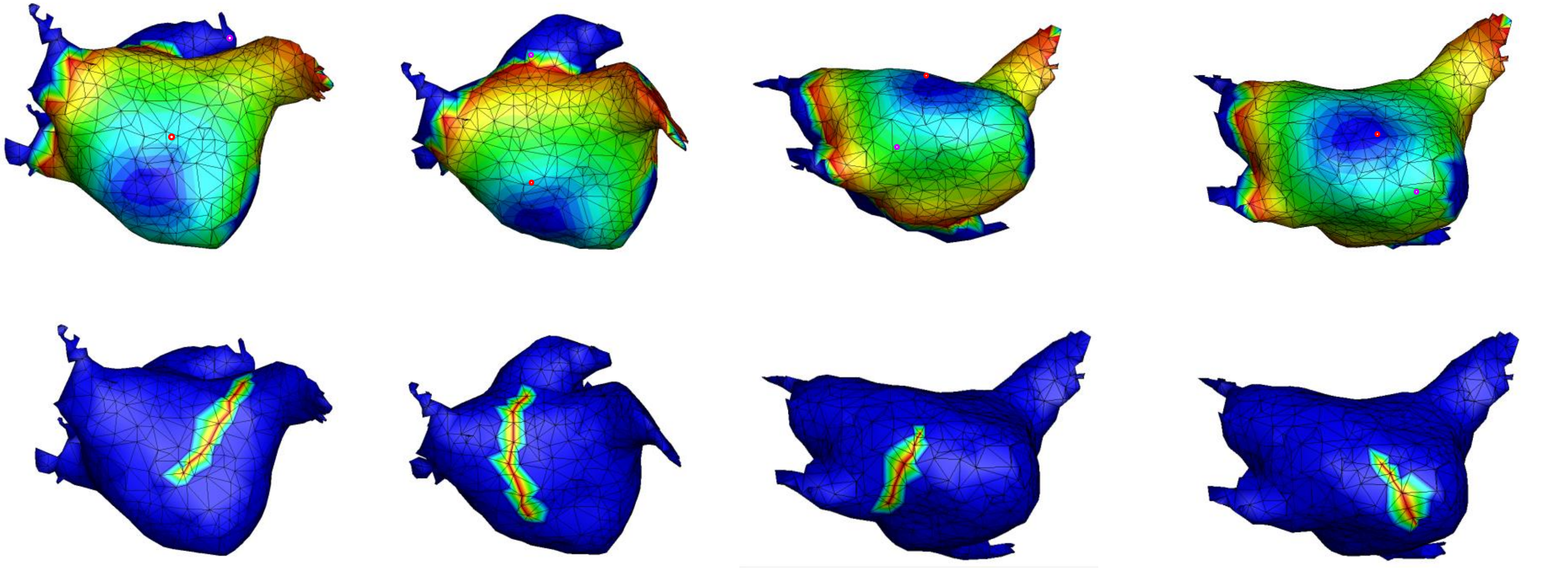
We consist in estimating the differential property at each point p as the average value of the slopes computed in cells in the neighborhood of p.

$$\nabla f(p) \simeq \frac{1}{V_{B(p)}} \int_{B(p)} \nabla f dV,$$

where $B_{(p)}$ is a neighborhood of p and $V_{B(p)}$ is its volume or area.

Validation process

Pacing → LAA | Pacing → Roof | Pacing → Septum | Pacing → Low anterior site



$$v = \frac{s}{t},$$

where *v* is the geodetic velocity,
s is the geodetic distance, and
t is the accumulated integration activation time.

Results

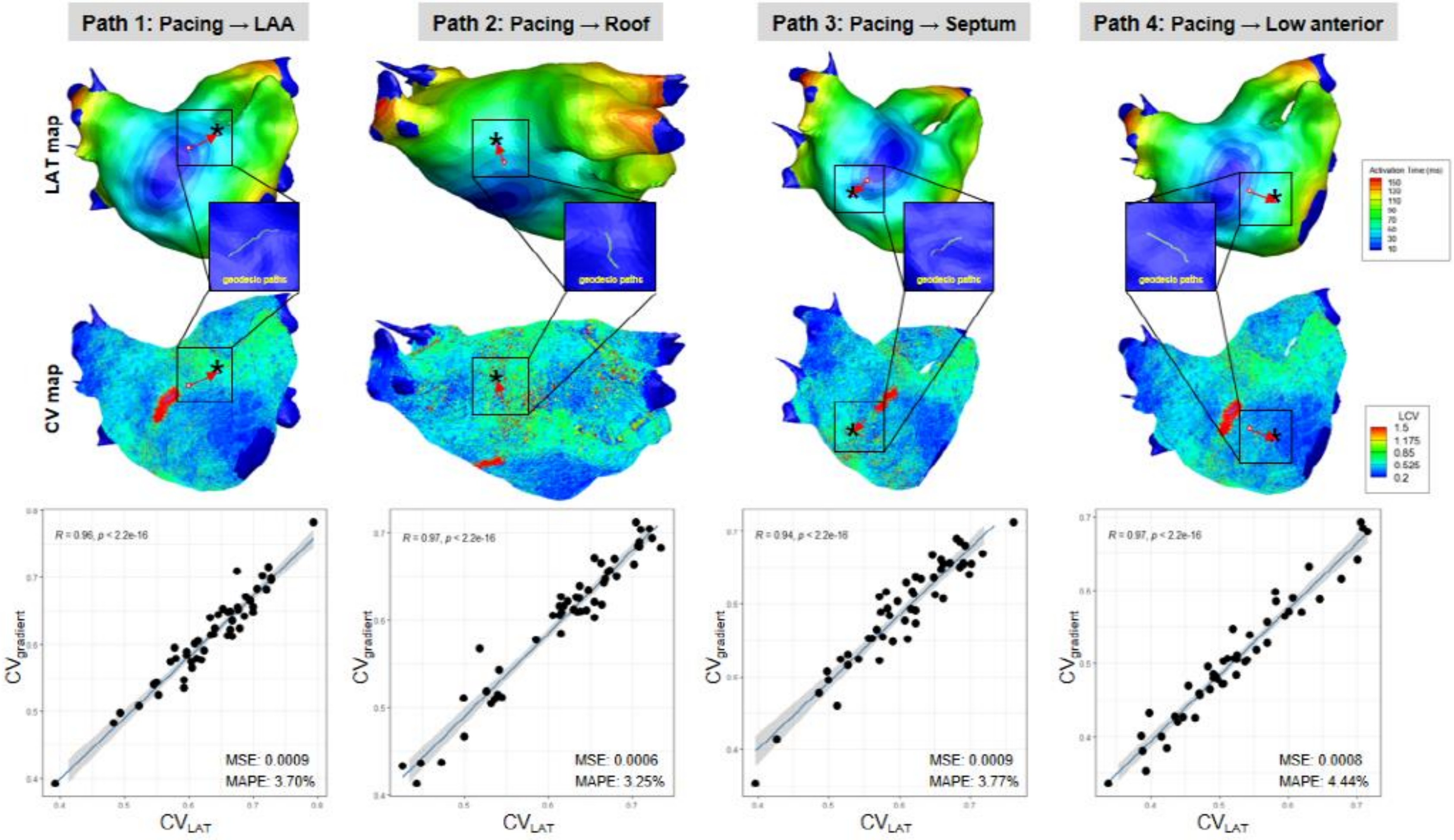
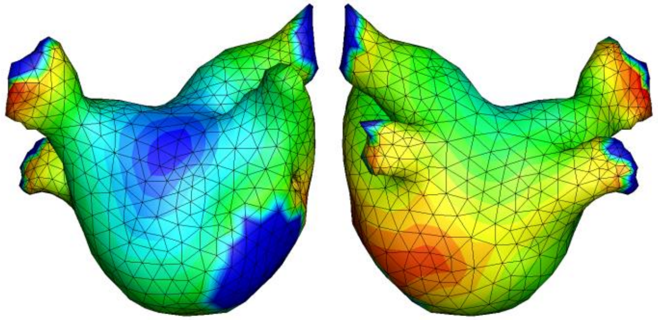


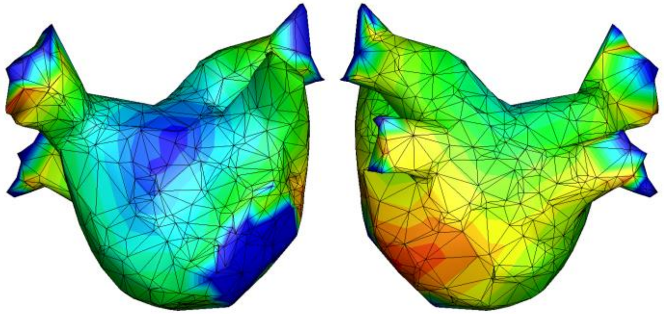
FIGURE 2. Evaluation results compared to CV_{LAT} and $CV_{Gradient}$ (linear integral) calculated from the geodesic paths of four sites.

Comparison Isotropic and Anisotropic topologies

Isotropic



Anisotropic



For all non-computable triangles (approximately 3% of all triangles) by the conventional triangulation method have been improved for both isotropic and non-isotropic meshes.

Conclusions

- Our proposed average nodal gradient-based CV estimation algorithm was able to estimate accurate CV independently of the spatial resolution and uniformity of triangles.

- The proposed method can be considered for the estimation of accurate CV in clinical practice built with super-resolution cardiac mapping systems in the future.

Thank you for your attention.

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