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Sphygmic Stress Diagnosis in Arterial Blood Vessels by Electromagnetic Radiation Scattering

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ABSTRACT

In this paper the feasibility of a new in vivo approach for blood vessel deformation detection is analyzed. The proposed method is based on the measurement of variations in electromagnetic wave scattering due to deviation from circular section of the vessel. A geometrical model of the radial artery, based on data available in the literature, is presented and numerical simulations of the scattering of an electromagnetic wave are carried out by means of Finite Element Method analysis and confirmed by computation of the exact analytical solution by means of the so called Elliptical Cylindrical Wave Approach. Results are shown in the case of an electromagnetic plane wave of suitable frequency and polarization impinging on the arterial vessel.

1. INTRODUCTION

Innovative in vivo analysis of mechanical behavior of peripheral blood vessel represents an important branch of biomedical studies. The complexity and importance of cardiovascular system justifies the wide variety of diagnostic techniques proposed in the literature for the estimation and monitoring of the most significant physiological parameters such as Heart Rate, Blood Viscosity, Vessel Wall Thickness, Vessel Wall Elasticity or Hematocrit. They are commonly taken into account as indicators for an early diagnosis of important pathologies or simply for monitoring the course of a disease.

Simple models of human cardiovascular system such as Lumped Element Model

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(LEM) (Rideout 1991), have been developed with the idea of facilitating the study and simulation even of long vessel section with a certain ease also in case of pathological anomalies.

The development of a new noninvasive electromagnetic technique for the remote detection of the behavior of peripheral blood vessels could provide a new point of view of the phenomenon, allowing to correlate the electromagnetic response of the system to the mechanical characteristics of the vessels provided, as mentioned before, by Lumped Element Model (LEM).

2. GEOMETRY OF THE PROBLEM AND INCIDENT FIELD

Geometrical outline of the blood vessel is shown in Fig. 1 in which typical dimensions of the radial artery have been chosen. The artery is supposed to undergo a compression due to the measure procedure and a subsequent expansion due to sphygmic impulse. In Fig. 1(a) the vessel is shown in the compressed state (major semi axis: external 5.3mm, internal 2.3 mm; minor semi axis: external 3.5 mm, internal 0.5 mm). In Fig. 1(b) the vessel is shown in expanded state (external radius 4.5 mm, internal radius 1,5 mm). Polar (ρ,ϑ) and Elliptical (u,v) Coordinates Reference Frames are shown in Figs. 1(a) and (b), respectively.

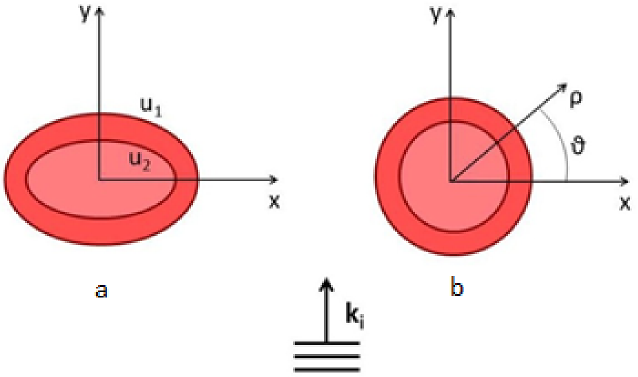

Figure 1: Geometrical outline of a typical human radial artery: (a) compressed state; (b) expanded state

The mechanical behavior of the vessel under deformation is supposed to respect the hypothesis of limited tangential expansibility of the arterial walls under strain, thus undergoing an isoperimetric deformation, led by the contraction and expansion of one of its transversal axes due to pressure superposition on the vessel. In particular, we suppose a reduction and subsequent expansion of the cylinder transverse section along the y direction, thus obtaining an elliptical cross section whose major axis, extending along the x direction, depends on the measure of the minor axis in order to keep the vessel transverse section perimeter constant.

An electromagnetic plane and uniform wave $\boldsymbol{E_z} = \boldsymbol{E_0} e^{i\boldsymbol{k_i}\cdot\boldsymbol{r}}$is supposed to impinge orthogonally with respect to the cylinder axis direction $\hat{z}_o$ (i.e., $k_i \perp \hat{z}_o$) in TM linear polarization (i.e., $\boldsymbol{E} // \hat{z}_o$). The incident field, impinging on the vessel gives rise to a scattered field Esc_z.

3. EM PARAMETERS

A simple model of the electromagnetic behavior of an arterial blood vessel may be obtained by applying homogenization theory results to compute effective permittivity of a multilayered dielectric cylinder.

As shown in Sihvola (1999) in the case of an electromagnetic wave orthogonally impinging on an infinite dielectric cylinder, the Maxwell-Garnett formula may be applied to evaluate effective dielectric permittivity to be used in simulations,

$$\varepsilon_{\mathrm{eff}} = \varepsilon_e + 3f\varepsilon_e \frac{\varepsilon_i - \varepsilon_e}{\varepsilon_i + 2\varepsilon_e - f(\varepsilon_i - \varepsilon_e)} \qquad (1)$$

in which ε_e and ε_i represent the dielectric permittivity of external and internal material, respectively, and f represents the volume fraction of the mixture of the two materials.
In the case oflossy dielectric materials, the complex permittivity may be obtained from the complex continuation of the Maxwell-Garnett formula applied to the two complex permittivities of the external and internal materials $\varepsilon_e = \varepsilon_e' - j\varepsilon_e''$ and $\varepsilon_i = \varepsilon_i' - j\varepsilon_i''$.

$$\varepsilon_{eff} = \varepsilon_{eff}' - j\varepsilon_{eff}'' = \qquad (2)$$

$$= \varepsilon_e' - \mathrm{j}\varepsilon_e'' + 3f(\varepsilon_e' - j\varepsilon_e'')\frac{\varepsilon_i' - \varepsilon_e' - j(\varepsilon_i'' - j\varepsilon_e'')}{(1-f)\varepsilon_i' + (2+f)\varepsilon_e' - j[(1-f)\varepsilon_i'' + (2+f)\varepsilon_e'']} \qquad (3)$$

Typical values for blood vessel tissue and blood in the frequency range 10^7-10^8 Hz, as available in the Gabriel (1996), and respective computed values for ε_e, ε_i and ε_{eff} are shown in Table 1.

	Vessel		Blood		Mixed Effective values		Fat	
Frequency f [Hz]	ε'_{rel}	ε''_{rel}	ε'_{rel}	ε''_{rel}	ε'_{rel}	ε''_{rel}	ε'_{rel}	ε''_{rel}
2,00E+07	9,54E+01	3,26E+02	1,55E+02	1,03E+03	9,63E+01	3,33E+02	9,73E+00	2,87E+01
2,51E+08	4,94E+01	3,75E+01	6,68E+01	9,30E+01	4,96E+01	3,81E+01	5,68E+00	2,78E+00
3,16E+08	4,81E+01	3,08E+01	6,54E+01	7,52E+01	4,83E+01	3,13E+01	5,62E+00	2,26E+00
3,98E+08	4,70E+01	2,53E+01	6,42E+01	6,09E+01	4,73E+01	2,57E+01	5,58E+00	1,86E+00
1,00E+09	4,46E+01	1,31E+01	6,11E+01	2,85E+01	4,48E+01	1,33E+01	5,45E+00	9,62E-01

4. SIMULATION OF THE SCATTERED FIELD

The numerical evaluation of the scattered field has been carried out using *Comsol Multiphysics* simulation software based on Finite Element Method. Results have been confirmed by comparison with an exact solution for the electromagnetic field through analytical Elliptical Cylindrical Wave Approach. Such approach consists in the solution of the Helmholtz equation in Elliptic Cylindrical Coordinates and in the representation of the electromagnetic field as an infinite series expansion in terms of Mathieu Functions. Numerical codes for the computation of the scattered field have been implemented in MatLab.

5. DEPENDENCE ON SHAPE OF THE VESSEL– RESULTS

Numerical results are shown in Fig. 2 in which values of the ratio $\frac{|Esc_z|}{|E_0|}$ are plotted versus different values of the vessel cross section external minor semi axis at frequency 316 MHz. The graph shows a good agreement between numerical results obtained from both methods.

6. CONCLUSIONS

Simulation plots show an appreciable variation of the scattered field distribution depending on variation of the blood vessel shape. These first results, although testifying the necessity of further research, hint at the possible development of future applications of electromagnetic scattering to remote noninvasive diagnosis of mechanical parameters on peripheral blood vessels. Providing data sensing of mechanical vessel deformations to Arterial Lumped Element Model may lead to an alternative in vivo measure of important parameters such as blood viscosity and hematocrit.

The presented noninvasive diagnostic methodology might undergo a gradual extension to inferior scale, possibly targeting nano-scale at capillary level.

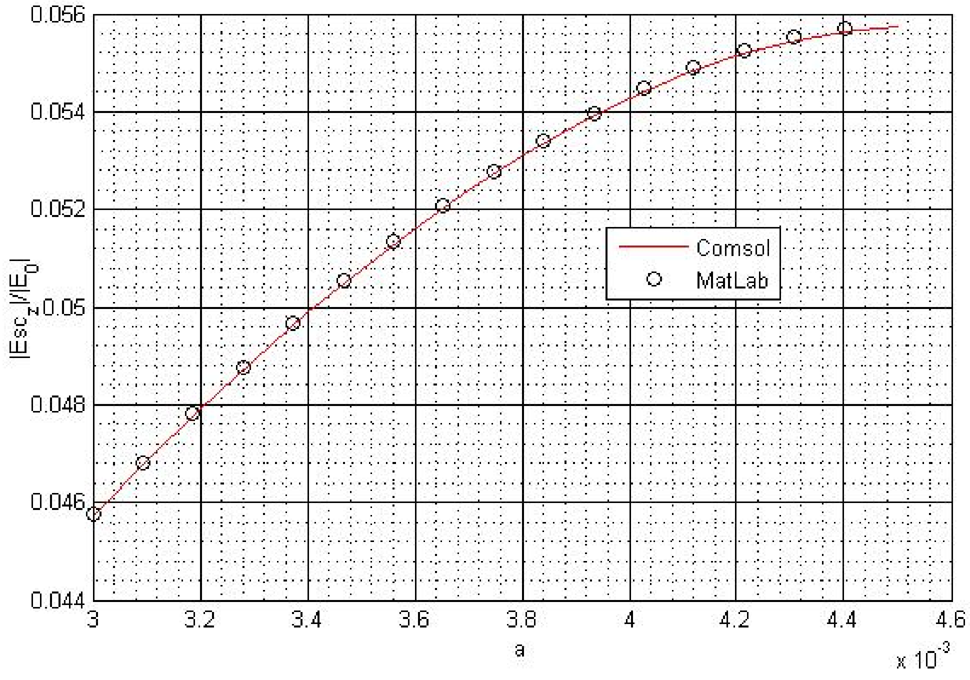

Figure 2: Plot of the ratio $\frac{|Esc_z|}{|E_0|}$ versus vessel cross section external minor semi axis *a* [m] at frequency 316 MHz

7. FURTHER DEVELOPMENTS

Further developments include the analysis of scattering pattern perturbation introduced by the presence of a plane surface separating two different dielectric half spaces (modeling the discontinuity between air and tissues in which blood vessels are supposed to be immersed) and more accurate modeling of skin and artery tissue stratification by multilayer lossy dielectric structures.

8. REFERENCES

Gabriel, S., Lau, R.W. and Gabriel, C. (1996), "The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz", *Phys. Med. Biol.*,41(11), 2251-2269.

Rideout, V.C. (1991), *Mathematical and Computer Modeling of Physiological Systems. 2nd Ed.*, Prentice Hall, New York, 261.

Sihvola, A. (1999), *Electromagnetic Mixing Formulas and Applications*, The Institute of Electrical Engineers, London, 48-79.