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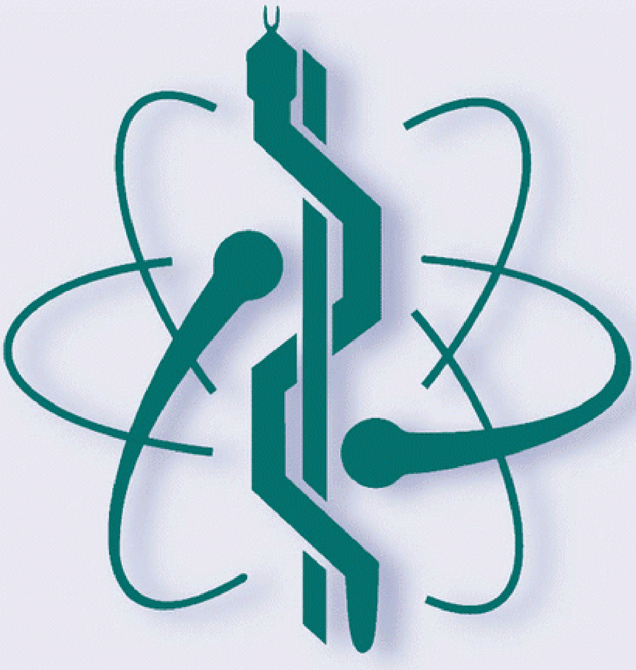

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A Review of Telemedicine Services in Finland

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Abstract— **Telemedicine is gaining popularity due to the provision of ubiquitous health care services that is a fundamental need for every socialized society. In this paper, telemedicine services in Finland are discussed, as well as how they came into existence, how they are funded, evaluated, and what are their impacts on health care systems and society. Telemedicine services like teleradiology, telelaboratory, telepsychiatry and remote consultations, are being offered in all hospital districts. Primary health care centers in Finland are lacking telemedicine services, and are planning to have them. Electronic Patient Records (EPR), with e-referral and e-discharge letters, have prevented patients from unnecessary repeated laboratory examinations and treatments. The e-Archive (Finland's national EPR) is in the planning stage, making EPR on national level, to promote ease of access to patient records and ubiquitous care. The e-Prescription project is also in the planning stage, which aims to enhance drug safety, prevent forged prescription, and prevent threat to a patient's life.**

Keywords— **Telemedicine, Teleradiology, Finland, Ubiquitous Care.**

I. INTRODUCTION

Telemedicine results from the contribution of Information and Communication Technology (ICT) towards heath care, and the improving health and welfare of society. This is achieved by providing ubiquitous health care services to remote regions. Telemedicine has many advantages, such as serving people in remote areas due to unavailability or lack of health care professionals, and improving health care quality via consultations with specialists. The biggest considerable advantage of telemedicine is the savings of time (travel to appointments, requirements for both patient and professional to be available, administrative tasks, etc.), cost (organizational work load, administrative resources, reduced travel, utilization of consultation services at a distance, etc.), and effort for a patient.

Finland is a Nordic country in Northern Europe, with a population of 5.3 million people. Finland's northern areas cover about 30% of the total area, even more, these areas are sparsely populated. Even though citizens in these areas may have access to primary health care, they are consistently lacking specialized care. For patients in northern areas, it can be very difficult to visit Oulu district hospital for special care. Teleradiology was the first telemedicine application started in northern areas of Finland that improved the health care system and eventually benefited patients, heading towards Finland's goal for the completion of the ubiquitous health care dream.

Finland has good international relations and supports international research and development programs, particularly in the areas of ICT and health care services. Finland cooperates with its neighboring country Russia in many development programs and has bilateral agreements on education, health and economic co-operation. Finland is among the first three countries who established the first international teleradiology connection in the world, and it was established between university hospitals of Oulu (Finland), Reykjavik (Iceland), and Tromsoe (Norway) [1].

After an introduction to telemedicine highlights in Finland, the article is organized as follows: section 2 highlights the background of telemedicine in Finland; section 3 describes about the methodology involved in this paper, how the literature was collected and reviewed; section 4 discusses current applications of telemedicine in Finland, and factors associated with its implementation and evaluation; and section 5 summarizes the literature studied. The paper concludes with discussion and future implications for telemedicine systems in Finland.

II. BACKGROUND AND STATUS OF TELEMEDICINE SERVICES

This section discusses about the Finnish Health Care system, the background of telemedicine services in Finland, how they were evolved, evaluated, implemented and adopted in the Finnish Health Care system. Furthermore, it describes the current telemedicine development, and the status of telemedicine services according to a survey made in 2005.

Teleradiology refers to electronic transfer of radiological images such as x-ray, computed topography (CT) images and magnetic resonance images (MRI) from one clinical setting to another for diagnostic purposes. The first experiments took place in 1969, but did not enter the practical world until the

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beginning of 1990's. Telemedicine services were a major interest in the sparsely populated northern areas, but services quickly spread around the country [2]. Finland has an extensive health care system, comprised of 21 hospital districts including five university hospital districts (Helsinki, Tampere, Kuopio, Oulu and Turku). One hospital district provides specialized health care to several primary health care centers in its area [3]. Private health care in Finland comprises of private clinics and private hospitals. The physicians working at private clinics are mostly specialists who work full time at a public hospital. By 1994, all five university hospital districts had teleradiology services implemented. Hospitals utilize teleradiology services to transmit radiological images to specialists such as neurosurgeons, and the neurosurgeons, after analyzing and studying the images used to report or consult, would contact the client's hospital via telephone earlier as all data networks were implemented simplex i.e. one-way, but later on they started reporting and consulting via videoconferencing.

Finland has implemented an electronic patient record (EPR) system as a primary patient database in its health care system; however, some records are kept and presented in traditional paper format. Oulu University Hospital has used multimedia medical records since 1995, and now they have merged e-referrals and e-discharge letter features to this. In 2005 [4], 16 out of 21 hospital district were providing e-referrals and e-discharge features to its subsidiary health care centers. These features allow health care professionals to view a patient's electronic record along with laboratory results and the imaging database, thus avoiding unnecessary examinations. Imaging databases include x-ray, and DICOM (the Digital Imaging and Communications in Medicine) format radiological images such as computed tomography (CT), ultrasound (US), and magnetic resonance imaging (MRI) images [1]. The EPR usage in Finnish health care system in 2005 [4] is shown in Table1.

Finland has also produced the first pocket-sized Nokia Communicator PDA (Personal Digital Assistant) device with integrated GSM phone, under the EU funded MEMODA project (Mobile Medical Data) during the years 1998-2000. These PDA terminals were utilizing GSM data pathways, helping physicians to view DICOM images on a secure connection and proved to be most effective for neurosurgery department. These PDA terminals were enhanced during the years 2002-2004 under the EU funded PROMODAS project (Professional Mobile Data Systems). The major enhancement was upgrading transport technology to GPRS (General Packet Radio Systems) that eventually reduced the system operating costs, and it is in clinical use these days [1].

The pharmacies in Finland are required to check every prescription by law. According to The Association of Finnish Pharmacies, pharmacies have to cope with over half a million unclear or inaccurate prescriptions for medicine every year, such as wrong dosage for a medicine or unavailability of drug in the market or prescribed medicine effects CNS (central nervous system). These checks have also revealed forged prescriptions and even fake physicians [5]. Therefore, Finland started a national e-Prescribing pilot-project in 2004-2006 [6], covering two hospital districts and a couple of primary health care centers involved with it. A doctor creates a prescription with a legacy system, signs it with electronic signature, and sends a SSL secure message to national prescription database referred to be as the Prescription Centre. When a patient goes to a pharmacy, pharmacist accesses the database, makes required changes, marks dispensing information on the electronic prescription, signs the markings with a personal smart card, and saves the markings to the prescription in the database. Then, the medicine is dispensed to the patient.

Table 1 EPR usage in Finnish health care system

Quantity	Hospital District	Primary Health Care	Private Health Care Providers	Status	Usage intensity
17	×			In use	> 90%
1	×			In use	50 – 60%
2	×			In use	25 – 49%
1	×			Planning	
229		×		In use	> 90%
3		×		Testing	
8		×		Planning	
11		×		Merging with neighbor	
25			×	In use	> 90%
3			×	---	

The Prescription Centre is accessible to health care professionals and pharmacists through a professional smart card, issued by Valvira (National Supervisory Authority for Welfare and Health). The Prescription Centre will contain other information along with medicine name such as pricing, interchangeable products, and clinical nutrients. The legislation for e-Prescription has been accepted in December 2006, and a national e-Prescription database has been created by the Social Insurance Institution (KELA). After a successful implementation, the patients will still have a right to choose prescription on paper [6]. It is aimed to be fully integrated with different EPRs to cover all pharmacies, and to reside continuously updated knowledge about all prescribed drugs of the patients, which will offer a platform for drug safety decisions. The prescription information is stored in the Prescription Centre for 30 months only, and then is archived in the Prescription Archive for 10 years, and then destroyed. It will help health care professionals to view, subject to a patient's oral consent, a patient's previous treatments, medication, avoid adverse drug interactions, and overlaps. The stored data can be used for supervision, drug safety operations, the payments for drug reimbursements, and research.

The health care system uses different systems for information management, which makes the distribution of patient's records complex, limiting use of systems, increasing costs, and paper archive preferred. Therefore, the Government of Finland decided to implement EPR on a national level rather than on a regional level, and store the records in a uniform technical format so that it can be distributed and accessed evenly. The National EPR project is expected to be finished by the end of 2011, and is maintained and handled by the Social Insurance Institution (KELA). The legislation for the National EPR was laid out in December, 2006 [4], and it will reside on a national public key infrastructure (PKI) for health care professional. The patients can refuse publishing of their records in the directory database, and their records can only be seen with an oral consent. The National EPR will offer citizens to view health information, such as reference and discharge letters, certificates, statements, results of examinations, and log data about visits to the personal health records, eventually making the system more secure to view without oral consent of a patient.

Other telemedicine applications include: sending laboratory or pathology results to physicians or specialists; telepsychiatry, teleophthalmology, teledentistry, distance teaching for other health care institutes and personnel via videoconferencing; and forwarding digital real-time reading parameters (pulse rate, oxygen saturation, blood pressure, ECG, etc.) of a patient in an ambulance heading towards the hospital.

III. METHODOLOGY

This section reveals the method of the study; namely, how the literature was obtained, the challenges and problems in accessing data, efforts to access and gain information, literature contents, and what information was of interest are explained in this section.

Initially, a search was made for various scientific articles regarding telemedicine focusing on the impact, progression, projects, and applications. The author hoped to find sufficient information through searching e-journals, e-databases, universities' publication databases, and organizations' published information. However, this proved to be a much more difficult task than was expected. One of the main hindrances to finding accurate and current information was language barriers. The official languages of Finland are Finnish and Swedish; Swedish being spoken and written in the metropolitan areas only. Because of this, it was very difficult to obtain literature and other information in English. The literature search started from e-journals, e-databases, search engines, and moved ahead to contact organizations, universities, library services of Aalborg University, Tampere University of Technology, Aalto University, individual professors, in addition to Pirkanmaa Hospital, and authors of different publications which were accessible only through direct exchange. After contacting individual authors, it was soon apparent that most of the journals are in the Finnish language and only the abstract is available in English, even though the language of the article may be listed differently in literature publication databases. After contacting library services in Finland, they suggested to look into TelMed – the leading database for medical publications in Finland, which eventually helped to access 3 more publications. While searching for pertinent information, it became painfully clear to the authors, that there is a serious gap in information regarding telemedicine in Finland. Further, we can understand from a European Union point of view that much more information could be disseminated regarding past and present telemedicine initiatives, particularly if it were made available in a common language, i.e. English.

The search for literature resulted in 30 papers and 4 research and review reports. Most of the papers were review articles – telemedicine pros and cons, project implementation phases, uses, and future aspects, but none of the papers revealed the technical aspects of interest: topology, operation principles and management. Out of the 30 papers obtained, 20 of the papers were dated 1991 -1999, while the rest were published in the year 2000 or later, no information or articles were found for the year 2010. Papers were accessed through e-journals, e-databases and universities research centers (Telemedicine Laboratory, Tampere University of Technology, and Finn TeleMedicum – Center of Excellence for TeleHealth, University of Oulu) while the reports were accessed from National Institute of Health & Welfare (THL) and its underlying centers: the National Research and Development Centre for Welfare and Health (Stakes) and Finnish Office for Health Technology Assessment (Finohta).

IV. TELEMEDICINE APPLICATIONS AND FACTORS AFFECTING IMPLEMENTATION AND EVALUATION IN FINLAND

In this section, qualities of telemedicine applications in Finland are described. There are many factors affecting the successful implementation and use of telemedicine systems, including funding and reimbursement, licensing and insurance barriers, and social acceptance. Some of these factors, funding, current applications and social acceptance are discussed here, to give an overview about the status and evaluation of telemedicine applications in Finland.

A. *Funding*

In this section, the various sources of funding for telemedicine projects in Finland are discussed, how the telemedicine projects are funded and run, which organizations are key players for it, and which specific area they are involved in. The organizational structure for funding is widely distributed, varying from public to private sector, all contributing towards the better health and welfare for the Finnish Society.

The Ministry of Social Affairs and Health in Finland [7] is the top level organization for administration, innovation, and management of health services in Finland. The National Institute for Health and Welfare (THL) [8] is expert in the research and development of health and welfare. THL runs many research centers under their umbrella, including the National Public Health Institute (KTL), the National Research and Development Centre for Welfare and Health (Stakes), and the Finnish Institute of Occupational Health (TTL). These research centers are involved in research and development for societal health and welfare, and funded by THL.

The Technical Research Centre of Finland (VTT) [9] is the biggest funding source for multi-technological applied research projects in Finland, and the biggest research organization in Northern Europe. VTT is an international scientific technology network that runs research projects and research programs associated with universities to develop, enhance, and innovate the technology to put the applied research to improve competencies into action. Along with other technologies, VTT provides high-end technology solutions and innovation services in Telemedicine as well.

The Academy of Finland [10] is the prime funding agency for basic research in Finland. The academy operates within the administrative sector of the Ministry of Education. It allocates funding of about 300 million Euros for the highest quality, and produces the most innovative, scientific research. Universities are the most important partner for the academy as research is involved, it supports and funds research projects, research programs, and Centers of Excellence. Centers of Excellence (CoE) offer excellent opportunities to carry out high quality research with six-year funding. The Academy of Finland also encourages the mobility of researchers (to and from Finland), such as FiDiPro (Finland Distinguished Professor), to extend and improve research collaboration, businesses, industry, and public administration internationally as well as nationally. Internationally, the academy cooperates with a number of other countries as well as with international funding organizations.

The Finnish Funding Agency for Technology and Innovation (Tekes) [11] is another main public funding organization for innovative research and development that works with the top innovative companies and research units in Finland. Tekes supports the projects that contribute towards the greatest benefits in the economical and social sectors in Finland. Along with other fields of innovative interest, Tekes funds many projects in Telemedicine as well.

Sitra, the Finnish Innovation Fund [12] is an independent public fund which promotes the welfare of Finnish society and has a mission to build a successful Finland for tomorrow under the supervision of the Finnish Parliament. Sitra co-operates closely with both the public and private sectors. Sitra chooses and changes programs themes aiming at the welfare of the society. Sitra enhances impact of its programs by various methods that include research, strategy process, innovative experiments, business development, and investment in internalization. Currently, Sitra does not focus actively on any health care program but, in the past, a health care program has been completed. This particular health care program was a research, training, and experimental program, having paper-free health care and seamless service as one of the key areas.

KanTa, the National Archive of Health Information, is a collective name for several national medical information systems, which are e-Prescription, e-Archive (national EPR), and online access by citizens to view their medical and prescription data. There lies a problem of funding in KanTa; the State will fund construction and operational costs to KanTa till 1st April 2011 only. Afterwards, the system will rely on funding obtained via user fees, which will be set at a level sufficient [6].

Finland also participates in a European Union (EU) Commission's Seventh Framework Programs (FP7) project, titled ISISEMD (Intelligent System for Independent living and SElfcare of seniors with cognitive problems or Mild Dementia). The ISISEMD project focuses on the elderly living people, having some problems or a mild loss of memory (dementia). In the past, the EU has funded three telemedicine projects under Fifth Framework Programs

(FP5) in Finland, titled RUBIS, PROMODAS (Professional Mobile Data Service) and MOMEDA (Mobile Medical Data) [1]. The remainder of funding comes from the private sector and giant companies of interest, such as Nokia and Remote Analysis, who want to innovate and develop their products for the welfare and health system in Finland. Most of the research projects in Finland today are funded by a co-operation of these funding agencies, e.g. a project funded by Nokia, Tekes, Intel, and Nvidia Graphics. These funding agencies start a research program or project and hire scientific staff or handover research to universities in order to evaluate the larger, "real" picture.

B. *Current Applications*

In this section, the current status of telemedicine applications and implementation are discussed. This section reveals more about the role that telemedicine applications have played in the Finnish health care system, how hospitals started utilizing telemedicine services and how it benefited both parties of the patients and the health care system.

Finland has many telemedicine applications currently in use: teleradiology, telelaboratory, telepsychiatry, teleopthalmology, teledermatology and teledentistry. Video conferencing is the key part of most used telemedicine service, where the physician is at one location while the patient (and the nurse) is at another location. It is used to consult a specialist of a hospital e.g. for patients with psychological or ophthalmological problems, and the services are known as telepsychiatry, teleopthalmology and teledentistry respectively [2]. In 2005 [4], 11 out of 21 were providing remote consultations and 21 out of 179 primary health care centers had purchased videoconferencing equipments, the growth is expected to develop as more health care centers are either planning or testing it. Video conferencing improves the quality of health care especially in case of telepsychiatry [13] – mental health care, expands the co-operations between primary and secondary health care units, it is currently used in all hospital districts, almost all primary and secondary care units, and is planned to expand further. The telemedicine applications mentioned above have been implemented in university hospital districts and other hospitals in Finland; meanwhile, the other applications are in the pipeline.

- Teleradiology

Finland has many telemedicine applications currently in use: Currently, 18 out of 21 (86%) hospital districts in Finland utilize this application [2]. In 1969, initial experiments took place when radiological images were transmitted between Helsinki hospital district and Oulu hospital district using the broadcasting network of Finnish national television (YLE). Some hospitals started teleradiology services utilizing existing copper telephone lines (POTS) to transmit X-ray images, but later upgraded to using Integrated Systems Digital Network (ISDN) lines as transport medium. The teleradiology and telemedicine applications network expanded widely along with the passage of time, Asynchronous Transfer Mode (ATM) dominated data transport technology, replacing ISDN lines and the YLE broadcast network there. While ATM was a dominant data transport technology, some hospitals also utilized Ethernet 10Mbps connections, because of compatibility issues - the equipment didn't support any ATM cards as an interface. The imaging database can be viewed in three ways: regional database, regional PACS (Picture Archiving and Communication System) or EPR having e-referral and e-discharge letters. In 2005, 52 out of 179 primary health care centers were utilizing some teleradiology services, where as it use in district hospitals is summarized in Table2 [4].

Table 2 Teleradiology services in Finnish health care system

Measure		No. of hospital districts
Teleradiology	Production Phase	16
	Pilot Phase	2
	Usage > 90%	5
Regional Archive	Production Phase	10
	Pilot Phase	3
	Usage > 90%	3
	Either teleradiology or regional archive	18

- Telelaboratory

Telelaboratory refers to electronic distribution of laboratory results from one location to another location and this application between hospitals is very common nowadays. According to a 2005 survey [1], 90% of the hospital districts were using electronic methods of distribution for laboratory results, where-as 27% of the primary care centres were receiving daily laboratory results electronically via a regional database and the rest were either at planning or testing stage. In earlier times, Integrated Services Digital Network (ISDN) lines were used for inter-laboratory communication, which was later on replaced by ATM connections along with data transport technology upgradation.

- Telepsychiatry

Telepsychiatry refers to interactive psychiatric consultations over distance that enables simultaneous sound and video connections between two or more interested parties (patient - psychiatrist or patient, nurse/physician - psychiatrist). The primary communication method used in telepsychiatric consultation is teleconferencing, because a psychiatrist tries to understand the problem through therapy and observing a patient, and these observations include physical movement, thoughts, reaction to certain actions, expressions and many other factors of a patient that are often difficult to quantify but are known indicators in Psychiatry. Initially, 3 pairs of ISDN lines (384 Kbps) were used for teleconferencing, as the technological revolution continued, Finland switched to using ATM connections.

- Teledentistry

Finland has a shortage of dental health care professionals, lacking odontology services in sparsely populated regions. Odontology is a branch of dentistry that deals with the teeth, their structure, development, and their diseases. Teledentistry refers to provision of dental services at remote end using videoconferencing, but it is mostly used for distance learning specialist education and clinical consultation purposes in dentistry. Turku university hospital odontological clinic hosts specialist training, which is distributed to various health care centers and hospitals in Western Finland. Videoconferencing was made possible through standard videoconference equipment and wireless intraoral camera technology, utilizing ISDN as well as TCP/IP network connections. Wireless intraoral camera is a tiny digital camera that fits comfortably in one's mouth and shows a clear real time view of one's smile and teeth to a dentist for analysis and diagnostic purposes [14]. In some health care centres, computer-aided consultation is also utilized for patient diagnosis and treatment planning. For a patient, some photographs using digital camera or digital images for x-ray films are obtained and sent via email for consultation, saving patient's time and effort [15]. Teledentistry is expected to develop further in near future.

The data transport technology used in telemedicine services is compared in Table 3.

Table 3 Data transport technology for telemedicine services

Application	Transport Technology
Teleradiology	YLE Network, POTS, ISDN, ATM
Telelaboratory	ISDN, ATM
Telepsychiatry	ISDN(3 pairs – 384 Kbps), ATM
Teledentistry	ISDN, TCP/IP

C. *Social Acceptance*

It seems as though the Finnish society has accepted telemedicine applications from a technical point of view, but there continue to be hindrances to social acceptance. The patients had to wait a long time for appointments, but recent system has improved, and resulted in less awaiting times for appointment. In near future, a hindrance will appear, when KELA will start charging fees about e-Prescription and e-Archive services from patients.

V. LITERATURE REVIEW

This section summarizes the papers studied and a review of literature as show in Table 4.

Table 4 Literature review

No.	Study	No. of participants	Methodology	Tool	Results
1.	Teledentistry (specialist education) [16]	26 specialists	Cost analysis	Videoconferencing	Costs saving per student €40,000. Attracted more students
2.	E-health development project 'ProViisikko' [17]	5 hospital districts	Process innovation	Analytical tool Interactive consulting centre	Enhance patient care, patients can book appointments, check laboratory test results online, and receive SMS acknowledgment.
3.	Child and adolescent psychiatry [18]	42 child and adolescent units in 21 hospital districts	Questionnaire (qualitative and quantitative analysis)	Videoconferencing	Savings of time & cost, availability of mental health services, can be improved by encouraging hospital staff to utilize videoconference on a proper schedule and improve technical support.

Table 4 *(continued)*

4.	EPR and general practitioner (GP) [19]	GPs in 8 health care centers	Use EPR system to look for specific data	3 types of EPR systems (2389 patient cases accessed)	Need to overcome shortage of qualified personnel to use and enter data correctly into EPRs.
5.	Extending EPR to e-referral and discharge letters [20]	12 university clinics and primary health care centers of 13 municipalities	Send XML message between EPR or on a secure server using VLAN or VPN.	EPR, imaging and laboratory database	Saves time in referral management, avoids unnecessary repeat imaging and laboratory examinations. Legalization for national electronic signatures and patient privacy are awaited.
6.	Development of working process [21]	--	Literature review Case study (interviewing and quantitative analysis of care process)	Technology (ICT)	A hypothesis – e-health services can be effective tool in improving and empowering patients in their own care, suggestion to start e-health pilot project for diabetes care.
7.	Fundus screening of type 2 diabetes patients [22]	Primary health care centers in South-Ostrobothnia, approx. 3000 patients screened each year	Take mobile unit to local centre, take fundus images and updates on central archive	Mobile digital fundus screening unit and central archive	Type 2 diabetes patients' fundus screening performed according to national health guidelines (one in 2.5 years) avoiding diabetic retinopathy and reducing university hospital workload.

VI. CONCLUSION

Finland is a pioneer in ICT services, and home to giant ICT company Nokia. Finland is sparsely populated, especially in northern areas, where telemedicine services can improve and provide specialized health care to the society. The Finnish Health Care system has been utilizing telemedicine services since 1994 to its community. The statistics presented in 2005 reveal that almost all of the district hospitals have teleradiology, telelaboratory, and remote consultations services to offer to primary health care centers. About 30% of primary health care centers have bought videoconferencing equipments to support remote consultations, and created links to district hospitals, the rest are planning to have them in near future. All hospitals utilize EPR, which is no longer a good measure for accounting telemedicine services. Therefore, the merging of e-referral and e-discharge letters with EPR have extended telemedicine services, and helped in avoiding repeated examinations and viewing patient history. In order to cope with incorrect prescription and drug safety, e-Prescription project is a good step forward, which will help in avoiding overlaps, incorrect dosages, and prevent threats to a patient's life. The e-Archive (national EPR) project will help to digitize all hospital records, creating a uniform technical format for documents, making ease of access of patient records. The national EPR will include e-discharge, e-referral letters as well; the patient can refuse publishing of his/her information, and can check through log files that who viewed his/her records. The other applications are the fundus screening of type 2 diabetes patients, which prevents diabetes retinopathy (sight blindness), and teledentistry that cops with shortage of dental care professionals in Finland.

Due to language barriers, it was difficult to find literature about telemedicine services in Finland in English. After searching through library databases, e-journals, e-databases, internet, and finally contacting some Finnish universities research centers and institutions, the information was gathered to study and review telemedicine services in Finland. Majority of the literature was dated 1991-1999, but no any recent information in the last two years about telemedicine services in Finland was found. The funding for the development, implementation and evaluation of telemedicine projects is supported by various funding bodies, but a barrier for e-Prescription project appears in April 2011. The Finnish society has an acceptance to telemedicine services, but hindrances are expected to be in near-future regarding charging fees for e-Archive and e-Prescription services. Telemedicine services have contributed towards the betterment and welfare of the Finnish society.

REFERENCES

1. Jarmo Reponen. Radiology as a part of comprehensive telemedicine and ehealth network in northern Finland. International Journal of Circumpolar Health, 63:4 429-435, 2004
2. European Health Telematics Association: country report – Finland. Retrieved from http://www.i2health.org/forum/tasks-sources/task-force-sustainable-telemedicine-and-chronic-disease-management/annex-to-the-ehtel-briefing-paper/country-report-finland. Accessed 14 October 2010.
3. Hospital District of Helsinki and Uusima: health services in Finland. Retrieved from http://www.hus.fi/default.asp?path=59,404,4024,4023 . Accessed 14 October 2010

4. Jarmo Reponen, Ilkka Winblad, Päivi Hämäläinen. Current Status of National eHealth and Telemedicine Development in Finland. Studies in Health Technology and Informatics, 134: 199-208, 2008
5. Pharamcies Deal with Thousands of Incorrect Prescription. (2010, December 11). Retrieved December 13, 2010, from YLE - News: http://www.yle.fi/uutiset/news/2010/12/pharmacies_deal_with_thousands_of_incorrect_prescriptions_2212660.html
6. Funding – National Archive of Health Information (KanTa), Finland. Accessed 11 December 2010. Retrieved from https://www.kanta.fi/web/en/funding
7. Ministry of Social Affairs and Health, Finland. Retrieved from http://www.stm.fi . Accessed 14 October 2010.
8. National Institute for Health and Welfare, Finland. Retrieved from http://www.thl.fi/en_US/web/en/research;jsessionid=6C831396E60D4AEA474673F8F293BDA0. Accessed 14 October 2010.
9. Technical Research Centre of Finland (VTT). Retrieved from http://www.vtt.fi . Accessed 14 October 2010.
10. The Academy of Finland. Retrieved from http://www.aka.fi . Accessed 14 October 2010.
11. The Finnish Funding Agency for Technology and Innovation (Tekes), Finland. Retrieved from http://www.tekes.fi . Accessed 14 October 2010.
12. Sitra, the Finnish Innovation Fund, Finland. Retrieved from http://www.sitra.fi . Accessed 14 October 2010.
13. Marja-Leema Mielonen, Leena Väisänen, Juha Moring, Arto Ohinmaa, Matti Isohanni. Implementation of a Telepsychiatric Network in Northern Finland. Current Problems Dermatology, 2003, 32, 132-140.
14. Ignatius E, Mäkelä K, Happonen R-P, Hallikainen S, Perälä S. Videoconferencing as a teaching tool in specialist education in dentistry. Finnish Dental Journal, 17: 958- 962, 2004
15. Ignatius E, Mäkelä K, Perälä S. Computer aided dental consultation. Finnish Dental Journal, 16: 864-868, 2003
16. Eino Ignatius, Kari Mäkelä, Risto-Pekka Happonen, Sami Perälä. Teledentistry in dental specialist education in Finland. Journal of Telemedicine and Telecare, 12: 46-49, 2006
17. Teemu Paavola, Kari Mäkelä, Virpi Pyykkö, Sami Perälä. A national Finnish e-health development project "ProViisikko". Journal of Telemedicine and Telecare, 12: 67-69, 2006
18. Lilli Pesämaa, Hanna Ebeling, Marja-Leena Kuusimäki, Ilkka Winblad, Matti Isohanni, Irma Moilanen. Videoconferencing in child and adolescent psychiatry in Finland - an inadequately exploited resource. Journal of Telemedicine and Telecare, 13: 125-129, 2007
19. K Mäkelä, I Virjo, J Aho, P Kalliola, A-M Koivukoski, H Kurunmäki, M Kähärä, L Uusitalo, M Valli, V Voutair, S Ylinen. Electronic patient record systems and the general practitioner: an evaluation study. Journal of Telemedicine and Telecare, 11: 66-68, 2005
20. J Reponen, E Marttila, H Paajanen, A Turula. Extending a multimedia medical record to a regional service with electronic referral and discharge letters. Journal of Telemedicine and Telecare, 10: 81-83, 2004
21. Noora Ekroos, Kari Jalonen. E-health and diabetes care. Journal of Telemedicine and Telecare, 13: 22-23, 2007
22. Riku Lemmetty, Kari Mäkelä. Mobile digital fundus screening of type 2 diabetes patients in the Finnish county of South-Ostrobothnia. Journal of Telemedicine and Telecare, 15: 68-72, 2009

Repeatability of Pressure Oscillation Amplitudes during the Interrupter Measurement of Respiratory Resistance

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Abstract— **Interrupter resistance (Rint) technique for assessing respiratory mechanics requires minimal cooperation and can therefore be successfully performed in young children. Analysis of recorded oscillations of the mouth pressure (Pmo) has been suggested to provide additional indices of change in airway mechanics. The aim of this study was to establish the repeatability of pressure oscillation amplitudes.**

Children performed two sets of Rint measurements. Further analysis of Pmo tracings was performed using MATLAB software. Pmo data were normalized to the last recorded pressure and afterwards oscillation amplitudes (Amp) were found as the difference between the first Pmo maximum and minimum. Intra-measurement repeatability was assessed by the coefficient of variation (CV) and between-test repeatability - by the coefficient of repeatability (CR).

92 young children (aged 3 to 7 years) were studied (49 of them healthy, 18 wheezers and 25 coughers). Median CV values for both measurements were 14% and 15% for Rint, and 14% and 13% for Amp. Our between-test Rint repeatability was similar to that of previous studies (CR was 0.23 $kPa{\cdot}L^{-1}{\cdot}s$ or 33.3% of baseline value). CR for Amp was 0.24 or 27.6% of baseline value. There was no significant difference between groups of children.

We measured short term repeatability for the most simple pressure oscillation amplitude and found that this is similar to Rint repeatability.

Keywords— **airway resistance, interrupter technique, pressure oscillations, amplitude analysis**

I. INTRODUCTION

The diagnosis and monitoring of airway disease in young children is more difficult than in older ages because children under 5-6 years of age can rarely perform repeated forced expirations needed for lung function measurements. A number of techniques applicable to lung function measurement in young children have been introduced several decades ago but these methods did not become popular in clinical physiology for a long time. Automated and portable commercial devices became available later, and because these techniques require passive co-operation only and measurements can be performed in children down to the age of 2 years, these methods have now become more widely used. One of the possibilities is to measure respiratory resistance by the interrupter technique.

The method involves a brief (100 ms) occlusion of the airflow during the tidal breathing while pressure measured at the airway opening equilibrates with alveolar pressure. The interrupter resistance (Rint) can be calculated when dividing the driving pressure by flow at the mouth immediately prior to occlusion. Measurement of Rint has been used to determine bronchodilator response (BDR) and also bronchial hyperresponsiveness (BHR) in young children, and detailed guidelines have been published [1, 2].

Immediately after occlusion, there is a very rapid change in pressure, followed by damped pressure oscillations and finally, there is a relatively slow rise in pressure. In addition to calculating just one Rint value, there have been attempts to pay more attention to the dynamic behavior of oscillations on the mouth pressure-time transient [Pmo(t)] to provide additional indices of change in airway mechanics [3-7]. Different algorithms to find the pressure oscillation amplitudes have been studied, however, the short-term repeatability of pressure oscillations has not been assessed.

The aim of our study was to establish the repeatability of pressure oscillation amplitudes using a commercial device in order to measure reliable baseline values and assess bronchodilator or bronchoconstrictor effects.

II. MATERIALS AND METHODS

A. Subjects

Study subjects were children aged 3-7 years who attended the respiratory outpatients' clinic in Tartu Children's Clinic, healthy siblings or those who came after receiving the invitation sent to local kindergartens. All children had to be free of respiratory tract infection in the preceding 3 weeks and not wheezing at the time of testing.

When attending the study, a questionnaire was completed by parents. Questions about respiratory symptoms, diagnosed asthma, eczema and hayfever were asked. Subjects who reported wheeze during the previous year were classified as "wheezers". Children with recurrent or persistent

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cough (i.e. with at least three coughing episodes in the last 6 months or every day for three consecutive weeks) and with no wheeze during the last 12 months were classified as "coughers".

The Ethics Review Committee on Human Research of the University of Tartu approved the study and written informed consent to take part was obtained from the parents on behalf of their children.

B. Equipment and measurements

Rint was assessed using a single MicroRint device (Micro Medical, UK) throughout the study. During normal and quiet breathing, children performed two sets of Rint measurements (15 min apart). One set consisted of up to 10 interruptions on the peak flow of the expiration.

The valve of such a device closes within 10 ms and remains closed for 100 ms. Sampling frequency of the pressure signal was 2000 Hz. Before the analysis all Pmo(t) graphs were checked using Rida software (Micro Medical, UK). Methodology of interrupter resistance measurement and graph rejection criteria we used have been described by others [8, 9]. For example, manual rejection was performed in case of tracings with a horizontal or declining pressure signal suggesting leakage at the mouth. The mean of 5-10 acceptable readings was taken as a measurement.

C. Data analysis

In addition to absolute Rint values obtained from a MicroRint device we also calculated z-scores [z = (measured value – reference value)/RSD, where RSD is the residual standard deviation in the reference population] using previously published reference data [10].

Further analysis of Pmo(t) tracings was performed using MATLAB (MathWorks Inc., USA). Prior to the oscillation analysis, Pmo(t) curves were normalized by dividing every pressure value by the last recorded pressure of that curve, in order to avoid the possible effect of interruptions occurring at different flows [3-4]. Oscillation amplitude (Amp) was found as the difference between the first mouth pressure maximum and minimum (Figure 1).

Intra-measurement repeatability was assessed by the coefficient of variation (CV) which was calculated for all parameters as the ratio of the standard deviation to the mean of the 5–10 individual readings (in %).

Between-test repeatability was assessed by the coefficient of repeatability (CR): twice the standard deviation of the mean difference between two sets of values. To compare CR for Rint and Amp we also expressed it as a percentage of the baseline value.

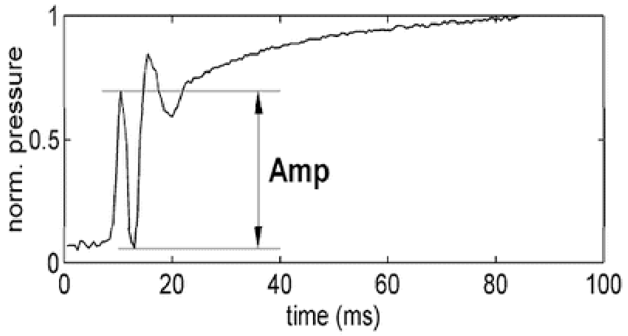

Fig.1 Finding the oscillation amplitude (Amp) as the difference between the first pressure maximum and minimum

To examine whether the variability was independent of the level of Amp, the differences between paired measurements were plotted against their means (Bland-Altman plot).

III. RESULTS

92 young children (aged 3 to 7 years) were studied, their anthropometric data and Rint values in comparison with reference data are shown in Table 1.

Table 1 Anthropometric data and interrupter resistance (Rint) values by groups

	Healhty (n=49)	Coughers (n=25)	Wheezers (n=18)
Male/female	23/26	12/13	12/6
Age* yr	5.9 (0.8)	5.7 (1.2)	5.6 (1.1)
Height* cm	117.2 (4.6)	115.2 (5.3)	116.4 (4.2)
Rint* kPa·L^{-1}·s	0.68 (0.16)	0.68 (0.20)	0.73 (0.27)
Rint z-score*	−0.88 (1.50)	−1.07 (1.49)	−0.70 (2.19)

* mean (SD)

Intra-measurement repeatability: median coefficients of variation for both measurements were 14% and 15% for interrupter resistance (with a range from 5 to 48%), and 14% and 13% for oscillation amplitude (with a range from 3 to 36%). To visualize the repeatability of pressure oscillations, a set of normalized Pmo(t) graphs from one measurement can be seen in Figure 2.

Finite Element Implementation of a Structurally-Motivated Constitutive Relation for the Human Abdominal Aortic Wall with and without Aneurysms

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Abstract— **The structural integrity of the abdominal aorta is maintained by elastin, collagen, and vascular smooth muscle cells. Changes with age in the structure can lead to development of aneurysms. This paper presents initial work to capture these changes in a finite element model (FEM) of a structurally-motivated anisotropic constitutive relation for the "four fiber family" arterial model. First a 2D implementation is used for benchmarking the FEM implementation to fitted biaxial stress-strain data obtained experimentally from four different groups of persons; 19-29 years, 30-60 years, 61-79 years and abdominal aortic aneurysm (AAA) patients. Next the constitutive model is implemented in an anisotropic 3D FEM formulation for future simulation of intact aortic geometries. The 2D simulations of the biaxial test experiment show good agreement with experimental data with a standard deviation below 0.5% in all cases. The maximum axial and hoop stress in the group of AAA patients was 94.9 kPa (±0.283 kPa) and 94.3 kPa (±0.224 kPa) at maximum stretch ratios of 1.043 and 1.037, respectively. In the 3D simulations, the maximum stress is also found to occur in the AAA patient group, with the highest stress in the circumferential direction (275 kPa). Comparison with an already published isotropic model indicates that the latter underestimates the peak stress significantly. Based on these results it is concluded that the four fiber family model has been successfully implemented into a 3D anisotropic finite element model and that this model can provide more accurate insight into the stress conditions in aortic aneurysms.**

Keywords— **Biomechanics, aortic aneurysms, four fiber family model, anisotropic finite element analysis.**

I. INTRODUCTION

The wall of the normal human aorta is a layered structure consisting of three layers; the intima, the media and the adventitia. The primary structural components of the aortic wall are the elastic fibers (elastin and associated microfibrils), collagen fibers and vascular smooth muscle cells (vSMC). With age the structure of the aortic wall changes, it becomes stiffer, and more vulnerable to damage leading to diseases like atherosclerosis and aneurysms. So, it is interesting to construct a simulation model to capture these structural changes and gain more insight into the pathology of these diseases from a biomechanical point of view. The current challenge is to determine the arterial wall stress and strength accurately. This presents some difficulty, because arterial tissue is anisotropic and nonlinear in the stress-stretch relationship, displays pseudo-elastic behavior, and changes material properties with age due to structural change and remodeling. The aim of this work is to implement the structurally-motivated phenomenological "four fiber family" model introduced by Baek et al. [1] for simulation of biomechanical properties in the human aorta with and without aneurysms. As a first step, a 2D finite element model (FEM) implementation is presented and used as a benchmark to numerically reproduce the stress-strain relations obtained in biaxial stress-strain experiments [2,3]. Next, the four fiber family model is implemented in a 3D anisotropic FEM and its ability to reveal detailed stress-strain information in arterial tissue is compared to that of an already published isotropic model [8].

II. MATERIALS AND METHODS

A. Constitutive framework

It is assumed that the aortic wall is a constrained mixture of four locally parallel families of collagen fibers (axial, circumferential, symmetric diagonal) embedded in an amorphous isotropic matrix dominated by elastic fibers. The biomechanical properties of a normal abdominal aorta and an aneurysm are described using the general formulation of the Cauchy stress (true stress) [4]

$$\boldsymbol{\sigma} = -p\mathbf{I} + 2\mathbf{F}\frac{\partial W}{\partial \mathbf{C}}\mathbf{F}^T , \qquad (1)$$

where $\boldsymbol{\sigma}$ [Pa] is the Cauchy stress tensor, p is a Lagrange multiplier, $\mathbf{I}$ is the identity tensor, $\mathbf{F}$ is the deformation gradient tensor, W [Pa] is the SEF and $\mathbf{C}=\mathbf{F}^T\mathbf{F}$ is the right Cauchy-Green tensor. In order for the SEF to be as general as possible the model accounts for compressibility by splitting the SEF in a purely volumetric elastic response, $W_{vol}(J)$, and a purely isochoric elastic response, $W_{iso}(\mathbf{C},\mathrm{M}^{(k)})$ [5],

$$W\left(\mathbf{C},\mathrm{M}^{(k)}\right) = W_{vol}(J) + W_{iso}\left(\mathbf{C},\mathrm{M}^{(k)}\right), \qquad (2)$$

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where J=det($\mathbf{F}$) is the deformed-to-undeformed volume ratio and $M^{(k)}$ being a unit vector describing the direction of orientation of the collagen fiber families. Here the aortic tissue is assumed to be incompressible. To infer incompressibility the so-called penalty method is used in the finite element implementation. Here the tissue is modeled as slightly compressible by applying a very high bulk modulus in the volumetric elastic response, which has the simple form

$$W_{vol}(J) = \frac{\kappa}{2}(J-1)^2, \tag{3}$$

where κ [Pa] is the bulk modulus [4]. The isochoric response is modeled by the four fiber family constitutive relation [1]

$$W_{iso}\left(\mathrm{C}, \mathrm{M}^{(k)}\right) = \frac{c}{2}(I_C - 3) + \sum_{k=1}^{4} \frac{c_1^{(k)}}{4c_2^{(k)}} \left\{ \exp\left(c_2^{(k)} \left(IV_C^{(k)} - 1 \right)^2 \right) - 1 \right\} \tag{4}$$

where c, $c_1^{(k)}$, $c_2^{(k)}$ are material parameters, I_C is the first invariant of $\mathbf{C}$ and $IV_C^{(k)} = M^{(k)}\mathbf{C}M^{(k)}$ is the fourth invariant of $\mathbf{C}$. This model has proven useful by providing increased insight into differences in the mechanical behavior due to structural abnormalities in the arterial wall [6]. For detailed information on the material parameters used in this study we refer to [6]. In brief, the determination of material properties is based on biaxial testing of tissue slabs from four different age/patient groups; 19-29 years, 30-60 years, 61-79 years, and AAA patients. Within each group the mean value of each material parameter is used.

B. Simulation of biaxial and inflation-extension test of arteries

Biaxial tension test of arteries is a well-known method for deducing the biomechanical properties of arteries [7]. Here we have simulated the biaxial testing of both normal abdominal aorta and pathological AAA tissue described by Vande Geest et al. [2,3] using COMSOL Multiphysics v4.1 (COMSOL AB, Stockholm, Sweden). In the simulation a tension value of 120 N/m is applied to the tissue corresponding to the circumferential tension per unit axial length in a thin-walled cylindrical tube pressurized to 113 mmHg, and the resulting stretch ratios and Cauchy stress components in the tissue sample are calculated. The inflation-extension test is also a commonly used experiment for determination of arterial properties, since the normal geometrical configuration of the artery is preserved [4]. Here a uniform internal pressure, $P_i = 15$ [kPa] is applied corresponding to 113 mmHg, which results in a radial force on the interior wall of a circular axis-symmetric cylinder. The cylinder has a radius of 1 cm and a length of 5 cm.

C. Analysis of simulated experiments

The implementation of the four fiber family model involves programming equations (1) – (4) into the finite element program. As the 2D variant of eq. (1) was used by Ferruzzi et al [6] to estimate the parameters of the constitutive model from the biaxial test data, the same equation can serve as a reference for benchmarking a 2D FEM implementation. In this perspective, stress-strain relations computed with a correct FEM implementation should be superimposed on the stress-strain relations calculated by hand using eq. (1). After benchmarking the implementation against biaxial test data the model is tested for predictability in the 3D case by comparing the anisotropic model to the isotropic model proposed by Raghavan and Vorp [8]. In this paper a negative Cauchy stress is interpreted as a compressive stress, and a positive stress is interpreted as a tensile stress. In addition, the unloaded configuration of the tissue is assumed to be stress free.

III. RESULTS

A. Simulation of biaxial test

Comparison of the numerical simulation of the biaxial test and the analytical solution for the Cauchy stress components is shown in Fig. 3. The superimposition of the FEM results on the hand calculated curves confirms a correct FEM implementation of the model. The maximum stress values are seen in the circumferential direction (hoop stress) ranging from 85-175 kPa (638-1313 mmHg) compared to 85-165 kPa (638-1238 mmHg) for the axial direction. The maximum standard deviation was below 0.5% for both the hoop and axial stress; ±0.224 kPa and 0.283 kPa respectively for the AAA patient group, which has the highest standard deviation compared to the other groups (not shown). In general the aortic tissue becomes less compliant with age, and AAA tissue is significantly stiffer than normal abdominal aortic tissue. However, using the mean values of the material parameters indicate that the biomechanical properties of the normal AA for the groups 30-60 years and 61-79 years are similar. The tissue from the group 61-79 years is less compliant in the axial direction compared to the group of 30-60 year-olds. But in the circumferential direction the difference is minimal. This clearly shows that the anisotropy of the aortic tissue is captured by the constitutive relation, since the stretch ratios in the two directions are different from each other for all four groups of test subjects.

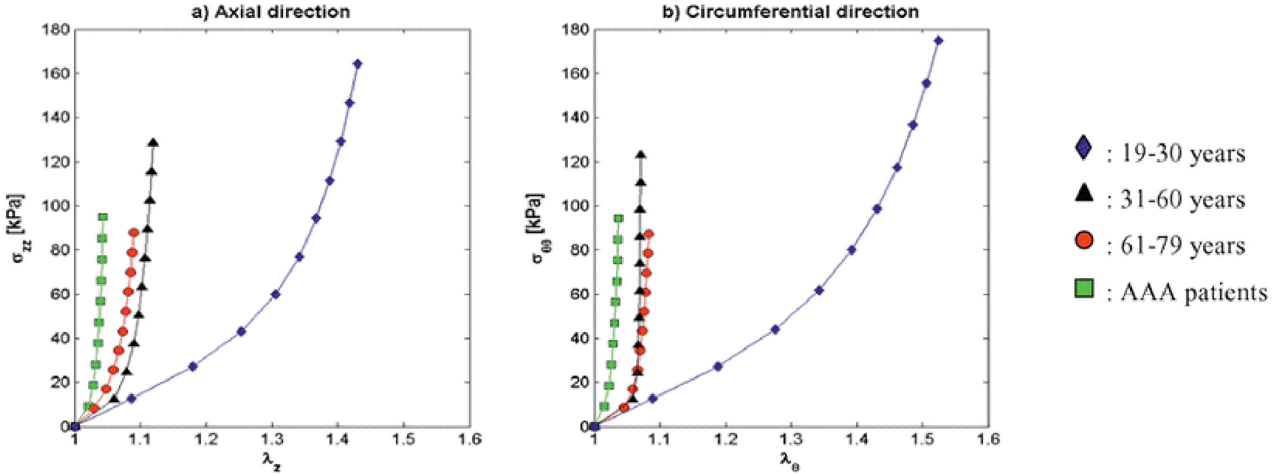

Fig. 1 Stress-stretch plot comparing the known analytical solution for biaxial loading. (a) shows the axial Cauchy stress (σ_z) as a function of axial stretch ratio (λ_z) for all four patient groups. (b) shows the Cauchy hoop stress ($\sigma_{\theta\theta}$) as a function of circumferential stretch ratio (λ_θ) for all four patient groups. The solid lines are the solutions of the experimental fit, and the symbols indicate the numerical solution.

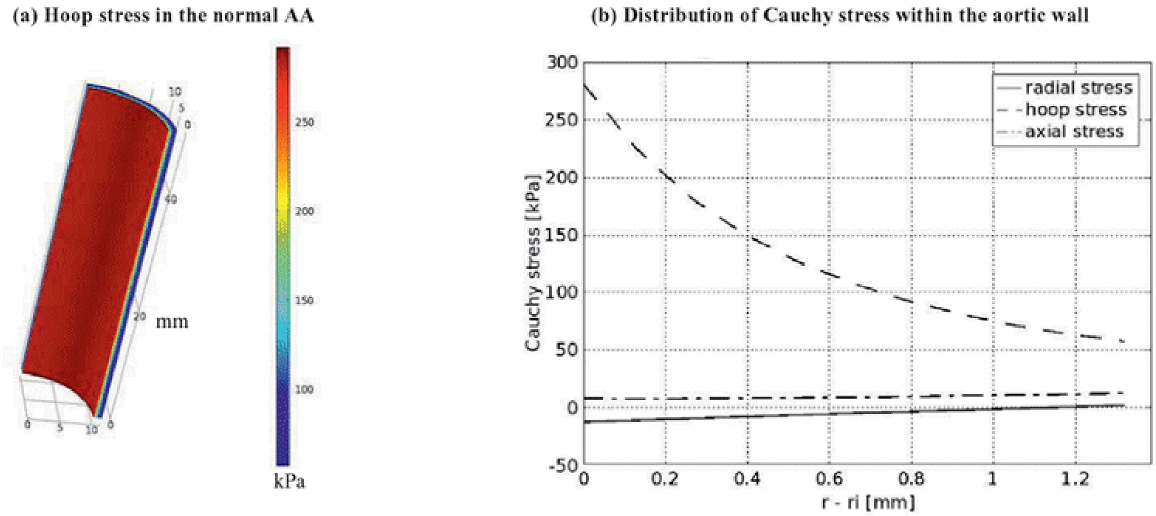

Fig. 2 (a) simulated inflation-extension experiment showing the amount of hoop stress within the aortic wall for the AAA patient group. (b) shows the stress distribution within the aneurismal wall for the AAA patient group. The dashed line is the hoop stress, the dash-dot line is the axial stress, and the solid line is the radial stress.

B. Simulation of inflation-extension test

The four fiber family constitutive relation was implemented in an anisotropic 3D FE model and applied to a circular, axis-symmetric cylinder. To exploit symmetry only one quarter of the cylinder is simulated. The simulation result for the hoop stress is shown in Fig 2a for the AAA patient group. A maximum hoop stress of 275 kPa is seen at the innermost part of the cylinder, and 60 kPa at the external part of the cylinder. With the new 3D model it is possible to investigate the anisotropic nature of the stress distribution within the aortic wall for the AAA patient group (see Fig 2b). The largest stress component is the hoop stress. The axial stress is almost constant varying from 8-10 kPa, and the radial (outward) stress is 15 kPa at the inner wall, corresponding to 113 mmHg, and zero at the external part of the wall. Comparing the results of the anisotropic model to the isotropic model for AAA tissue suggested by Raghavan and Vorp [8] (results not shown) the isotropic model underestimates the magnitude of the stress components within the wall (peak hoop stress is 70 kPa) and the change in stress distribution within the wall is more uniform within the aortic wall.

IV. DISCUSSION AND CONCLUSION

In this paper a finite element implementation of the four fiber family constitutive relation in COMSOL Multiphysics is presented. When the condition of plane stress is secured in the biaxial test protocol, the axial and circumferential Cauchy stress components can be deduced analytically. The analytical model represented by eq. (1) serves a dual purpose. First, it can be used to fit parameters of a strain energy density function to experimental data and thereby provide a constitutive model for the stress-strain relationship. Secondly, the analytical model can serve as a reference for benchmarking numerical models such as finite element models. The former application was used by Ferruzzi et al [6] to develop a constitutive anisotropic model of arterial tissue from biaxial test data obtained by Vande Geest et al. [2]. The latter application was used successfully in this paper to benchmark an implementation of the four fiber model in the finite element program COMSOL Multiphysics. The use of mean values of the material parameters in finite element models is common [10]. But here the mean values indicate that there is not a significant difference between the groups of 31-60 years and 61-79 years in the biomechanical properties. This is surprising due to a significant difference in mean age (43 and 70 years respectively). The number of subjects in each group is the same with similar distribution among the sexes. This raises the question whether the division in the current age groups is suitable. An alternative could be to subdivide the group of 31-60 year-olds into smaller intervals of five or ten years, since it seems that the most significant change in arterial structure takes place in this period. Another possibility is to use the median of the material parameters, since this would eliminate the effect of outliers in the different patient groups. This exploration of the parameter space, together with extension of the mechanical tests to include inflation-extension tests of both normal abdominal aortic and aneurismal tissue, could improve the current model. In addition, with these improvements it might also be possible to obtain more complete knowledge about when the critical damage to the aortic tissue is most likely to occur. The model considered here is purely passive and does not account for the contribution from activation of vascular smooth muscle cells. The reasons for not including the active part are two-fold. There is lack information on the change in smooth muscle activity in normal AA. Secondly, AAA contains limited amounts of smooth muscle cells, [4,6].

Extending this finite element implementation to patient-specific model geometries with matching patient-specific blood flow will give the clinician a very powerful tool for detailed evaluation of AAAs.

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REFERENCES

1. Baek S, Gleason RL, Rajagopal KR, Humphrey JD (2007) Theory of small on large: Potential utility in computations of fluid-solid interactions in arteries. Comput Method Appl M 196:3070-3078
2. Vande Geest JP, Sacks MS, Vorp DA (2004) Age dependency of the biaxial biomechanical behavior of human abdominal aorta. J Biomech Eng – T Asme 126:815-822
3. Vande Geest JP, Sacks MS, Vorp DA (2006) The effect of aneurysm on the biaxial mechanical behavior of human abdominal aorta. J Biomech 39:1324-1334
4. Humphrey JD (2002) Cardiovascular solid mechanics: cells, tissues and organs. NY:Springer, New York
5. Holzapfel GA (2000) Nonlinear solid mechanics – a continuum approach for engineering. John Wiley& Sons, Chichester
6. Ferruzzi J, Vorp DA, Humphrey JD (2010) On constitutive descriptors the biaxial mechanical behavior of human abdominal aorta and aneurysms. J R Soc Interface DOI:10.1098/rsif.2010.0299
7. Sacks MS (2000) Biaxial mechanical evaluation of planar biological materials. J Elasticity 61:199-246
8. Raghavan ML, Vorp DA (2000) Toward a biomechanical tool to evaluate rupture potential of abdominal aortic aneurysm: identification of a finite strain constitutive model and evaluation of its applicability. J Biomech 33:475-482
9. Humphrey JD, Taylor CA (2008) Intracranical and abdominal aneurysms: similarities, differences, and need for a new class of computational models. Annu Rev Biomed Eng 10:221-46
10. Vorp DA (2007) Biomechanics of abdominal aortic aneurysm. J Biomech 40:1887-1902

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Assessment of the Optical Interference in a PPG-LDF System Used for Estimation of Tissue Blood Flow

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Abstract—**The aim of this study is to assess the optical cross interference in a system including laser Doppler flowmetry (LDF) and photoplethysmography (PPG) with regard to the illuminating power of PPG-LEDs and distance between the light detector/s and light source/s.**

Reduced or missing blood perfusion can lead to pressure ulcers. Monitoring changes in blood flow in areas prone to pressure ulcer development would be a valuable tool for prevention of pressure ulcer development.

The probe, with one to two LDF-channel/s and two PPG-channels (PPG$_G$/560 nm and PPG$_{IR}$/810 nm), covers 10 cm x 10 cm. Influence from PPG-LEDs to the LDF-system and influence from the LDF-laser to the PPG-system was investigated. Three different light intensities were used for the PPG-LEDs.

Recordings were repeated using two different placements of the LDF-fibre, changing the distance between light source/s and light detector/s of the reciprocal technique.

The LDF did not show any influence from light from the PPG.

PPG$_G$ is more affected by laser light than PPG$_{IR}$. Laser light influenced PPG$_G$, most at lowest intensity of the PPG-LEDs. The influence of the laser light to the PPG-channels is less in the outer position of the LDF-fibre.

Interference can be totally avoided by switching, only measuring by one technique at a time. Rapid flow changes are then not possible to monitor fully. When rapid blood flow variations at different vascular depths are of interest to monitor, placement of the LDF-fibre in the outer position and use of a higher light intensity of the PPG-LEDs might be an alternative. However, interference still can be present, and further, the measurement volume of LDF will be different from that covered by PPG-channels.

Keywords—**PPG, LDF, interference, peripheral flow, pressure ulcer**

I. INTRODUCTION

Local damage to skin and tissue in combination with reduced or missing blood perfusion can lead to pressure ulcers. The prevalence of pressure ulcers in hospitals in five European countries was estimated to 18 % 2006 [1]. A system giving the possibility to monitor both slow and fast blood flow changes in areas prone to pressure ulcers development would be a valuable tool for prevention. It is of interest to monitor both fast and slow blood flow changes at several vascular depths.

For none invasive tissue blood flow measurement we combined two methods: laser Doppler flowmetry (LDF) [2] and photoplethysmograpy (PPG) [3].

LDF is a technique utilizing monochromatic laser light for assessing the microcirculation of a small volume, less than 1 mm^3 according to Monte Carlo simulations [4]. The light is emitted through an optical fibre and scattered. Some of the light is reflected by moving red blood cells and the frequency is shifted. The frequency shift is used to estimate the total perfusion of the underlying tissue. The perfusion is presented in arbitrary units scaling linearly to the velocity and concentration of red blood cells.

PPG is based on absorption of light in tissue and blood. Monochromatic light illuminates the tissue and back reflected light is collected by a photo detector. Variations in the signal correlate to changes in several parameters, whereof pulsative changes in blood volume and blood flow are regarded as most important. Different wavelengths of the light and different distance between light source and detector can be utilized to monitor different tissue volumes (typical depths 5-20 mm) [5].

A probe combining PPG and LDF has previously been developed and evaluated regarding the ability to discriminate between blood flows at different tissue depths [6]. It was, however, fixed in a wooden frame making it stiff and having a linear sensor configuration. A new flexible probe has been developed with the PPG-LEDs arranged to cover a measurement area of 10 cm x 10 cm. Initial tests of this new probe has been performed [7], but also called for further investigations. The aim of the present study is to assess the optical cross interference between the PPG- and LDF-channel/s in the multi-technique system with regard to the illumination power of PPG-LEDs and distance between the light detector/s of and light source/s of the reciprocal technique.

II. MATERIALS AND METHODS

A. Optical probe

The layout of the probe is a matrix of LEDs of two different wavelengths surrounded by five photo detectors at

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