Abstract. Lymphoedema can be a side effect of cancer treatment. Eventhough several methods for assessing lymphoedema are used in clinical practice, an objective quantification of lymphoedema has been problematic. The aim of the study was to determine the objectivity, reliability and repeatability of the computer aided measurement laser (CAML) technique. CAML technique is based on computer aided design (CAD) methods and requires an infrared laser scanner. Measurements are scanned and the information describing size and shape of the limb allows to design the model by using the CAD software. The objectivity and repeatability was established in the beginning using a phantom. Consequently a group of subjects presenting post-breast cancer lymphoedema was evaluated using as a control the contralateral limb. Results confirmed that in clinical settings CAML technique is easy to perform, rapid and provides meaningful data for assessing lymphoedema. Future research will include a comparison of upper limb CAML technique between healthy subjects and patients with known lymphoedema.

1. Introduction
Lymphoedema is a condition of localized fluid retention and tissue swelling due to the accumulation of high molecular weight protein fluid in the interstitial spaces of the affected body part. It is caused by a compromised lymphatic system and can be a side effect of cancer treatment. Often, following breast cancer surgery, for the purpose of local radicality and cancer staging, an axillary lymphadenectomy is performed. The removal of axillary lymph nodes is a predisposing factor to ipsilateral upper limb lymphoedema. However other factors, such as local radiation therapy or cancer progression, may be responsible. Lymphoedema is not the swelling which may occur immediately after surgery and may be present at the post-operation visit, it is a chronic condition that, if ignored, can lead to immobilization and severe infections [1]. These complications can worsen the physical and psychological strain of dealing with breast cancer and significantly impact the quality of life of the patients [2]. Even though several methods for assessing lymphoedema can be used in clinical practice and are reported in literature, an...
objective quantification, in particular for volume measurements, has been challenging [3] [4]. Despite the fact that various measurement approaches and criteria have been applied, there is no gold standard for measuring or detecting lymphoedema, therefore assessment and diagnosis has been problematic [5]. Most of the measurements are detected on the most affected part of the limb and compared with a control [6]. Finding a 2cm difference or more in limb girth between the affected and non-affected limbs usually guarantees a clinical diagnosis of lymphoedema. Other documented methods of diagnosis measure a 200ml limb volume difference or a 10% limb volume change from baseline and/or between limbs as well as self-reported signs and symptoms [7] [8]. Although these methods can provide data, they also can be time consuming, complicated, expensive or inaccurate. Increased measurement accuracy can improve lymphoedema incidence and prevalence understanding and assist treatment intervention decisions [9].

In clinical practice circumferential measurements are mostly used because they are easy to perform and allow for use of the contralateral limb as a control [10]. However, its objective quantification, especially volume, has always been tricky [11]. The Computer Aided Measurement Laser (CAML), a 3D laser scanning technology, suggests a more sensitive and accurate method that could provide a fast, precise and non invasive technique to quantify upper arm lymphoedema. This technique is based on infrared laser scanning and computer aided design (CAD). Measurements are collected by the laser that scans the object in real-time and then used to design a 3D model of the item using CAD. The aim of this study is to determine the objectivity, reliability and repeatability of the CAML technique in the diagnosis and assessment of upper arm post-breast cancer lymphoedema.

2. Materials and Methods
CAML technique requires an infrared laser scanner and a CAD system. The 3D laser scanner analyzes a real-world object and collects data on its size, shape and appearance. This data can then be used to design a digital 3D model of the tested limb using CAD. The non-contact active scanner, in order to probe an object, emits light and detects its reflection. Laser scanners can send trillions of light photons toward an object and only receive a small percentage of those photons back via optics. Laser flow rate depends on the type of material struck by the beam. Concerning the laser wavelength, the reflectivity of the material changes: greater the reflectivity, greater the flow rate, while lower the reflectivity, therefore greater the proportion of energy absorbed, lower the flow rate. While white surfaces reflect light, black surfaces reflect only a small amount and transparent objects refract the light, therefore laser scanners collect information about surfaces that are not obscured. Optical technologies, however, encounter many difficulties with shiny, mirroring or transparent objects that can change their reflectivity and give false 3D information. A scanning laser system provides, as a direct result of the measurement session, a set of three-dimensional coordinates. 3D scanners collect distance information about surfaces within their field of view and describe the distance to a surface at each point in a local coordinate system relative to the scanner. These coordinates identify a large number of points (point cloud) that define the surface of the scanned object. Laser scanning systems are fully automatic and are able to acquire a considerable number of points per second, sometimes even in the thousands, allowing to operate on small distances offering high accuracy. The purpose of a 3D scanner is to create a point cloud of geometric samples on the surface of the subject. These points are used to extrapolate the shape of the subject, a process called modelling, with CAD software. The information gathered from scanning defines size and shape of the limb. These data are processed, allowing to create a model through which we can determine circumferential and limb volume measurements. Reliability and repeatability of CAML method was initially determined using phantoms and then evaluated on a group of patients presenting post-breast cancer upper limb lymphoedema. In this study the Physical and Rehabilitation Medicine Chair and the Medical Engineering Service of the Tor Vergata University in Rome in collaboration...
with the Reha Group O&P Center used the FastSCAN Cobra handheld laser scanner built by Polhemus to scan the phantoms and the upper arm of the enrolled patients. The FastSCAN works by projecting a fan of laser light on the object while the camera views the laser to record cross-sectional depth profiles. 3D surfaces are instantly acquired gathering measurements by sweeping a handheld laser scanning wand over an object. The finished scan is processed to combine any overlapping sweeps, significantly reducing the time to develop surface models. A full three-dimensional surface of the object is reconstructed in real-time, without the need to place untidy or unwanted registration marks on the object itself. This 3D data is then exported to a host computer with 3D CAD programs. FastSCAN resolution along the laser line depends on wand-object range, typically 0.5mm to 200mm. Scanning rate is 50 lines/second and line-to-line resolution depends on wand movement, usually 1mm at 50mm/second. Scanning range from wand to transmitter and/or receiver to transmitter can be selected from a radius up to 75cm. Operation in presence of metal objects or electromagnetic fields may interfere with the scanner’s tracking and degrade performance. Therefore transmitter, wand and receiver must be kept sufficiently far from metal objects or fields. The FastSCAN system includes a System Electronics Unit, a power supply, a receiver and a transmitter. The Electronics Unit contains the hardware and software necessary to generate and sense the magnetic fields, compute position and orientation, control the handheld laser scanner and the interface with the host computer. The transmitter is a triad of electromagnetic coils, enclosed in a plastic shell, that emits the magnetic fields. Handheld laser scanner contains the laser unit, a video camera which records the three-dimensional surface of the scanned object, and the receiver, which detects the position of the scanner. The reliability and repeatability of the CAML method were initially determined using two truncated cone-shaped phantoms, made using a lathe. These two cones of 34cm height and 14.5cm small diameter, differ having a greater diameter of 20.5cm and 35cm (Fig.2). 53 scans were performed from which, using the CAD software, it was possible to determine the volumes of the cones and the circumferences’ values of the upper and lower surfaces of the two cones. These were compared with the cone values measured, to determine the accuracy. In addition we analyzed the possible covariates, such as the different operators who performed the scan and the different days of measurements, to confirm the objectivity of the measure. In a second phase of the project CAML technique was evaluated on a group of patients presenting post-mastectomy upper limb lymphoedema, using the contralateral limb as control. In this analysis the actual presence of lymphoedema has been verified by comparison with the healthy limb. In order to validate the objectivity, reliability and repeatability of the CAML technique in the diagnosis and evaluation of upper arm post-mastectomy lymphoedema, a statistical analysis of data was carried out using calculating and STATA/SE softwares.

3. Results

For what concerns the phantoms, reliability was measured and confirmed comparing the scanned measurement values with the numerical values calculated. The normalized data obtained were analyzed using the one-tailed t-test with a 0.05 alpha value, assuming an acceptable error value
of 2% (Fig. 3). 94% of the normalized data, indicating the measurement error, were found to be less than the chosen error value. Therefore the method is able to provide reliable measures of circumference and volume.

Regarding the determination of repeatability, circumference and volume measures of the phantoms were analyzed with the ANOVA test, as a function of the two covariates, operator and time. For what concerns the circumferential analysis only time was used as covariate, while in the volume analysis both covariates were studied. A One-way ANOVA test with Bonferroni correction was performed for the covariate time. Results showed a value of $F = 1.55$ for the circumferences and a value of $F = 2.41$ for volumes. For volume data both covariates, operator and time, were considered in the two-way ANOVA test. Results determined a value of $F = 0.98$. By comparing these $F$ values with the $F$ critical values from the known statistical tables, a statistical significance wasn’t obtained. This confirmed that the mean values between groups are the same and therefore the repeatability of the measure is established. A statistical analysis of the data obtained from the upper limb measurements of patients with post-mastectomy lymphoedema was also performed (Fig. 4). In this case the volume values of the limb affected by lymphoedema were compared with those of the healthy contralateral limb by using the one-tail $t$ test. A significant statistical difference was shown ($p = 0.029$), confirming an increased volume of the limb presenting lymphoedema.

Figure 2. Phantom used to determine measurements’ repeatability and reliability and image of the scanned limb model obtained with CAML technique.

Figure 3. Reliability results.

Figure 4. 3D Model and Mesh of the limb affected by lymphoedema and its contralateral obtained with CAML technique.
4. Conclusions

Upper limb lymphoedema is a distressing sequel of breast cancer treatment. If upper limb volume discrepancies are detected in early post-mastectomy lymphoedema, treatment may be instituted quickly, leading perhaps to a lesser impact on the patient’s quality of life and body image. In order to gauge the efficacy of upper limb lymphoedema treatment, limb circumference and volume need to be measured. Accurate, valid, reliable, specific, sensitive and practical tools are required to measure upper limb volumes. CAML technique provides meaningful circumferential and volume data to evaluate post-breast cancer upper limb lymphoedema through a quick and easy implementation. The CAML method is able to determine circumference measures, comparable to data obtained with circumferential measurements, but with minimal margins of error. Above all CAML provides measures of volume, parameter that allows objective quantification of lymphoedema and that is usually difficult to calculate. Future research will aim to study this technique by comparing upper limb CAML data between healthy subjects and patients with known lymphoedema.

References

[1] Armer J M, Stewart B R and Shook R, 2009 Occurrence of Lymphedema Continues To Increase Twelve to Thirty Months after Breast Cancer Treatment, Cancer Res 69 (24) Suppl Abstract nr 2070
[2] Cormier J N, Xing Y, Zaniletti I, Askew R L, Stewart B R and Armer J M, 2009 Minimal limb volume change has a significant impact on breast cancer survivors, Lymphology 42 (4) pp 161–75
[3] Sander A P, Hajer N M, Hemenway K, Miller A C, 2002 Upper-extremity volume measurements in women with lymphedema: a comparison of measurements obtained via water displacement with geometrically determined volume Phys Ther 82 pp 1202–12
[4] Ridner S H, Montgomery L D, Armer J M and Stewart B R, 2007 Comparison of upper limb volume measurement techniques between healthy volunteers and individuals with known lymphoedema Lymphology 40 1 pp 35–46
[5] Armer J M and Stewart B R, 2005 A comparison of four diagnostic criteria for lymphoedema in a post-breast cancer population Lymphat Res Biol 3 (4) pp 208–17
[6] Taylor R, Jayasinghe U W, Koelmeyer L, Ung O, Boyages J, 2006 Reliability and validity of arm volume measurements for assessment of lymphedema Phys Ther 86 (2), pp 205–14
[7] Armer J M, Stewart B R and Shook R, 2009 Breast cancer survivors often meet multiple criteria for lymphoedema Cancer Res 69 (24) Suppl Abstract nr 2074
[8] Armer J M, Stewart B R and Shook R, 2009 30-Month Post-Breast Cancer Treatment Lymphoedema J Lymphoedema 4 (1) pp 14–18
[9] Armer J M, 2005, The problem of post-breast cancer lymphedema: impact and measurement issues Cancer Investigation 23 (1) pp 76–83
[10] Brown J A, 2004, Clinically useful method for evaluating lymphoedema Clin J Oncol Nurs 8 (1) pp 35–8
[11] Deltombe T, Jamart J, Recloux S, 2007, Reliability and limits of agreement of circumferential, water displacement and optoelectronic volumetry in the measurement of upper limb lymphedema Lymphology 40 pp 26–34