IMAGE ANALYSIS OF THE HUMAN FETUS AND NEWBORN – DEVELOPING NEW CLINICAL TOOLS FOR PERINATAL CARE

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ABSTRACT

It is an exciting time for imaging in perinatal care. Technical advances in imaging technology mean that good quality clinical 3D ultrasound images of the growing fetus can be acquired from an early gestational age (GA) (11 weeks GA onwards). With the help of advances in MR-based reconstruction which compensate for fetal motion, high quality images of the fetal brain (and other organs) can be obtained which are providing, on the one hand exciting visualizations of the developing brain, as well as are leading to the introduction of fetal MRI into clinical practice for assessing the health of the fetus from around 24 weeks GA. The Oxford Biomedical Image Analysis Laboratory has been developing a program of research on image analysis for perinatal care over the last 3-5 years. This paper summarizes some of our recent published findings, and suggests some future directions of research.

Index Terms— fetal imaging, human development, obstetrics imaging, perinatal care.

1. INTRODUCTION

Perinatal care deals with the period of approximately 5 months before birth to 1 month after. Clinicians monitor pregnancies in this period if, for instance, biometry suggests that the fetus is small for gestational age (SGA), it is a multiple pregnancy, the mother shows risk factors such as high blood pressure (which may lead to pre-eclampsia), or some other pregnancy complication arises. The use of image analysis to support perinatal care remains very rudimentary, and well below the sophistication we see supporting other areas of medicine such as oncology, neurology and cardiovascular medicine. In part this is because the object of interest (the fetus) can be relatively difficult to image (due to such factors as the mother's BMI, position of the placenta and fetal motion), and the area of medicine has depended largely on 2D ultrasound imaging until relatively recently. In the case of the latter, skill (and time) is required to accurately find good diagnostic (biometry) 2D planes, and the image analysis challenge is to automatically measure standard biometry measurements such as biparietal diameter (BPD), head circumference (HC), abdominal circumference (AC), crown-rump length (CRL), femur length (FL) as well as a clinical expert (see ISBI 2012 Challenge "Challenge US: biometric measurements from fetal ultrasound images"). With the advent of 3D obstetric ultrasound (including recent introduction of matrix technology probes), and advances in fetal MR reconstruction methods, the quality of information that can be provided by imaging for perinatal care is significantly improving. This poses the question as to how these new imaging technological advances, which provide volumetric images, in conjunction with image analysis can be used to improve perinatal care. At least in the forseeable future, perinatal imaging will remain dominated by ultrasound imaging, due to cost and the high through-put demands of most maternity departments in hospitals. But when you can safely acquire volumetric ultrasound scans readily throughout pregnancy (or in most cases at least to 34 weeks), can see more in an ultrasound scan than ever before, and can perform multimodality (MR-US) alignment of the fetus, it provides the opportunity to take a fresh look at the management of women during the perinatal period. We look at some of the image analysis solutions we are developing towards this goal in the next section (Section 2).

2. IMAGE ANALYSIS TOOLS FOR IMPROVING PERINATAL CARE

Ultrasound image analysis has been an important tool in obstetrics for many years with a number of automated methods proposed for biometric measurements in the 18-22 week GA period (the abnormality scan). However, looking outside this GA window, as the fetus grows beyond around 24 weeks the quality of the scan decreases and hence measurement accuracy decreases, and in the brain for instance, new structures become visible with increased GA, and tissue composition changes. This makes it difficult to develop a single image analysis solution for a given

measurement task that works across GA which would be the ideal scenario. At Oxford, this has led us to investigate machine learning approaches to ultrasound image analysis. In an attempt to help standardize image appearance we make use of fusion ultrasound (compounding of multiple ultrasound scans) wherever possible, as well as have found the use of local phase as an image feature leads to superior image segmentation/quantification results than intensity-gradient based analysis alone.

2.1. Quantitative Volumetric Analysis (3D Biometry)

Ultrasound imaging is most widely used in obstetrics for fetal biometry. However, automating fetal biometry is non-trivial because of the varying quality of fetal ultrasound scan, and characteristic ultrasound artefacts (e.g. shadowing, missing boundaries) which results in most classic image segmentation methods failing.

In [1,2] we were posed with the problem of estimating the volume of the femur for a clinical study looking at the effect of vitamin D supplement on bone development of the fetus and newborn. 3D ultrasound scans of the fetal femur were available of varying quality. The boundary definition of the femur was also generally low suggesting an edge-based approach would not work well. We developed instead an efficient volumetric segmentation solution using 3D Fast Weighted Random Forests [1].

2.2. Neuro-Sonography

The identification of fetal brain structures is an essential part of basic prenatal screening for abnormalities [3] as well as necessary for accurate estimation of fetal head circumference, which is used in dating pregnancies beyond 14 weeks. Finding such structures is not straightforward, particularly from 3D scans, and is highly subjective since the visibility of fetal brain structures is determined by factors including ultrasound machine settings, maternal tissue, orientation of the fetus, and sonographer experience.

In [4] we present results of a novel study looking at machine learning (specifically a solution based on the Random Forests framework) to detect key *local* brain fetal structures that define the diagnostic planes used in fetal neuro-sonography, Fig 1. This work is interesting as it provides insight into which local structures can be reliably detected in scans. This has important implications for both automated analysis/measurement and registration tasks.

2.3. Perinatal Image Analysis

Soft tissue measurement in the fetal limbs has been shown to correlate with fetal nutritional state, and its quantification is hypothesized to be a good indicator of fetal growth [5]. Although fetal MRI has superior tissue differentiation that fetal ultrasound, it would clearly be desirable from a clinical management perspective to estimate fetal adipose tissue volume from ultrasound scans. This has led us to develop a novel method for segmentation of 2D ultrasound images of

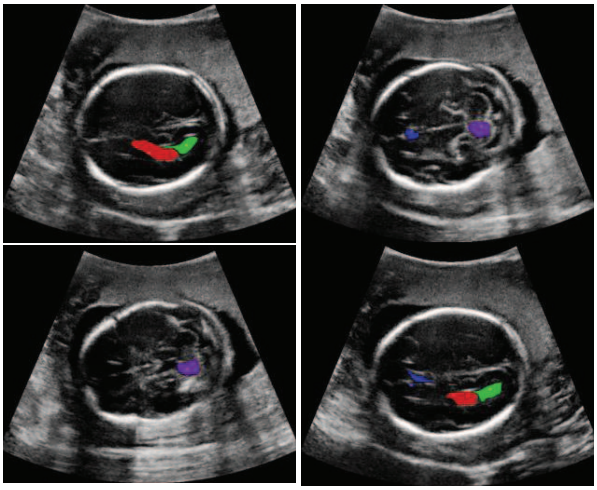


Figure 1. Automatic detection on 2D slices from 3D volumes. Colors represent the manual delineation of structures while the small brighter color square is the automatically detected position of a structure. Color codes are green for choroid plexus, red for posterior ventricle cavity, blue for cavum septum pellucidum and purple for cerebellum (from reference [4]).

the fetal arm based on the fuzzy connectedness framework, Fig 2 and [6]. This approach uses local phase and feature-asymmetry to define the affinity function, shape-based boundary completeness and regularization based on mean-curvature flow. First results reported in [6] indicate this approach works well across a wide GA range [21-30 week healthy subjects were used in that study]. Extending the method to 3D and comparison of measurements from healthy and intra-uterine growth restricted (IUGR) fetuses is the subject of on-going work.

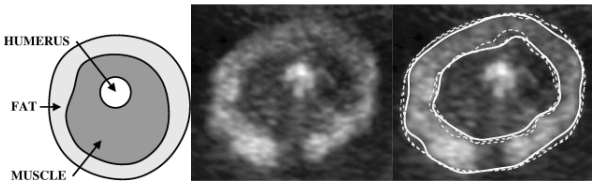


Figure 2: From left to right: Schematic of the fetal arm, fetal ultrasound scan, and delineation of fetal adipose tissue using the method of [6]. In the right-most sub-figure: automatic segmentation (continuous line) and manual segmentation (dashed line).

2.4. Analysis of the Placenta

Much of the focus in perinatal care is on the health of fetus and newborn but the health of the mother and placenta clearly cannot be over-looked. Conditions such as pre-eclampsia and the likelihood of a SGA baby can be related to the health of the placenta. Traditionally placental health has been assessed by either measuring uterine artery blood

flow or estimating its size from 2D or 3D ultrasound; a small placenta being indicative of likelihood of an SGA baby. However, automating the 3D segmentation of the placenta is non-trivial as the placenta-uterus interface is not always well-defined. In [7] a fast and efficient semi-automatic segmentation method based on the Random Walker algorithm was developed for this purpose which has been validated against manual segmentations and is now in regular use in clinical research studies in Oxford [8]. However, it is placental function rather than anatomy that gives the better indicator of placental health. This requires looking at the flow of blood through, for instance, spiral arteries using color or power Doppler. This is non-trivial to do for two reasons. First, we are interested in visualizing flow across surfaces of the placental-utero anatomy which are not well-aligned with the (x,y,z) geometry of conventional image acquisition. To address this we have developed a novel visualization technique based on surface parameterization [9]. Secondly, standardizing power Doppler flow measures to make them quantitative and allow comparisons across GA is problematic. Developing methods to do this from 3D power Doppler ultrasound is the subject of on-going research.

3. SUMMARY

This paper has summarized recent work by the Oxford group and clinical collaborators in the area of perinatal image analysis which aims to provide obstetricians and neonatologists with new image-based information and tools for perinatal care and monitoring. Our research is ultrasound-based, and thus naturally fits in with current clinical practices both in the developed and resource-constrained world where the solutions may have clinical value. However, we are only scratching at the surface of problems that might be looked at in the future. Multi-modality image analysis [10], new image-based biomarkers of nutrition and metabolism, and longitudinal image analysis are all likely to become active areas of research in the future. Underpinning the success of these needs to be an investment in carefully conducted large clinical imaging studies to both understand healthy pregnancy as well as to characterize common problems in pregnancy. Intergrowth-21st [11] provides one such important study, but from an image analysis perspective, we need other large scale multi-modality studies to be done to provide research databases for the image analysis community to work on collectively to develop new clinical tools for perinatal care.

4. ACKNOWLEDGEMENTS

JAN acknowledges the financial support of the NIHR funded Oxford Biomedical Research Centre Women's Health Theme, and the Oxford Centre of Excellence in Personalized Healthcare funded by the Wellcome Trust and EPSRC under grant number WT 088877/Z/09.

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