Building Intrapartum Research Through Health – an interdisciplinary whole system approach to understanding and contextualising physiological labour and birth (BIRTH)

(COST Action IS1405)

Report of the Short Term Scientific Mission (STSM)

"An analysis of cardiotography (CTG) biosignals by utilising complexity algorithms to quantify, correlate and predict fetal movement"

Investigator: Dr George Tzagkarakis
R&D dept. Constrat Ltd, Greece / Dept. Electr. Eng. TEI of Crete, Greece

Date of STSM: 12th November – 18th November 2017

HOST Site: Queen's University Belfast, School of Nursing and Midwifery, Belfast

Host Person in Charge: Dr Maria Healy

Table of Contents **Page No.**

1. Background and research protocol 3
1.1 Introduction 3
1.2 Aim of the study 4
1.3 Methods 5
1.4 Signals' analysis 5
References 7
2. Description of activities performed during STSM 10
Day 1: November 12th 10
Day 2: November 13th 10
Day 3: November 14th 11
Day 4: November 15th 11
Day 5: November 16th 13
Day 6: November 17th 13
Day 7: November 18th 13
3. Findings of the STSM – Future collaboration 14
Further Collaboration 14
Conclusion 14
4. Confirmation from Host of successful execution of the STSM 15
5. Photo Gallery 15

1. Background and research protocol

1.1 Introduction

Electronic fetal monitoring (EFM) or cardiotocograph (CTG) is a technical recording of the fetal heart rate and uterine contractions, undertaken during pregnancy or labour to assess fetal wellbeing. Since its first introduction in the 1960s, CTGs have become widely used by obstetricians and midwives for high-risk pregnancies as a screening tool to detect fetal hypoxia. Internationally, some maternity units have adopted the policy of utilizing continuous EFM for most women during labour, although intermittent auscultation with a doptone or pinard is recommended to assess fetal heart rate of all low risk women. A CTG should be undertaken for 20 minutes however, if concerns arise from intermittent auscultation followed by an assessment to determine if the CTG can be discontinued or should be continuously used throughout labour [1-6].

To provide guidance on the use of a CTG, NICE [6] recently published a guideline including principals for interpretation of a CTG trace. Hourly assessment and documentation of all four features on a CTG is recommended, these include: baseline fetal heart rate, baseline variability, presence or absence of decelerations and presence of accelerations. Following interpretation the midwife and/or obstetrician needs to decide if the CTG is normal/reassuring, non-reassuring or abnormal.

Normal baseline FHR is between 100-160 beats per minute. Baseline is considered as one of the fundamental features of the FHR pattern recognition, as most of the other features rely on its value. Variability is believed to reflect the interactions between the sympathetic nervous system (SNS) and the parasympathetic nervous system (PSNS) of the fetus. Stimulation of the PSNS results in a decrease in heart rate of the normal fetus while stimulation of the SNS results in an increase in heart rate. During stressful situations for the fetus, such as during uterine contractions, the sympathetic nerves may act as a compensatory mechanism to improve the fetal heart pumping activity, which is reflected in the FHR signal variations. Variability can also be identified as the resting level of the fetal heart rate [7-8].

Assessments of fetal wellbeing often include the monitoring of the fetal heart rate (FHR), fetal growth and fetal movement (FM) [7-10]. Fetal movement has long been recognised as an indicator of fetal wellbeing [9] in particular, an increase in fetal activity of frequency and strength through the last trimester [10]. CTG is not a usual method to directly assess FMs, although it is the primary method of antenatal fetal monitoring, especially when the woman has reported reduced FMs after 28 weeks gestation [4-5]. Before 28 weeks gestation the features on a CTG cannot be interpreted accurately because of the underdeveloped fetus [4,11]. Research has confirmed the association of maternal perception of reduced fetal movement and the risk of late stillbirth [10]. Analysis of fetal movement is therefore an integral part of a fetal wellbeing assessment.

A CTG has both strengths and limitations, including: the high sensitivity for identifying fetal hypoxia but also a high “false positive” rate where following assessment at birth (cord ph and APGAR) the infant scores were within normal range. In addition, some maternity care clinicians have difficulty in correctly appraising and interpreting the multiple factors that can affect the features seen on a CTG. Subsequently, the rate of intervention and caesarean sections has dramatically increased over the last four decades without a significant change in neonatal cerebral palsy rates. Maternal morbidity and

mortality has also increased because of the increased intrapartum interventions, for example morbidly adherent placentae [5,12,13].

Today modern CTGs contain an actograph function. This is integrated into the heart rate transducer, which makes it possible to record FHR and FMs simultaneously using a Doppler technique. This allows separation of the high-frequency signals derived from the fetal heart and the low-frequency signals derived from movements of the maternal abdomen and movements of the infant's body and limbs. The presence of low-frequency signals is recorded on the cardiotocographic paper. This way, the observer can be additionally informed through information on the FM pattern, without the need for sonography [14-16]. However, the results, the signals output, are reproduced like bars and spikes, so there is again absence of image, although, two studies reported that the method has the ability to detect fetal limbs movements [15-16]. Also, in another study using actograph, kappa value showed fair and moderate agreement, in women with 31-34 and 37-40 weeks of gestation, respectively. In addition, one limitation of this method is the false-positive detection of FMs that can occur notably in early period of gestation. Generally it seems that the method is more efficient in bigger fetuses, which make more dynamic movements [14].

Most of the research relating to EFM has focused on FHR and/or the affect of uterine contractions (UC) on fetal heart [12,17]. To the best of our knowledge there is no study, which has correlated FM with the FHR and UC as part of an overall electronic fetal wellbeing assessment. Moreover, there is no study, which has investigated the correlation between FM, FHR and UC in relation to numerical indications to distinguish between physiological or pathological fetal signals with concomitant effort to anticipate events.

1.2 Aim of the study

This proposed study will try to correlate FHR with UC and FM, based on in depth analysis of 20 anonymous, retrospective antenatal CTGs recorded using the ultrasound transducer and undertaken between 34-42 weeks gestation. Following ethical approval, by using the trace export utility, data from the CTGs will be accessed from both the central computer based on the antenatal ward at the participating maternity unit, in Northern Ireland and if necessary from repository databases (including UCI data-base[1]).

By following algorithms (mathematical calculations), we will analyse FHR, UC and FM signals, in order to estimate each signal's complexity. Based on this analysis we will extract objective indexes, for each of the signals. These objective indices are real numbers that will consist of numerical cut-off values, which are able to distinguish between physiological or pathological signals/cases. Based on this analysis it will be possible to correlate FM with FHR and UC. This proposed method will help to minimise the subjectivity of existent evaluation method of these three signals.

Additionally, we will try to develop a method of FM prediction. Based on the same algorithms, we will analyse the FHR and UC behaviour before the emergence of a FM. Assuming that the complexity (or irregularity) of each signal, changes before a FM, it will be possible to examine the pre-movement condition of the fetus. This knowledge of FM prediction will further aid in the assessment of fetal welling

[1] e.g. https://archive.ics.uci.edu/ml/datasets/Cardiotocography

as FM is a better indicator of fetal wellbeing than fetal heart rate alone [18]. This study will act as a pilot with the results informing a larger multi-national retrospective study.

1.3 Methods

CTGs are normally undertaken in pregnancy for assessment of the fetus for example prior to, and post insertion of a vaginal pessary for the induction of labour or maternal reporting of reduced fetal movements etc. For this pilot project anonymised bio-signals (FHR, UC & FM) from (n=20) retrospective CTGs performed on pregnant women for similar reasons, during the antenatal period from 34-42 weeks gestation will be analyzed. If maternal pulse is exported via the export utility this signal will also be correlated against the fetal bio-signals. Authorized clinical staff will collect the data and all personal and medical details will be removed and forwarded to the researcher. The data will be checked for quality and any missing data will be followed up. Prior to collection of the signals IRAS permission and all relevant actions will have been undertaken by the researchers.

1.4 Signals' analysis

Non-linear dynamical analysis is a powerful approach to understanding biological systems. Entropy, as it relates to dynamical systems, is the rate of information production. Methods for estimation of the entropy of a system represented by a time series are not, however, well suited to analysis of the short and noisy data sets encountered in cardiovascular and other biological studies. The first successful effort to solve the previous problems, came by Pincus [19,20] who introduced approximate entropy (ApEn), a set of measures of system complexity closely related to entropy, which is easily applied to clinical cardiovascular and other time series. Since Pincus introduced ApEn, many other algorithms introduced in order to solve some of ApEn bias. There are two main categories of algorithms based on entropy as it is introduced in information theory. Both of these categories are used in non-linear systems' analysis.

a. single signal's analysis

The **first** methods' category includes: ApEn, Sample Entropy, Shannon Entropy, Permutation Entropy, Multiscale Entropy and Fuzzy Entropy. Each of these algorithms, analyse only one time series. Pincus [19,20] by introducing the ApEn, devised the theory and method for a measure of regularity closely related to the Kolmogorov entropy, the rate of generation of new information, that can be applied to the typically short and noisy time series of clinical data. This family of statistics, named ApEn, is rooted in the work of Grassberger and Procaccia and Eckmann and Ruelle and has been widely applied in clinical cardiovascular studies [20-36]. Richman and Moorman [37] developed and characterized a new family of statistics, sample entropy (SampEn) that does not count self-matches. SampEn is derived from approaches developed by Grassberger and co-workers [38-41]. Thus a lower value of SampEn also indicates more self-similarity in the time series. Rests of the methods in this category are based on ApEn and SampEn.

As **first step** in the proposed study, each of CTGs signals will be analyzed based on above algorithms by choosing the optimal parameters' combination for each algorithm.

b. multiple signals' analysis

The **second** methods' category includes Cross-Approximate Entropy, Cross-Sample Entropy and Conditional Entropy.

These algorithms resemble a non-linear measure of coupling between two time series.Unlike cross-spectral analysis, which detects linear coupling between two signals, in our study sequences from three distinct yet intertwined variables in a network (here: FHR, UC and FM) are compared by quantifying their asynchrony (conditional irregularity). The proposed analysis' algorithms would result in smaller values, if the association between the systems is strong and hence asynchrony is relatively low. In contrast, when there is only weak association between two signal time series, larger values would be obtained indicating a higher degree of asynchrony.

Most of the proposed algorithms measure, within a tolerance 'r', the conditional regularity of v-patterns similar to a given u-pattern with a window length 'm'. Greater asynchrony (or weaker association between signal complexities, more discordance) thus indicates fewer sub-pattern matches, as quantified by larger values. Conversely, lower values are indicative of more concordance or stronger coupling [42].

Synchrony or similarity between bivariate time series is widely applied to quantify interactions between different physiological subsystems [37, 43-46]. The traditional measurements such as coherency and spectral estimates are not suitable for characterizing non-linear and non-stationary signals. Based on the theories in the field of non-linear dynamic analysis and chaos, few of these methods such as the cross-approximate entropy, were applied for measuring synchrony between two time-series [43-44]. Richmann and Moormann further developed cross-sample entropy, also a generalized form of sample entropy (SampEn), which showed better performance [37,46].

As **second step** in the proposed study, all possible combinations of CTGs signals will be analyzed based on above algorithms by choosing the optimal parameters' combination for each algorithm.

c. predictive signals' analysis

As **third step** in the proposed study, above algorithms will be used in order to analyze signal's behanior before any FM. This analysis will check if there is any change in signals' complexity a short period before FMs.

References

1. Stout MJ, Cahill AG. Electronic fetal monitoring: past, present, and future. Clin Perinatol, 2011; 38(1):127-142.
2. Grimes DA, Peipert JF. Electronic fetal monitoring as a public health screening program: the arithmetic of failure. Obstet Gynecol, 2010; 116:1397-1400.
3. Devane D, Lalor J, Bonnar J. The use of intrapartum electronic fetal heart rate monitoring: A national survey. Ir Med J, 2007; 100(2):360-362.
4. Grivell RM, Alfiredic Z, Gyte GM, Devane D. Antenatal cardiotocography for fetal assessment. Cochrane Database Syst Rev, 2010:CD007863.
5. Pattison N, McCowan L. Cardiotocography for antepartum fetal assessment. Cochrane Database Syst Rev, 2000; 2:CD001068
6. National Institute of Clinical Excellence (NICE) (2014) Clinical Guideline 190 Intrapartum care: care of the healthy woman and their babies during childbirth. See:http://www.nice.org.uk/guidance/cg190/resources/guidance-intrapartum-care-care-of-healthy-women-and-their-babies-during-childbirth-pdf(Accessed 16th July 2016)
7. Al-Yousif SN and Ali MAM. Cartiotocography trace pattern evaluation using MATLAB program. International Conference of Biomedical Engineering and Tachnology, 2011; 11:153-158.
8. Van Geijn. Development in CTG analysis. Bailliers Clin Obstet Gynaecol, 1996; 10(2):185-209.
9. Neldam S. Fetal movements as an indicator of fetal wellbeing. Lancet, 1980; 1(8180):1222-1224.
10. Gonçalves H, Bernardes J, Rocha AP, Ayres-de-Campos D. Linear and nonlinear analysis of heart rate patterns associated with fetal behavioral states in the antepartum period, 2007; 83(9):585-591.
11. Alfirevic Z, Devane D, Gyte GM. Continuous cardiotocography (CTG) as a form of electronic fetal monitoring (EFM) for fetal assessment during labour. Cochrane Database Syst Rev, 2013; 31:5:CD006066.
12. Chandraharan E. Rational approach to electronic fetal monitoring during labour in 'all' resource settings. Sri Lanka Journal of Obstetrics and Gynaecology,2010; 32: p77-84.
13. Flynn AM, Kelly J, Mansfield H, Needham P, O'Conor M, Viegas O. A randomized controlled trial of non-stress antepartum cardiotocography. Br J Obstet Gynaecol, 1982; 89(6):427-433.
14. De Wit AC and Nijhuis JG. Validity of the Hewlett-Packard actograph in detecting fetal movements. Obstetrics & Gynaecology, 2003; 22(2):152-156.
15. DiPietro JA, Costigan KA, Pressman EK. Fetal movement detection: comparison of the Toitu actograph with ultrasound from 20 weeks gestation. JMatern Fetal Med 1999; 8: 237–242.
16. Melendez TD, Rayburn WF, Smith CV. Characterization of fetal body movement recorded by the Hewlett-Packard M-1350 - A fetal monitor. Am J Obstet Gynecol 1992; 167: 700–702.
17. Stacey T, Thompson J M D, Mitchell E A, Ekeroma A, Zuccollo J and McCowan L. Maternal Perception of Fetal Activity and Late Stillbirth Risk: Findings from the Auckland Stillbirth Study. Birth, 2011; 38:4 p 311 -316.
18. Nelson KB, Sartwelle TP and Rouse DJ. Electronic fetal monitoring, cerebral palsy, and caesarean section: assumptions versus evidence. BMJ, 2016; 355:i6405 p 1-3.

19. Pincus SM. Approximate entropy as a measure of system complexity. Proc Natl Acad Sci USA 1991; 88: 2297–2301.
20. Pincus SM. Approximate entropy (ApEn) as a complexity measure. Chaos 1995; 5: 110–117.
21. Dawes GS, Moulden M, Sheil O, and Redman CW. Approximate entropy, a statistic of regularity, applied to fetal heart rate data before and during labor. Obstet Gynecol 1992; 80: 763–768.
22. Fleisher LA, DiPietro JA, Johnson TR, and Pincus S. Complementary and noncoincident increases in heart rate vari- ability and irregularity during fetal development. Clin Sci 1997; 92: 345–349.
23. Fleisher LA, Pincus SM, and Rosenbaum SH. Approximate entropy of heart rate as a correlate of postoperative ventricular dysfunction. Anesthesiology1993*;* 78: 683 – 692.
24. Goldberger AL, Mietus JE, Rigney DR, Wood ML, and Fortney SM. Effects of head-down bed rest on complex heart rate variability: response to LBNP testing. J Appl Physiol 1994; 77: 2863–2869.
25. Ho KK, Moody GB, Peng CK, Mietus JE, Larson MG, Levy D, and Goldberger AL. Predicting survival in heart failure case and control subjects by use of fully automated methods for deriving nonlinear and conventional indices of heart rate dynamics. Circulation 1997; 96: 842–848.
26. Hogue CJ, Domitrovich PP, Stein PK, Despotis GD, Re L, Schuessler RB, Kleiger RE, and Rottman JN. RR interval dynamics before atrial fibrillation in patients after coronary artery bypass graft surgery. Circulation 1998; 98: 429–434.
27. Korpelainen JT, Sotaniemi KA, Makikallio A, Huikuri HV, and Myllyla VV. Dynamic behavior of heart rate in ischemic stroke. Stroke 1999; 30: 1008–1013.
28. Lipsitz LA, Pincus SM, Morin RJ, Tong S, Eberle LP, and Gootman PM. Preliminary evidence for the evolution in complex- ity of heart rate dynamics during autonomic maturation in neonatal swine. J Auton Nerv Syst 1997; 65: 1 – 9.
29. Makikallio TH, Ristimae T, Airaksinen KE, Peng CK, Goldberger AL, and Huikuri HV. Heart rate dynamics in patients with stable angina pectoris and utility of fractal and complexity measures. Am J Cardiol 1998;81: 27–31.
30. Makikallio TH, Seppanen T, Niemela M, Airaksinen KE, Tulppo M, and Huikuri HV. Abnormalities in beat-to-beat complexity of heart rate dynamics in patients with a previous myocardial infarction.*J Am Coll Cardiol 1996;* 28: 1005–1011.
31. Nelson JC, Rizwan-uddin, Griffin MP, and Moorman JR. Probing the order within neonatal heart rate variability. Pediatr Res 1998; 43: 823–831.
32. Palazzolo JA, Estafanous FG, and Murray PA. Entropy measures of heart rate variation in conscious dogs. Am J Physiol Heart CircPhysiol 1998; 274: H1099–H1105.
33. Pincus SM, Cummins TR, and Haddad GG. Heart rate control in normal and aborted-SIDS infants. Am J Physiol Regulatory Integrative Comp Physiol 1993; 264: R638 – R646.
34. Pincus SM and Viscarello RR. Approximate entropy: a regularity measure for fetal heart rate analysis. Obstet Gynecol 1992; 79: 249 – 255.
35. Ryan SM, Goldberger AL, Pincus SM, Mietus J, and Lipsitz LA. Gender- and age-related differences in heart rate dynamics: are women more complex than men? J Am Coll Cardiol 1994; 24: 1700 – 1707.
36. Schuckers SA. Use of approximate entropy measurements to classify ventricular tachycardia and fibrillation. J Electrocardiol 1998; 31 Suppl: 101 – 105.
37. Richman JS, Moorman JR. Physiological time-series analysis using approximate entropy and sample entropy. Am J Physiol Heart CircPhysiol 2000; 278(6):H2039-H2049.
38. Ben-Mizrachi A, Procaccia I, and GrassbergerP.The characterization of experimental (noisy) strange attractors. PhysRev A 1984; 29A: 975.

39. Grassberger P. Finite sample corrections to entropy and dimension estimates. Phys Lett A 1988; 128: 369.
40. Grassberger P. and ProcacciaI. Estimation of the Kolmogorov entropy from a chaotic signal. Phys Rev A 1983; 28: 2591–2593.
41. Grassberger P, Schreiber T, and Schaffrath C. Nonlinear time sequence analysis. Int J Bifur Chaos 1991; 1: 547, 1991.
42. D. Gallelty, D. Buckley, B. Robinson, and T. Corfiatis. Heart rate variability during propofol anaesthesia. Brit J Anaesth, 2007; 24:626-633.
43. Liu PY, Pincus SM, Keenan DM et al. Analysis of bidirectional pattern synchrony of concentration-secretion pairs: implementation in the human testicular and adrenal axes. Am J Physiol Regul Integr Comp Physiol 2005; 288(2):R440-6.
44. Pincus SM, Singer BH. Randomness and degrees of irregularity. Proc Nat Acad Sci USA 1996; 93(5):2083-2088.
45. Xie H, Zheng Y, Guo J et al. Cross-fuzzy entropy: A new method to test pattern synchrony of bivariate time series. Inform Sciences 2010; 180(9):1715-1724.
46. Zhang T, Yang Z, Coote JH. Cross-sample entropy statistic as a measure of complexity and regularity of renal sympathetic nerve activity in the rat. Exp Physiol 2007;92(4):659-69.

2. Description of activities performed during STSM

Day 1: November 12th 2017

Arrival at Athens airport at 9:25. Arrival at Manchester airport at 15:15. Arrival at Belfast at 18:05.

Day 2: November 13th 2017

The first day began with a meeting with Dr Maria Healy, Lecturer in Midwifery, School of Nursing & Midwifery, Queen's University Belfast (QUB), during which the following issues were discussed and resolved (8:00 am):

- How CTG technology works, the main advantages of entropy analysis theory and how exactly it will be used in our pilot study
- Design of the STSM program, general obligations during the stay and resolution of queries regarding STSM schedule
- Discussion and confirmation of the ethical approval applied for by Dr Maria Healy and obtained from QUB and the Western Health Social Care Trust (WHSCT) Governance.

At 10:00 am, I had a meeting with Prof. Cathy Craig, Dean of Postgraduates at the School of Psychology, Queen's University Belfast. Her area of research is Emotion, Perception and Individual Characteristics (EPIC), including Action Psychology. Prof. Craig is the Director of the Movement Innovation Lab. I made a short presentation about the cross-disciplinary collaboration and the aims of the current STSM. We discussed our interests and she demonstrated the research activities involved in the Movement Innovation. We also discussed the possibility of working on a pilot study relating to older people. In the next month we are going to finalize parameters of this pilot study.

At 14:00 am, George Tzagkarakis and Dr Maria Healy had a meeting with the Dr Matthew Rodger, Lecturer in School of Psychology, Queen's University Belfast. I made a short presentation about the cross-disciplinary collaboration and the aims of the current STSM. We discussed our interests and he presented an overview of his laboratory research activities in particular, his research into human motion. We discussed a number of possible research areas were we could possibly collaborate by integrating engineering and human motion. We also discussed the possibility of commencing a pilot study in Parkinsonian's patients. Next month we are going to finalize parameters of the pilot study.

Finally (15:00-17:00 pm), George Tzagkarakis and Maria Healy had a meeting to finalize the program for the following two days. I also had met with Professor Maria Lohan, Director of Research at School of Nursing and Midwifery, QUB.

Day 3: November 14th 2017

Meeting (9:00-12:00am) with Dr Maria Healy, to discuss in detail: (i) the research and data analysis undertaken to date on CTGs, (ii) confirmation of the research approach to be undertaken for our proposed study, (iii) the exclusion and inclusion criteria of the data signals (iv) the data acquisition procedure, (v) the algorithm's structure that I will use in data analysis and (vi) the main parameters.

Finally (14:00 am – 16:00 pm), George Tzagkarakis and Maria Healy met to finalize: (i) the research method to be employed, with necessary corrections and additions undertaken (ii) the categorization of the variables (iii) appointments with QUB researchers via emails or phone.

18:13 pm departure from Belfast City Hospital train station and arrival at 20.08 pm to Derry train station – overnight stay in Derry City for planned research activity in Altnagelvin Hospital on 15th November.

Day 4: November 15th 2017

8:30-12:30 pm: Meeting with Ms Sharon Woods, Midwife Ward Manager Antenatal and Maternal & Fetal Assessment Unit (MAFAU), Altnagelvin Hospital. Ms Woods was the site specific research collaborator at the WHSCT. During our meeting she (i) presented the use of the CTG devices, transferred her knowledge in relation to the common problems in CTG use and data acquisition. She also (ii) gave us an explanation on the interpretation of CTG signals based on real samples and (iii) explained how to use the appropriate software. In Altnagelvin Hospital, they use two kinds of CTG devices, Sonicaid Team 3 Series Fetal/Maternal Monitor by Huntleigh and Avalon FM30 Fetal Monitor by Philips.

Each CTG device measures:

- the fetal heart rate (FHR)
- uterine contractions (UC)
- fetal movement (FM)
- the pregnant woman's sense of fetal movement, indicated by the woman pressing a button attached to the CTG device when she feels movement ("FMb")

Each CTG device is connected to the central station-pc which has the software package, '*DCII Client'* (by Huntleigh) installed. This software enables the user to receive, represent and save data from both the CTG devices.

A typical graph of CTG signal is presented below:

We encountered a number of difficulties initially in relation to the data signals, these included:

- The CTGs recorded approx. five years previously did not note the maternal indication of fetal movements felt.
- For the CTGs which had recorded the maternal indication of fetal movement felt, the '*DCII Client*' software unfortunately could not save this signal in a csv format file. The procedure of correlation between the maternal button pressure and the rest of the CTG signals is therefore difficult and requires manual calculation which may decreased accuracy.
- In addition, personnel from the IT department had recently upgraded the central station-pc with Windows7, which was incompatible with the previously uploaded export utility. This utility had allowed the signal data to be exported via csv format directly from the PC.

Dr Healy contacted the Huntleigh's service manager and we were informed that the signals from identified CTGs could be forwarded in anonymized csv format. We decided to choose specific signals in collaboration with Ms Sharon Woods without missing data and which included FM and with maternal fetal movements indicated "FMb"

13:00-18:00 pm: Anonymized CTG signals based on above parameters were identified and the Huntleigh's Service manager informed of those selected.

Day 5: November 16th

8:00-12:00 pm: For each of the signals chosen for analysis, the corresponding anonymized graph in XPS document format was saved. A software package was identified to convert the XPS documents files to xls format file to enable analysis. The exact time points, when the pregnant women pressured the fetal movement button ("FMb") could thereby be identified and further analysis undertaken.

13:00-18:00 pm: At 13:00 we received the CTG signals from Huntleigh's Service manager in csv format. Initially, I checked the quality of each signal and if there was any missing data. I then organized the CTG signal data base in an appropriate format, for data analysis.

At 19:00 pm: Departed from Derry City train station and arrived at 21:50 pm in Belfast.

Day 6: November 17th

8:00 am - 12:00am: I commenced working on analyzing the data by using the following algorithms:

- For analyzing each signal separately, I used ApEn, Sample Entropy, Shannon Entropy, Permutation Entropy, Multiscale Entropy and Fuzzy Entropy
- For comparing two signals, I used Cross-Approximate Entropy, Cross-Sample Entropy and Conditional Entropy

12:00 – 14:00 pm: I met again with Dr Matthew Rodger, Lecturer in School of Psychology, Queen's University Belfast, at a Motion Innovation Labs' showcase presentation. I also had the opportunity to experiment with Virtually Reality projects involving human motion and a Virtually Reality application for athletes' performance with members from Dr. Michalis Doumas' team.

14:00-20:00 Completed initial data analysis and wrote the STSM report.

Day 7: November 18th

Travelled from Belfast airport and arrived at London Heathrow airport at 10:20. Arrival at Athens airport at 17:50. Arrival at Heraklion at 22:50.

3. Findings of the STSM – Future collaboration

This STSM program provided the opportunity to explore a new way of CTG, FM, FHR and UC analysis, which enables the quantification and comparison of these signals. The proposed algorithms have already been used in several fields. It is anticipated that the results from this study will enable further understanding of fetal welling and reduce unnecessary obstetrical intervention.

From the findings and the results of this STSM research two articles will be conducted:

a) Quantification and correlation of CTG, FM, FHR, UC for increasing accuracy of infant wellbeing assessment and b) Prediction of FM for a better understanding of fetal health

We aim to submit both articles for publication by July 2018.

Further Collaboration

- With Prof. Cathy Craig, Dean of Postgraduates in School of Psychology and Director of the Movement Innovation Lab, Queen's University Belfast. We are planning to start a new pilot study for upgrading/ the proposed algorithms in elder people motion.

- With Dr Matthew Rodger, Lecturer in School of Psychology, Queen's University Belfast. We are planning to start a new pilot study for upgrading the proposed algorithms in Parkinsonian's patients.

- Possible application for small funding with Dr Maria Healy, to undertake further work and with more participants.

Conclusion

In conclusion, the STSM program provides the opportunity for early stage researchers to work at Universities in other countries, learn from their expertise and from leading academics and researchers. Personally, for me it was a unique opportunity to attend a top University in Europe and to work with academics and other researchers. The collaboration with personnel from a University in another country and the exchange of knowledge is a great asset for any early stage researcher. In simple words the experience provided, the opportunity for knowledge transfer and what a STSM program offers is excellent.

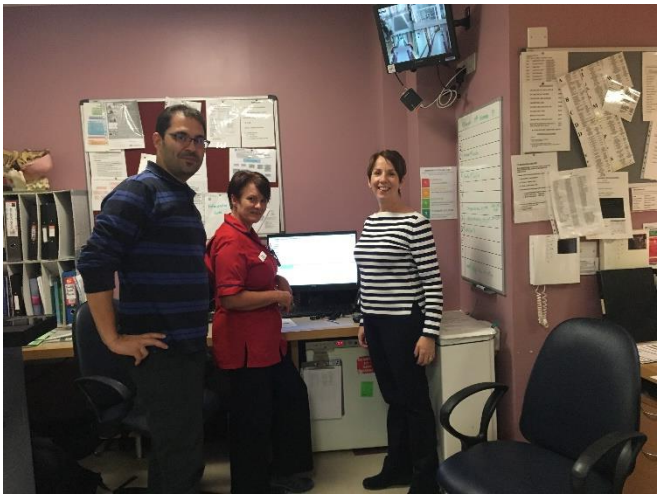
4. Confirmation from Host of successful execution of the STSM

I hereby confirm that the activities and outputs described above took place. Dr George Tzagkarakis was a very dedicated, innovative and creative addition to our team while he was at Queen's University Belfast. He was extremely interested in all the opportunities available to him, fully engaged, and a very active contributor to debate, to present and to working out the issues and problems in the work he undertook. It was a pleasure to have him with us for the week, and we look forward to working with him in the future.

Maria Healy

Dr Maria Healy

5. Photo Gallery



Dr George Tzagkarakis, Ms Sharon Woods and Dr Maria Healy
in Altnagelvin Hospital