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IFPA meeting 2017 workshop report: Clinical placentology, 3D structure-based modeling of placental function, placental bed, and treating placental dysfunction☆

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ABSTRACT

Workshops are an important part of the IFPA annual meeting as they allow for discussion of specialized topics. At IFPA meeting 2017 there were four themed workshops, all of which are summarized in this report. These workshops discussed new knowledge and technological innovations in the following areas of research: 1) placental bed; 2) 3D structural modeling; 3) clinical placentology; 4) treatment of placental dysfunction.

1. Placental bed in the next generation

Chairs: John Aplin and Larry Chamley.

Speakers: John Aplin, Judith Bulmer, Graham Burton, Larry Chamley, Terry Morgan.

1.1. Outline

In this workshop, after Larry Chamley had set the scene, four established investigators introduced materials available to help

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familiarize researchers with the complexities of placental bed histology and pathology, with a strong emphasis on vascular function. Speakers posed questions they considered important for future research. The session was a true workshop, with questions and comments from the floor to all speakers stimulating intense discussion.

1.2. Summary

Graham Burton discussed placental bed resources available at the Cambridge Centre for Trophoblast Research. The Centre for Trophoblast Research holds two archival collections of placental histological material available for study. The Boyd collection comprises material from over 200 pregnancies collected in the 1960's and 1970's [1]. The most informative slides are the placenta-*in-situ* specimens, which range in gestational age from 6 to ~34 weeks. Runs of serial sections stained with different dyes are available for some of the earlier specimens. Representative sections of the larger slides have been scanned and can be viewed at http://www.trophoblast.cam.ac.uk/Resources/boyd-collection. The Dixon material was collected in the 1970's and comprises ~60 placenta-*in-situ* specimens from 8 to 16 weeks gestational age that are believed to have come from normal pregnancies. Unfortunately, there are no clinical data or blocks associated with either collection.

John Aplin shared a histology resource for normal and pathological term placental bed. He described a set of term placental bed specimens originally produced in Leuven by Robert Pijnenborg. They have been used for teaching at the Queen's University placenta workshops in Kingston, Ontario, and in the Manchester Master of Research in Reproduction and Pregnancy program. There are 15 tissues from normal or pathological pregnancies, each in a set of 4 serial sections stained with different markers. With respect to vascular features, there are examples of deep myometrial arteries that remain untransformed, spiral arteries that have undergone normal physiological conversion as well as profiles exhibiting a range of pathological features. The respective patterns of trophoblast invasion are well documented. The scanned slides are available for online study; Dr Aplin will supply details on request.

Judith Bulmer described first and second trimester placental beds in Newcastle. Uterine spiral artery remodeling is crucial for a successful pregnancy, but these arteries are not readily accessible. In Newcastle, a reliable technique was developed to biopsy the placental bed after termination of pregnancy using a transvaginal approach [2]. Over 500 placental bed biopsies ranging from 6 to 20 weeks gestational age have been collected. Collection of decidua and placenta from the same patients has allowed investigators to combine *in situ* immunohistochemical studies or laser capture and PCR with functional studies of decidua and trophoblast populations. There was discussion of the extent to which endothelial cells become displaced from spiral arteries during remodeling. Dr Bulmer agreed that residual endothelial cells remain during active remodeling and can later reform a continuous covering layer in remodelled vessels.

Terry Morgan presented uterine radial artery remodeling and the progressive disintegration of spiral artery plugs. Contrast-Enhanced Ultrasound has provided the sensitivity to detect low level intervillous space (IVS) perfusion as early as 6 weeks gestation with significantly more flow measured at 13 weeks. His group's histopathological review of the Boyd collection in Cambridge revealed loosely cohesive 'plugs' with capillary-sized channels filled with red blood cells at 7 weeks gestation and progressive disintegration of these plugs thereafter. Interestingly, the progressive loss of spiral artery plugs was not reflected in IVS blood flow data. Resistance did not appear to change from 7 to 12 weeks. Instead, myometrial radial artery remodeling was observed beginning at the end of the first trimester, which may be more closely related to the observed increase in early second trimester blood flow. Delegates discussed the phenotype of cells in the plugs, some of which are $CD56^{+}$.

1.3. Conclusions

Collections of placental beds/placentae *in situ* are available in the three centers included in this workshop (as well as the Carnegie collection, not discussed here). These samples provide invaluable information regarding human implantation and their ongoing examination continues to provide new insights as we reinterpret the histology in the light of information provided by new technologies. As many of these specimens are irreplaceable it is imperative that the collections are maintained and access to them assured. One of the aims of this very well-attended workshop was to inform and stimulate young investigators, and no one who attended could doubt that there are important unanswered questions in placental bed pathobiology.

2. 3D structure-based modeling of placental function

Chairs: Paul Brownbill, Igor Chernyavsky, Alys Clark, Oliver Jensen, Ed Johnstone, Lopa Leach, Rohan Lewis, Carolyn Salafia, Henning Schneider.

Speakers: Alys Clark, David Elad, Marcel Filoche, Rohan Lewis, Michelle Oyen, Gareth Nye.

2.1. Outline

The workshop comprised of three synergistic parts, each followed by interactive discussion: (i) placental imaging, accounting for state of the art three-dimensional microscopy; (ii) human placenta physiology relating to blood flow and oxygen transfer; (iii) advances in human placental mathematical modeling predicting transfer and blood flow based on placental structural morphology.

2.2. Summary

In the first section on "Structure", **Rohan Lewis** introduced multi-scale 3D imaging of placental villi as the basis for modeling and functional analysis. It was described how the three-dimensional structure of the placental villi and the complex spatial relationships of the cells they contain are central to placental function. Multi-scale imaging techniques including micro-CT, whole-mount confocal, light sheet and serial block-face scanning electron microscopy now allow three-dimensional imaging of whole placentas or regions of placenta down to the nm scale. There was an illustration of how these approaches can inform computational and molecular studies and advance our understanding of placental function. Discussion centered on pericyte associations with the endothelium; and potential future insight into the true meaning of syncytial knots, given the high-resolution imaging that is now possible at the microvillous surface.

In the second section on "Function", **David Elad** showed how the *ex vivo* human placental perfusion model could be used in a single (fetal) side perfusion adaptation to analyze resistance indices in the feto-placental chorionic plate vasculature with Doppler. The efficacy of material exchange in the human placenta depends on proper blood perfusion through the complex 3D branching network of the feto-placental vasculature. Accordingly, obstetrics monitoring guidelines have evolved based on clinical studies that explored correlations between umbilical Doppler indices and pregnancy outcome. However, the biophysical foundation is vague and only based on simplified lumped element models of electronic

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circuits without experimental validations. David and his co-workers have developed an *ex vivo* placental perfusion model to study placental insufficiency by exploring the dependency of umbilical Doppler indices on obstruction levels of major fetal vessels in the chorionic plate. There was some discussion on interpretation of values in relation to the resistance from the underlying microcirculation. The context of the study was also explained, as this was a single-sided perfusion model, which only explored feto-placental vascular resistance.

Continuing with the "functional" theme, **Gareth Nye** presented a new method to probe oxygen transfer function in the human placenta *ex vivo*. Fetal growth restriction (FGR) is associated with reduced placental functional capacity, including compromised oxygen transfer. However, there is little information on placental oxygenation *in vivo* and its correlation with flow and structure. In this talk, Gareth discussed a novel approach to assess oxygen transfer dynamics *ex vivo* in a dually perfused human placenta that involves measuring both the net oxygen transfer rate and systematic mapping of oxygen levels in the intervillous space. This methodology could bridge the gap between structure and function in health and FGR, forming the basis for validation of placenta-specific computational models. There was discussion on how the *ex vivo* human placental perfusion model has seen numerous variations, relating to different research questions. In this instance the single maternal-side cannula was defended, in an aim to simplify the system for the purposes of low flow interference during 3D tissue mapping of pO_2.

Moving onto engineering and modeling approaches in the "Integration" section, **Alys Clark** spoke on how computational models of the placenta can be used to guide diagnostics. Advances in imaging technologies and computational power are allowing predictive models of the placenta to be developed with increasing anatomical detail. This opens the door for the development of models that can begin to be used, in conjunction with imaging, to guide diagnostics and therapies. Alys discussed models that have successfully bridged the gap between physiology and the clinic, and challenges for the future. There was debate on how we should interpret drug effects on transfer function and their effects on resistance to fetal blood flow. Also, how changes in patient treatment strategies might be assisted by modeling of the placenta, with a comparison on how models could be used to predict effects of changes in lung ventilation. The appeal from the bioengineers and modelers to clinical scientists is "what are the big questions that need to be addressed in their work." Answering the wrong questions can be wasteful in terms of their translational efforts.

This talk was followed by **Michelle Oyen**, who presented the question "How do we validate virtual placenta models?" There has been significant recent interest and progress in the area of computational modeling of the human placenta in pregnancy. However, the thorny question of how to validate those models has no easy or obvious solution. The use of *in silico* studies for human pregnancy has obvious ethical advantages over any experimental study involving pregnant women. However, without validation the models are "garbage in, garbage out" exercises where the quantitative results could mean anything. This talk highlighted the key issues and challenges going forward towards a functional virtual placenta model that is useful for clinical and research understanding. Technicalities were explored during the discussion, of how in the finite element model, the whole picture is broken down into parts, e.g. how fetal capillary tortuosity affects fetal blood flow; how inflow rates to a network affects the flux of oxygen across the placental barrier. Modeling efficacy means little without the processing of quality data, including sufficient slice sampling during structural reconstruction and without too much error in meshing data.

In the final talk, **Marcel Filoche** spoke about the role of morphology in mathematical models of placental gas exchange. One of the main functions of the human placenta is to transfer oxygen from maternal to fetal blood. To assess its performance as a gas exchanger, mathematical and numerical models must account for the physiology of exchange and organ morphology. Recent progress in imaging permits the extraction of detailed morphological information, which can be used as input for these models. Marcel presented an overview of the gas exchange models in the placenta, discussing their advantages and shortcomings. He showed how geometrical information can improve our understanding of the working of the placenta, and suggested future approaches based on the latest experimental techniques. Discussion ensued on knowing the geometry of what is being examined and knowing what questions are being asked in relation to this. The need to understand flow around complex geometric shapes, i.e. the villous tree and the prospect of setting agreed upon international standards was raised. From a pathologist's perspective, the most vexing questions would relate to stillbirth and the need to work this into experimental and modeling investigations; relating to this, which measurements should be performed? We should consider that materno-placental flow probably does not cover the entire villous surface simultaneously; there is a functional dynamic here. The rheology of blood flow was discussed, being different in the maternal intervillous space, compared to the vascularized feto-placental circulation.

With such a vast array of questions that could be asked, **Igor Chernyavsky** closed the workshop by highlighting the importance of establishing the standards for emerging experimental techniques, computational models' validation and data sharing to allow for more quantitative and direct inspection of structure-function interaction in the human placenta than ever before.

2.3. Conclusions

Placental modeling has been conducted over many decades relating to heat, nutrient and water exchange across the placental barrier. More recently, technical advances in microscopy and other imaging techniques have led to several groups taking serious attempts to couple structure with function, using mathematical modeling. The *ex vivo* dual perfusion of the human placenta and other *in vitro* human placental techniques are also being developed in parallel and provide rich means of validation for computational models in predicting the outcomes for placental transfer and placental oxygen consumption. This research direction is vital in considering placental pathology, where placental architecture and blood flow relationships diverge from normality in a non-trivial way. The interdisciplinary placenta community is thus at a juncture of developing some important modeling tools for use by obstetricians, in combination with advanced *in vivo* imaging, to help predict and manage problem pregnancies, including fetal growth restriction.

3. Clinical placentology

Chair: Alexander Heazell.

Speakers: Ganesh Acharya, Alexander Heazell, Sally Collins, Edward Johnstone and Jenny Myers.

3.1. Outline

The placenta is critical in the etiology of many pregnancy complications, including: fetal growth restriction, preeclampsia, stillbirth and morbidly invasive placenta. Despite this, direct assessment of placental size, structure and function is rare in clinical practice.

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This workshop focused on how assessment of the placenta currently influences clinical management of women's pregnancies and how this might develop in the future. The workshop consisted of interactive case presentations, including: assessment of placental structure and depth of invasion by ultrasound scan and magnetic resonance imaging, assessment of placental function by biochemical markers of placental function and the use of novel techniques to image placental oxygenation and placental blood flow.

3.2. Summary

Alexander Heazell discussed that clinical detection of placental dysfunction or abnormal placentation largely relies on ultrasound and in most cases, this is suggested by measurement of fetal size. However, there is no evidence that this approach reduces perinatal mortality. In addition, there is insufficient evidence to support the use of biochemical tests of placental function to decrease perinatal mortality or increase identification of small for gestational age infants. Critically, the accuracy of tests is essential to direct intervention; a diagnostic test accuracy review suggested that measuring fetal size is best to identify a small for gestational age (SGA) infant, but that biochemical markers are better to identify a pregnancy that will end in stillbirth.

Ganesh Acharya discussed the assessment of utero-placental and feto-placental blood flow using Doppler ultrasonography. Most commonly used methods in clinical practice are qualitative assessment of the Doppler derived blood flow velocity waveforms for the presence or absence/reversal of umbilical artery end-diastolic blood flow, uterine artery proto-diastolic notching and pulsations in the umbilical vein, and calculation of semi-quantitative surrogate indices of vascular impedance (pulsatility index (PI), resistance index (RI) or systolic/diastolic (S/D) ratio) using blood flow velocities. Recently, reliable and reproducible estimation of utero-placental and feto-placental volume blood flow using non-invasive ultrasound has been shown to be feasible and the methods have been validated experimentally. This allows direct assessment of placental perfusion on both the fetal and maternal sides of the placenta. Fractions of maternal and fetal cardiac outputs distributed to the placenta can also be calculated to provide physiologically meaningful quantitative assessment of placental perfusion. Routine clinical application of placental volume blood flow measurement may improve diagnosis and management of fetal growth restriction in the future.

The idea of incorporating better assessment of uteroplacental blood flow was developed by **Edward Johnstone** whose talk focused on clinical cases that demonstrated the management of FGR. The use of uterine artery Doppler and placental biometry was highlighted in dealing with early onset FGR concluding that absence of effective treatment in this group, rather than predicting the outcome, remains the biggest problem for investigators. Furthermore, the problems faced by clinicians in predicting and managing late onset FGR were described in further cases, some of which demonstrated that even with increased observation some FGR-related death remains unpredictable. Newer technologies such as magnetic resonance imaging may help improve the management of FGR, by identifying true FGR distinct from SGA infants.

Jenny Myers presented a potential role for angiogenic factors which have recently emerged as markers of placental dysfunction. The value of these markers in diagnosing placental dysfunction in the context of challenging clinical situations was discussed. The case presented described a pregnancy complicated by type 2 diabetes, borderline hypertension and absent end diastolic flow with a baby estimated to be at the 50th centile. Measurement of placental growth factor (PlGF) in maternal plasma demonstrated low levels of PlGF − 13 pg/ml; diagnostic of placental dysfunction, despite the absence of definitive signs of pre-eclampsia or FGR. The current literature and a recent clinical study evaluating the utility of PlGF were presented and discussed, highlighting the value of PlGF as an emerging and important diagnostic tool of placental disease.

Lastly, **Sally Collins** discussed abnormally invasive placenta (AIP) and the difficulties encountered with ultrasound diagnosis of AIP. The recently published AIP standardized nomenclature was presented which should aid clinicians with describing and identifying AIP [3]. The inaccuracy of describing a spectrum condition as a binary outcome was also highlighted. Images of findings at laparotomy were presented along with an explanation of how each of these findings were represented by the various ultrasound signs. A new way of considering ultrasound reports as surgical guides was proposed. The difference in pathologies between AIP and abnormally dehisced uterus (uterine window) was also discussed.

3.3. Conclusion

As understanding of the role of the placenta in clinical conditions progresses, the desire to identify associated abnormalities of placental structure and function increases. This workshop discussed the importance of appropriate outcome measures, which may be placental dysfunction or histological abnormalities rather than surrogate measures such as birthweight or neonatal acidemia. The need to conduct methodologically rigorous clinical studies was also highlighted to better identify functional and structural abnormalities of the placenta. A clinical placentology working group might be able to inform translational research in this field.

4. Preclinical strategies for treating placental dysfunction

Chairs: Mark Dilworth and Natalie Hannan.
Speakers: Elizabeth Cottrell, Anna David, Mark Dilworth, Natalie Hannan, and Sebastian Illanes.

4.1. Outline

Mark Dilworth opened the workshop by stating the major aims of the workshop; (i) to inform on different pre-clinical strategies currently employed for candidate therapeutics targeted towards placental dysfunction, and (ii) to provoke discussion about the effectiveness and suitability of the strategies currently employed, and to discuss alternative strategies. He outlined the strategy of the re-purposing of drugs for use in placental dysfunction. These drugs would, ideally, have been used in pregnancy before and would be effective in diseases with phenotypes like those associated with placental dysfunction. He cited the example of Sildenafil citrate, the phosphodiesterase-5 inhibitor, which has been tested pre-clinically in several animal models of fetal growth restriction, and has now progressed to a randomized control trial in women due to report in 2017 (Sildenafil therapy in dismal prognosis early-onset intrauterine growth restriction, STRIDER).

4.2. Summary

To treat FGR, **Anna David**'s group has focused on “therapeutic angiogenesis”, the use of adenoviral delivery of Vascular Endothelial Growth Factor (VEGF) to increase uterine artery blood flow and enhance angiogenesis, improving uteroplacental nutrient and oxygen delivery and leading to better fetal growth. Finding the best animal model to test this hypothesis has been a challenge. Initial studies used normal pregnant sheep as non-invasive Doppler ultrasound could be used to show initial efficacy, followed up with flow probe data to study long term vascular changes. They found the best sheep model of FGR to be the over-nourished adolescent

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ewe, pioneered by Dr Jacqueline Wallace in Aberdeen, because of the close link between uterine blood flow and fetal size. The epitheliochorial placentation is not ideal, thus further efficacy studies were performed in the nutrient restricted guinea pig, as placentation is like that in human FGR mid-gestation. They have used the dual perfused *ex vivo* human placenta for toxicology studies of vector spread, and the *in vivo* pregnant rabbit to study pup toxicity and fetal vector spread. Translation to the clinic will be complex, but a bioethical study in patients and stakeholders showed no insurmountable objections to a clinical trial, an important consideration for any intervention in pregnancy.

Elizabeth Cottrell presented nutrient-based approaches to treating pregnancy complications. Adequate maternal nutrition in pregnancy is a key determinant of fetal growth. Although increased energy demands of pregnancy are nearly always met, micronutrient deficiencies are relatively common and associate with pregnancy complications. Dietary supplementation strategies in pregnancy draw largely on research from other fields, such as cardiovascular medicine, where specific nutrients have been shown to improve health (e.g. vascular function). They have employed this approach investigating whether dietary nitrate supplementation, via beetroot juice, can improve vascular function and blood pressure regulation in pregnancy. Results from preclinical models (using mice and *ex vivo* human placental tissues), and more recently a small feasibility trial in pregnant women, are promising. Nitrate supplementation may improve vascular health in complicated pregnancies and, importantly, this dietary approach was acceptable to women.

Natalie Hannan outlined the development of a pre-clinical pipeline to identify therapeutics for preeclampsia. Pathophysiological aspects of preeclampsia involve 1) placental oxidative stress, 2) release of antiangiogenic and pro-inflammatory factors, and 3) maternal endothelial dysfunction causing hypertension and end organ damage. However, there are no efficacious therapeutics for preeclampsia. Her group has developed a pre-clinical pipeline to test candidate drugs, safe in pregnancy, in various assays that mimic the different pathophysiological elements of disease. Specifically, they use primary human cytotrophoblasts, endothelial cells and placental explants, in addition to maternal arteries from human omentum. This strategy has enabled their team to identify novel candidate therapeutics, and they have begun Phase II randomized placebo clinical trials assessing whether the proton pump inhibitor, esomeprazole, can prolong gestation in women with severe pre-term preeclampsia. Additional clinical trials are planned to determine whether esomeprazole may be able to prevent preeclampsia in high-risk populations.

Sebastian Illanes summarized the role of aromatase in the physiopathology of preeclampsia, and discussed potential opportunities for intervention. In human placenta, androgens derived from the maternal and fetal adrenal glands are converted into estrogens by placental aromatase. This implies that alterations in placental steroidogenesis and, subsequently, in the functionality or bioavailability of placental aromatase may be mechanistically involved in the pathophysiology of preeclampsia. Data was presented establishing the utility of the steroid pathway as early biomarkers for the prediction of disease and as possible targets for disease prevention.

4.3. Conclusions

Placental dysfunction remains central to the etiology of major complications of pregnancy, particularly preeclampsia, fetal growth restriction and stillbirth. There are no efficacious treatments currently available; obstetricians therefore are often forced to deliver the baby early to save the mother, baby, or both. Translation of candidate therapeutics for placental dysfunction to the clinic relies upon appropriate pre-clinical models/strategies in which to test their effectiveness, before they can be tested in clinical trials. This workshop focused on bringing together key researchers utilizing different strategies to translate their pre-clinical research from the bench to the bedside. The workshop was successful in generating important discussion on how pre-clinical studies could be improved, and how best to facilitate the progression of this research towards clinical trials. In terms of discussion, much emphasis was placed on the design of the pre-clinical experiment, the models used and an urge for openness to identify and accept the limitations of different pre-clinical models. This included a discussion of the need for adequate phenotyping of animal models in each laboratory to ensure reproducibility of findings as well as a call for negative findings in pre-clinical studies to be published and the need for appropriate outlets in which to publish these negative data. A key message that resonated through the workshop was the importance of collaboration, and the need for scientists and clinicians to work together effectively in the hope of progressing basic research to the clinic.

Conflicts of interest

There is no conflict of interest.

References

[1] G.J. Burton, et al., Am. J. Obstet. Gynecol. 181 (1999) 718–724.
[2] S.C. Robson, et al., Am. J. Obstet. Gynecol. 187 (2002) 1349–1355.
[3] S. Collins, et al., Ultrasound Obstet. Gynecol. 47 (2016) 271–275.

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