Author/s:
Hui, L;Tabor, A;Walker, SP;Kilby, MD

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How do we safeguard competence and training in invasive prenatal diagnosis: the elephant in the room

L. Hui*†‡§, A. Tabor¶**, S. P. Walker†‡ and M. D. Kilby††

†Perinatal Medicine, Mercy Hospital for Women, Heidelberg, VIC, Australia; ‡Department of Obstetrics and Gynaecology, University of Melbourne, Parkville, VIC, Australia; §Public Health Genetics, Murdoch Childrens Research Institute, Royal Children's Hospital; Parkville, VIC, Australia; ¶Center of Fetal Medicine, Copenhagen University Hospital, Rigshospitalet, Copenhagen, Denmark; **Faculty of Medicine and Health Sciences, University of Copenhagen, Copenhagen, Denmark; ††Fetal Medicine centre, Birmingham Women's Hospital, University of Birmingham, Edgbaston, Birmingham, UK

*Correspondence. (e-mail: lisahui77@gmail.com)

Impact of new technology in prenatal screening

Cell-free DNA (cfDNA) screening for Down syndrome (and other common autosomal aneuploidies) has been a major advance in the field of prenatal care. The unprecedented accuracy of this new technology and its rapid uptake has forced a

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complete re-evaluation of traditional screening programs over the past three years.[1] One of the major benefits of this technology is that it reduces the requirement for couples to consider 'invasive prenatal testing', with its attendant risks of miscarriage. Obstetric healthcare systems that have introduced such testing have noted a significant reduction in numbers of chorionic villous sampling (CVS) and amniocentesis with potential significant effects upon service organisation and training. Population-based datasets[2-4] and institution-based studies[5-8] around the globe now confirm the predicted drops in the numbers of invasive prenatal testing due to cfDNA screening (Figure 1).

Importantly, this decline in diagnostic testing has not come at the expense of detection, but rather in association with historic rises in diagnostic yield. One in every six invasive procedures now detects a major chromosome abnormality, in contrast to four decades ago when only 1 in 100 procedures yielded a clinically significant diagnosis.[2] Invasive testing will certainly continue to have a key role in prenatal diagnosis for the foreseeable future, particularly for the genomic assessment of fetuses with structural abnormalities[9,10] as well as for diagnostic confirmation of high risk cfDNA tests. In Australia, a plateau in diagnostic testing rates is appearing, suggesting the arrival of a new steady state in prenatal testing after the initial impact of cfDNA screening (Figure 2).

What is the true procedure-attributable loss rate from invasive diagnostic testing?

One of the expected downstream benefits of fewer invasive procedures is a reduction in total procedure-related miscarriages. However, the actual numbers of miscarriages "averted" by the use of cfDNA screening is difficult to calculate due to the uncertainties in determining the true procedure related risk of miscarriage. For a "high risk woman" to be able to choose between a "safe" advanced screening test or an "invasive" diagnostic test, she and her partner need up-to-date comprehensive information on both the accuracy of cfDNA and the risks of procedure-related pregnancy loss.

A recent systematic review of cfDNA screening calculated sensitivities and specificities for trisomy 21 of 99.4% (95% CI 98.3-99.8%) and 99.9% (95%CI 99.9-100.0%) respectively, based on data from 148,145 tests. The corresponding figures for trisomy 18 were 97.7% (95% CI 95.2-98.9%) and 99.9% (95% CI 99.7-100.0%).[11] Thus cfDNA testing is well established as the most accurate screening test for the common autosomal aneuploidies, though poor reporting of false and inconclusive results remains a significant limitation of the existing literature.

Traditionally-quoted figures from a Cochrane systematic review suggest that in low risk populations, a second trimester amniocentesis imposes an additional ~1% risk of miscarriage (2.1% versus 1.3%; relative risk (RR) 1.02 to 2.52), with similar risks for CVS.[12] However, there is substantial variation in the literature surrounding procedure-attributable fetal loss rates, partly due to different definitions of pregnancy loss and completeness of follow up and few studies are randomized.[13] The problem with most controlled studies is that women undergoing amniocentesis or CVS are not comparable to those not having an invasive procedure. They may differ by maternal characteristics or by pregnancy characteristics, which is why some are offered an invasive test, and others are not. A recent meta-analysis of large controlled studies published over the last 10 years, has challenged conventional miscarriage risk figures by reporting substantially lower procedure-related risks of only 0.11% (95%CI, -0.04 to 0.26%) for amniocentesis and 0.22% (95%CI, -0.71 to 1.16%) for CVS.[14] This has led to calls for "women to be provided with accurate and up to date information on both invasive and non-invasive prenatal diagnostic testing so that they can make evidence based choices".[15]

While the procedure-attributable miscarriage risk may be lower than previously thought, it is uncertain if this level of safety will be maintained. As the overall

numbers of amniocenteses and CVS decrease due to cfDNA screening, so will operator and centre experience. Paradoxically, it is now a real possibility that the "per procedure" miscarriage risk will actually rise in the future as a direct consequence of this reduction in invasive testing. This is particularly so given that cfDNA screening performs least well in those where invasive procedures are likely to be the most technically challenging, ie in multiple pregnancies and obese women. Novel solutions are needed to ensure that the reduction in procedures- and attendant losses- with cfDNA screening are fully realised by patients and not compromised by an increase in loss rates due to diminishing experience.

Impact of operator experience on loss rates

It is undisputed that the procedural volume is an important factor in operative proficiency and in the minimisation of complication rates. In an early population-based study with 100% follow up, Halliday and colleagues demonstrated that operators who performed <150 CVS over three years had significantly higher miscarriage rates than those performing >150 procedures (RR4.3; p=0.003).[16] A recent census of 1953 amniocentesis and 241 CVS procedures was performed in Scotland on singleton pregnancies from May 2008 – April 2009, funded by NHS Scotland. Despite finding generalised good practice and fetal loss rates consistent with the international literature (0.7% for amniocentesis, 2.3% for CVS), the report

noted "*the most significant failings related to the number of sites where the procedures were carried out and the number of operators performing them. Too many operators performed too few procedures at too many sites*."[17] The report recommended that services providing amniocentesis and CVS in Scotland should be rationalised to reduce the number of operators and increase the number of procedures that each performs.

Aside from individual operator numbers, there may be benefit in the collective experience obtained in major centres. Institution-based data from the national Danish Registry demonstrated that miscarriage rates are inversely correlated with the number of procedures performed, with centres performing <500 procedures over 11 years having twice the risk of fetal loss compared to those performing > 1500.[18]

There is now a need for international reflection on the future provision of invasive prenatal testing.

Professional society recommendations on operator volume

In their 2010 Green Top Guidelines on Amniocentesis and CVS, the Royal College of Obstetricians & Gynaecologists (RCOG) acknowledges "*the lack of evidence in this area*" and comments that large throughput does not necessarily equate to competency. While the Australian, US and Danish Colleges do not specify a minimum volume to maintain professional competency, the RCOG has recommended at least 30 ultrasound-guided invasive procedures per annum as a "reasonable" and "feasible" volume to maintain competency for established practitioners.[19] In North America, the California Department of Public Health Genetic Disease Screening Program stipulates that practitioners must perform at least 25 procedures per annum to remain approved providers.[20]

However, the impact of cfDNA screening has meant that even a modest target of 25-30 procedures per annum may not be achievable for all current practitioners. In a recent survey of Australian obstetric sonologists, one in four (25%) respondents reported that they are currently performing < 25 total procedures per annum.[21] In this survey, the majority nominated 10-25 amniocenteses and 10-25 CVS per year as sufficient to maintain their skills, which is consistent with the total numbers recommended by US and UK bodies.

Impact of volume on training

Not only does a reduction in invasive diagnostic procedures potentially impact on operator competency and patient safety, but it also comes at a cost to the training of new specialists. Even before the introduction of cfDNA testing, concerns were raised about the effect of combined first trimester screening on training opportunities for amniocenteses and CVS.[22-24] The Royal Australian and New Zealand College of Obstetricians and Gynaecologists (RANZCOG) stipulate a minimum number for certification as subspecialist in maternal fetal medicine (100 amniocenteses/ 50 CVS over 3 years) or obstetric and gynaecological ultrasound (100 amniocenteses and 100 CVS over 3 years), but these numbers are consensus-, rather than evidence-based.[25,26]

To date, RANZCOG training data suggests that these procedural targets are still being met, with no significant reduction in invasive procedure numbers for subspecialty trainees over the most recent triennium. Nevertheless, this likely reflects that most subspecialty training is delivered in public tertiary obstetric centres. At these sites, procedure numbers are partly protected by a combination of high risk referrals (both structural and genetic abnormalities), and limited uptake of cfDNA screening in the public sector which remains significantly constrained by cost. If this latter source of referrals were to diminish - which seems inevitable given cost trends - then procedures available to trainees, and their trainers, will fall.

This is important, since trainees require high volumes of procedures in their early training to overcome the learning curve inherent in any procedural training. The existing data on CVS training describes a wide range of CVS numbers required before passing the learning curve. One study estimated that the effect of the learning curve for CVS was still evident after 50 procedures[27], and others have argued that as many as 400 CVSs are required before operator skills plateau.[28] In addition to the actual number of procedures performed, there are other influences on CVS learning curves, such as prior experience with amniocentesis.[27] Lessons from training for other invasive fetal procedures show protective effects of experienced supervisors , the "group learning effect" as an individual centre gains experience[29] and benefits of operator experience with other ultrasound-guided procedures and numbers of procedures performed annually.[30] Whether the reduction in prenatal diagnostic procedures will also have a "knock-on" effect on training in advanced fetal procedures such as fetal blood sampling and laser surgery is yet to be felt but this is a real possibility.

Training bodies may need to re-evaluate their approach to procedural training. The traditional approach of relying on clinical volume alone to achieve and maintain proficiency will likely become unsustainable. Moreover, the absence of good quality

data on the learning curve, and the influence of other factors such as prior experience in other invasive procedures, individual aptitude, and the experience of supervisor make meaningful numerical goals difficult to define. Possible solutions include: a shift toward competence-based assessment; novel training solutions including the use of simulation and/ or prioritising operator volume by centralising invasive procedures.

Competence-based assessment

Competency frameworks have been increasingly applied in the medical education sector over the last decade, although the terminology is often poorly-defined, applied and understood. Competency has been defined as: 'an observable ability of a health professional, integrating multiple components such as knowledge, skills, values and attitudes. Since competencies are observable, they can be measured and assessed to ensure acquisition by a professional'.[31] Procedural competency may be behaviourist (performance based; the ability to perform discrete tasks), situational (context dependent, with a greater emphasis on the work environment) or incorporate aspects of both. It has been suggested that the improved effectiveness of competency based medical education may reduce the overall time of training.[32] Could a similar argument exist for reducing the numbers required to achieve invasive procedural competence?

RCOG and RANZCOG are both evaluating the role of competence-based assessments to complement, or obviate, a target number for invasive procedures. For such a competency based training model to be effective, it needs to consider not just the individual steps needed to achieve procedural competence, but the range of clinical settings to be assessed, the formative and summative assessment tool, the number of trainees and adequacy of assessor time, a process for remediation and an acknowledgement of- and process to deal with- the fact that individuals learn at different rates.

Novel training solutions

Some countries allow trainees to learn CVS skills on women undergoing termination of pregnancy, or following a diagnosis of early pregnancy failure. This approach not only allows trainees to develop skills in patients without concerns about causing miscarriage , but can also provide benefits to the woman such as information on fetal karyotype after pregnancy loss.[33] Animal models could be developed for training purposes[34] but these are very limited by cost, accessibility, ethical issues and logistic challenges. Synthetic models, with or without electronic guidance systems, are another alternative to avoid training on pregnant women.[35,36] Many different proposals for low cost, low fidelity simulators using accessible materials

(such as supermarket food items) have been published.[37-39] Formal instruction using a structured simulator-based curriculum has been shown to improve performance scores[40] and decrease the number of attempts required by trainees to complete training in amniocentesis.[41] However, the persistent challenge with simulation modules is how to incorporate clinical variation and different degrees of difficulty. Despite their shortcomings, they have the potential to shorten the learning curve of trainees before they operate on human subjects. Modern technological solutions such as simulation models could potentially help reduce the learning curve. ISUOG currently has a task force addressing simulation training in ultrasound focusing on basic training. Expanding the scope of this task force to encompass training of invasive procedures might be a welcomed addition.

Is centralization the answer?

Extrapolating from the findings of the Scottish audit, there is clearly a need to consider reducing the number of centres (and the number of individuals within such centres) performing amniocentesis and CVS. Such a change may occur voluntarily, with such procedures only being offered in large, tertiary fetal medicine centres. If the decline in number of invasive procedures observed in Australia with the introduction of patient-funded cfDNA screening is extrapolated to Denmark (Figure 3), this would result in only 1000 amniocenteses and CVS being performed

nationally per annum when cfDNA screening becomes publicly-funded. Discussions are already underway to explore the feasibility of a Nordic MFM training network, as no single country in that region will have sufficient numbers to train new proceduralists in a timely manner. This approach is a natural solution for regions that are geographically close and densely populated. Centralization also brings the additional advantages of consolidating infrastructure and expertise in genetics, tertiary ultrasound and genetic counselling, as well as other invasive procedures such as in-utero blood transfusions and fetoscopic laser ablation for the treatment of twin twin transfusion syndrome (TTTS). From a quality and safety perspective, centralisation may better enable collection and analysis of outcome metrics, facilitate ongoing competency based assessments for proceduralists, and develop and implement processes for remediation of deficiencies.

It is possible that centres and practitioners will resist forgoing clinical skills (and income) if centralization becomes a reality. Such a change could be unpopular amongst patients themselves, if 'barriers' to a prenatal service are perceived to exist because of geographical circumstances and large travelling distances.

However, in a recent Swedish study on patients' attitudes towards centralization of specialized medical procedures, the factors that were most important to patients

were: i) quality of care, ii) continuity of treatment and iii) a well-functioning patient care pathway. Surprisingly, costs, income loss and geographical location were among the least important factors.[42] This is reassuring for countries already down the road to service rationalization, but it is unknown if these patient attitudes are generalizable to large countries were the population density is extremely low, such as Australia. In these settings, the trade-off between access, vicinity, travel cost and continuity of care may be very different.

In Australia, centralization of novel advanced fetal procedures such as fetoscopic laser ablation for TTTS has not been achievable due to the lack of feasibility of transporting high-risk patients long distances for treatment. An example of successful local (state-wide) collaboration for a centralized fetal therapy service exists in Victoria.[43] However, the prospect of rationalizing amniocenteses and CVS, procedures that are currently widely available and performed by specialists with a range of postgraduate training, is a matter that will generate debate regarding workforce planning, infrastructure and remuneration. The management of such issues will be dependent upon clinical leadership and a robust evidence-base. This may, however, in the end rely also on a degree of pragmatism.

Ongoing monitoring of individual performance

Ensuring high standards are maintained will require continuous performance monitoring of centres and individual practitioners, as previously discussed in this journal.[44] In the UK, the National Health Service Fetal Medicine Commissioning Group has set down in its quality dashboard a return of procedure related losses for CVS and amniocentesis (within 14 days) annually for a centre (with expected losses <1%). For individual practitioner monitoring, the RCOG currently proposes "thresholds for concern and independent review" if an individual has seven second insertions or four pregnancy losses in 100 consecutive amniocenteses, or five sampling failures or eight pregnancy losses after 100 attempted CVSs.

Monitoring relatively common complications such as multiple needle insertions and 'blood-stained' liquor volume, rather than miscarriages, have been suggested a more statistically suitable a method of continuous assessment of individual operators and may be used as proxy measures for procedure-related loss rate.[45] Some authors have suggested specific benchmarks, such as multiple insertions rates of < 2% for amniocenteses, < 5.5% for transabdominal CVS, and for unsuccessful CVS aspirations, < 0.3%.[13] Statistical methods such as the cumulative sum method (CUSUM) and 'funnel plots' have already been advocated for monitoring operator performance in fetal intravascular transfusions[29] and fetoscopic laser ablation for the treatment of TTTS.[30,46]

Whichever governance structure is chosen to monitor safety, the importance of attempting complete ascertainment of pregnancy outcomes cannot be overstated, as miscarriages are disproportionately concentrated in the group that are hardest to follow up.[47] Less than 100% follow up is very likely to underestimate loss rates.

Future consensus

The success of cfDNA technology, with its high sensitivity and specificity for trisomy 21, has raised important issues relating to the future conduct of invasive prenatal testing. There is an urgent need to future-proof the safe provision of amniocenteses and CVS. While there will always be a need to accommodate regional differences, patient safety and access to care should remain top priorities. We can no longer use a set quota of procedures as the only criteria for successful completion of training. Competency-based assessment and the use of simulation models to reduce the learning curve should be considered as adjuncts to a fixed level of procedural experience. The importance of experienced supervisors to maintain a safe and effective training environment should be recognised. Collaboration in the form of training networks may become necessary to ensure high standards of procedural training. Centralization of clinical services may be the best solution for countries where a balance between service provision and training volume can be achieved.

Finally, we may have to consider formal differentiation of specialists according to procedural skills if noninvasive prenatal testing continues to reduce indications for invasive testing. A robust, prospective national (and preferably international) consensus should help us to exploit the full potential of new technologies, whilst safeguarding quality of care for patients.

References

1. Gil MM, Quezada MS, Revello R, Akolekar R, Nicolaides KH. Analysis of cell-free DNA in maternal blood in screening for fetal aneuploidies: updated meta-analysis. Ultrasound Obstet Gynecol 2015;45(3):249-66

2. Hui L, Muggli E, Halliday J. Population-based trends in prenatal screening and diagnosis for aneuploidy: a retrospective analysis of 38 years of state-wide data. BJOG 2015. doi:10.1111/1471-0528.13488.

3. Larion S, Warsof SL, Romary L, Mlynarczyk M, Peleg D, Abuhamad AZ. Association of combined first-trimester screen and noninvasive prenatal testing on diagnostic procedures. Obstet Gynecol 2014; 123: 1303-10.

4. Robson S, Hui L. National decline in invasive diagnostic procedures in association with combined first trimester and cell-free DNA-based aneuploidy screening Aust N Z J Obstet Gynaecol 2015; doi 10.1111/ajo.12380

5. Platt LD, Janicki MB, Prosen T, Goldberg JD, Adashek J, Figueroa R, Rodis J, Liao W, Sehnert AJ, Snyder HL, Warsof SL. Impact of noninvasive prenatal testing in regionally dispersed medical centers in the United States. Am J Obstet Gynecol 2014;211(4):368.e1-7.

6. Wax JR, Cartin A, Chard R Lucas FL, Pinette MG. Noninvasvie prenatal testing: impact on genetic counselling, invasive prenatal diagnosis, and trisomy 21 detection. J Clin Ultrasound 2015; 43:1-6.

7. Mangegold-Brauer G, Kang Bellin A, Hahn S, De Geyter C, Buechel J, Hoesli I, Lapaire O. A new era in prenatal care: non-invasive prenatal testing in Switzerland. Swiss Med Wkly 2014; 144"w13915.

8. Chan YM, Leun WC, Chan WP, Leung TY, Cheng YK, Sahota DS. Women's uptake of non-invasive DNA testing following a high-risk screening test for trisomy 21 within

a publicly funded healthcare cystem: findings from a retrospective review. Prenat Diagn 2014; 35(4):342-7.

9. Hillman SC, McMullan DJ, Hall G, Togneri FS, James N, Maher EJ, Meller CH, Williams D, Wapner RJ, Maher ER, Kilby MD. Use of prenatal chromosomal microarray: prospective cohort study and systematic review and meta-analysis. Ultrasound Obstet Gynecol. 2013;41(6):610-20

10. Hillman SC, Willams D, Carss KJ, McMullan DJ, Hurles ME, Kilby MD. Prenatal exome sequencing for fetuses with structural abnormalities: the next step. Ultrasound Obstet Gynecol. 2015;45(1):4-9

11. Mackie FL, Morris RK, Hemming K, Allen S, Kilby MD. Cell free DNA based non-invasive prenatal testing : a systematic review and meta-analysis of diagnostic accuracy. BJOG 2015; 122 (2): 2-3

12. Alfirevic Z, Mujezinovic F, Sundberg K. Amniocentesis and chorionic villus sampling for prenatal diagnosis. Cochrane Database of Systematic Reviews 2003, Issue 3. Art. No.: CD003252. DOI: 10.1002/14651858.CD003252.

13. Mujezinovic F, Alfirevic Z. Procedure-related complications of amniocentesis and chorionic villus sampling. A systematic review. Obstet Gynecol 2007; 110(3): 687-94

14. Akolekar R, Beta J, Picciarelli G, Ogilvie C, D'Antonio F. Procedure-related risk of miscarriage following amniocentesis and chorionic villus sampling: a systematic review and meta-analysis. Ultrasound Obstet Gynecol 2015; 45: 16-26.

15. Borrell A and Stergiotou I. Cell-free DNA testing: inadequate implementation of an outstanding technique. Ultrasound Obstet Gynecol 2015; 45: 508-511.

16. Halliday JL, Lumley J, Sheffield LJ, Robinson HP, Renou P, Carlin JB. Importance of complete follow-up of spontaneous fetal loss after amniocentesis and chorion villus sampling. Lancet 1992; 340: 886-90.

17. Kilby MD. Amniocentesis and Chorionic Villus Sampling in Scotland: An audit of techniques and outcomes of all procedures over one year in Scotland. NHS Scotland, 2010 [http://www.healthcareimprovementscotland.org/our_work/reproductive,_maternal_child/programme_resources/amniocentesis_chorionic_villus.aspx).

18. Tabor A, Vestergaard CH, Lidegaard O. Fetal loss rate after chorionic villus sampling and amniocentesis: an 11-year national registry study. Ultrasound Obstet Gynecol 2009; 34: 19-24.

19. Royal College of Obstetricians and Gynecologists. Amniocentesis and Chorionic villus sampling. 2010. Alfirevic Z and Kilby MD. https://http://www.rcog.org.uk/en/guidelines-research-services/guidelines/gtg8/. [4 May 2015].

20. California Department of Public Health. Prenatal Diagnosis Center Standards and Definitions. California Department of Public Health Genetic Disease Screening Program: Richmond, CA; 2014.

21. Hui L, The S, McCarthy EA, Walker SP. Emerging issues in invasive prenatal diagnosis: safety and competency in the post-NIPT era. Aust NZ J Obstet Gynaecol 2015. doi 10.1111/ajo.12396.

22. Rose NC, Lagrave D, Hafen B, Jackson M. The impact of utilization of early aneuploidy screening on amniocenteses available for training in obstetrics and fetal medicine. Prenat Diagn 2013;33(3):242-4.

23. Jenkins TM, Sciscione AC, Wapner RJ, Sarto GE. Training in chorionic villus sampling: limited experience for US fellows. Am J Obstet Gynecol. 2004 Oct;191(4):1288-90.

24. Monni G, Zoppi MA. Improved first-trimester aneuploidy risk assessment: an evolving challenge of training in invasive prenatal diagnosis. Ultrasound Obstet Gynecol. 2013;41(5):486-8.

25. Royal Australian and New Zealand College of Obstetricians and Gynaecologists. Certification in Obstetrical and Gynaecological Ultrasound training program handbook. 2015. http://www.ranzcog.edu.au/training-handbooks2.html. [4 May 2015].

26. Royal Australian and New Zealand College of Obstetricians and Gynaecologists. Certification in Maternal Fetal Medicine training program handbook. 2015. http://www.ranzcog.edu.au/training-handbooks2.html. [4 May 2015]

27. Wijnberger LDE, van der Schouw YT, Christiaens GCML. Learning in medicine: chorionic villus sampling. Prenat Diagn 2000; 20: 241-246.

28. Saura R, Gauthier B, Taine L, Wen ZQ, Horovitz J, Roux D, Laulom B, Vergnaud A. Operator experience and fetal loss rate in transabdominal CVS. Prenat Diagn 1994;14(1):70-1

29. Lindenberg JT, Wolterbeek R, Oepkes D, Klumper FJ, Vandenbussche FP, van Kamp IL. Quality control for intravascular intrauterine transfusion using cumulative sum (CUSUM) analysis for the monitoring of individual performance. Fetal Diagn Ther. 2011;29(4):307-14

30. Peeters SH, Van Zwet EW, Oepkes D, Lopriore E, Klumper FJ, Middeldorp JM. Learning curve for fetoscopic laser surgery using cumulative sum analysis. Acta Obstet Gynecol Scand. 2014;93(7):705-11

31. Frank JR, Snell LS, Cate OT, Holmboe ES, Carraccio C, Swing SR, Harris P, Glasgow NJ, Campbell C, Dath D, Harden RM, Iobst W, Long DM, Mungroo R, Richardson DL,

Sherbino J, Silver I, Taber S, Talbot M, Harris KA. Competency-based medical education: theory to practice. Med Teach. 2010; 32(8):638-45

32. Australian Medical Council Policy Documents; Competence based medical education (August 2010). Accessed at http://www.amc.org.au/publications/policy September 18, 2015.

33. Nicholas S, Orzechowski K, Potti S, Baxter J, Berghella V, Weiner S. Early pregnancy failure as a training tool for chorionic villus sampling. Prenat Diagn. 2013 Nov;33(11):1110-2.

34. Nitsche JF, Brost BC. The use of simulation in maternal-fetal medicine procedure training. Semin Perinatol. 2013;37(3):189-98.

35. McWeeney DT, Schwendemann WD, Nitsche JF, Rose CH, Davies NP, Watson WJ, Brost BC. Transabdominal and transcervical chorionic villus sampling models to teach maternal-fetal medicine fellows. Am J Perinatol. 2012;29(7):497-502.

36. Nizard, J. D., M.; Ville, Y. Teaching ultrasound-guided invasive procedures in fetal medicine: learning curves with and without an electronic guidance system. Ultrasound in Obstetrics and Gynecology 2002; 19(3): 274-277.

37. Karasahin E, Alanbay I, Ercan M, Yenen MC, Dede M, Başer I. Simple, cheap, practical and efficient amniocentesis training model made with materials found in every obstetrics clinic. Prenat Diagn. 2009;29(11):1069-70.

38. Wax JR, Cartin A, Pinette MG. The birds and the beans: a low-fidelity simulator for chorionic villus sampling skill acquisition. J Ultrasound Med. 2012; 31(8):1271-5.

39. Zubair I, Marcotte MP, Weinstein L, Brost BC. A novel amniocentesis model for learning stereotactic skills. Am J Obstet Gynecol. 2006;194(3):846-8.

40. Pittini R, Oepkes D, Macrury K, Reznick R, Beyene J, Windrim R. Teaching invasive perinatal procedures: assessment of a high fidelity simulator-based curriculum. Ultrasound Obstet Gynecol. 2002;19(5):478-83.

41. Khurshid N, Trampe B, Heiser T, Birkeland L, Duris E, Stewart K, Shah D, Iruretagoyena J. Impact of an amniocentesis simulation curriculum for training in MFM fellowship program. Am J Obstet Gynecol 2014; S212.

42. Svederud I, Virhage M, Medin E, Grundström J, Friberg S, Ramsberg J. Patient perspectives on centralization of low volume, highly specialised procedures in Sweden. Health Policy 119(8): 1068-1075.

43. Teoh M, Walker SP, Cole S and Edwards E. 'A problem shared is a problem halved': success of a statewide collaborative approach to fetal therapy. Outcomes of fetoscopic laser photocoagulation for twin–twin transfusion syndrome in Victoria. Aust NZ J Obstet Gynaecol; 53:108-113.

44. Alfirevic Z. Who should be allowed to perform amniocentesis and chorionic villus sampling? Ultrasound Obstet Gynecol. 2009;34(1):12-3.

45. Lane S, Weeks A, Scholefield H, Alfirevic Z. Monitoring obstetricians' performance with statistical process control charts. BJOG. 2007;114(5):614-8.

46. Papanna R, Biau DJ, Mann LK, Johnson A, Moise KJ Jr. Use of the Learning Curve-Cumulative Summation test for quantitative and individualized assessment of competency of a surgical procedure in obstetrics and gynecology: fetoscopic laser ablation as a model. Am J Obstet Gynecol. 2011;204(3):218.e1-9;

47. Halliday JL, Sheffield LJ, Danks D, Lumley J. Complete follow-up in assessing fetal losses after chorionic villus sampling. Lancet 1990; 335(8698):1156.

Figure legends.

Figure 1. Australian Medical Benefits Scheme (MBS) billing numbers of amniocenteses and CVS Jan 1994 – June 2015 in relation to introduction of combined first trimester screening (FTS) and cell free DNA screening (cfDNA). Annual numbers for 2015 projected from first six months only.*

Figure 2. National MBS billing numbers for amniocenteses and CVS by quarter from Jan 2013 to June 2015 (period of commerically-available cfDNA screening)*

*Source: MBS database at http://medicarestatistics.humanservices.gov.au/statistics/mbs_item.jsp for procedural item numbers 16600 (diagnostic amniocentesis) and 16603 (chorionic villus sampling by any route) [accessed 4 Aug 2015]

Figure 3. Danish registry data on annual numbers of amniocenteses and CVS from 2000-2014

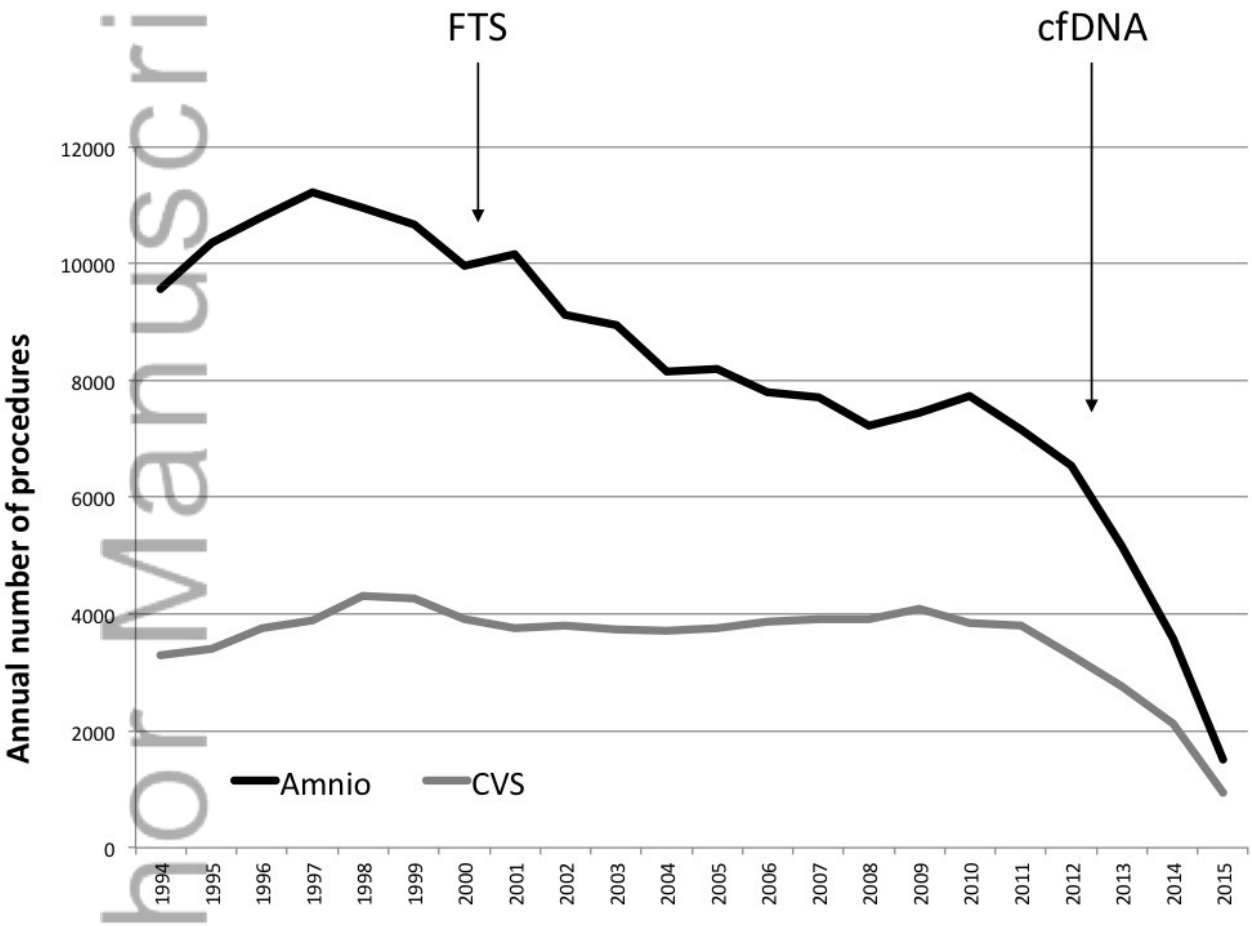

Figure 1.jpg

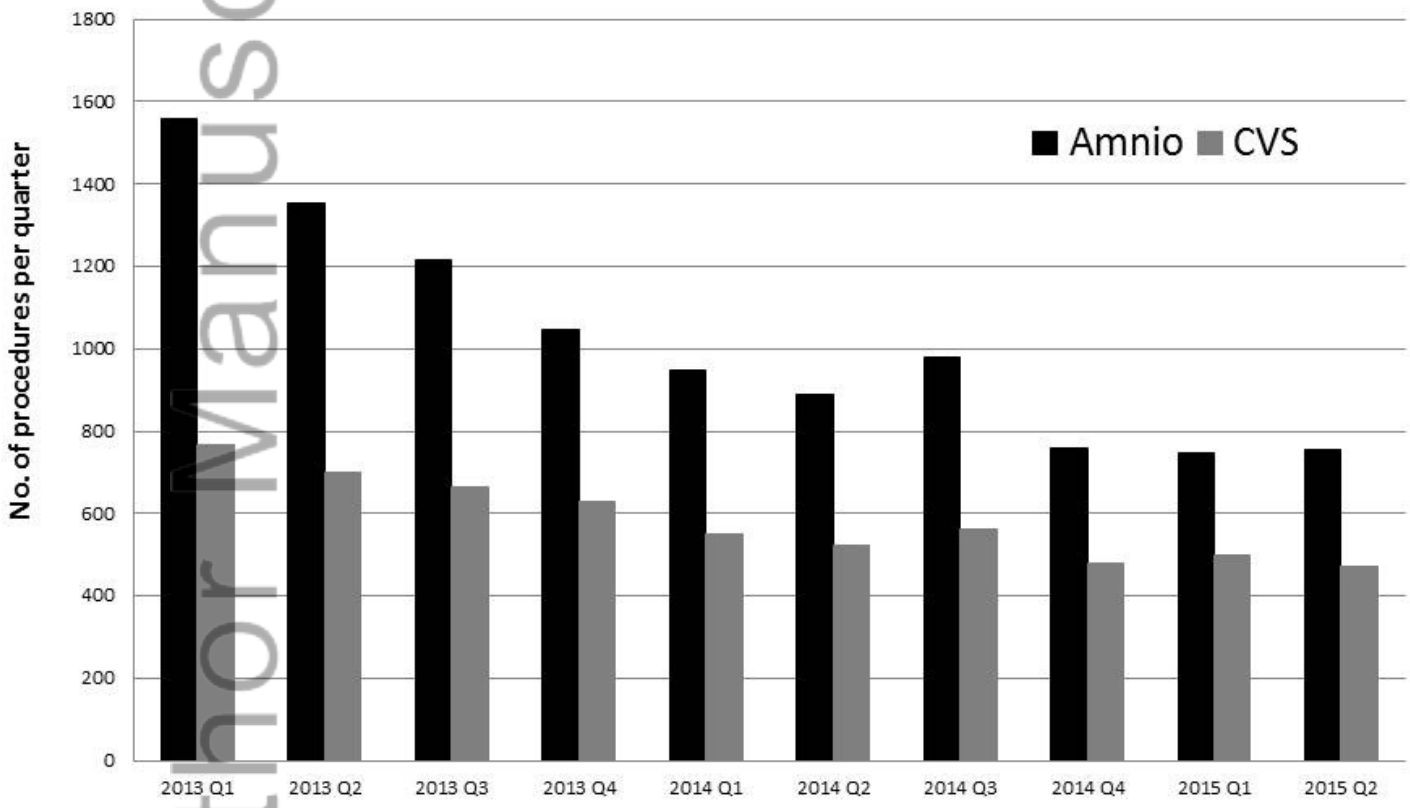

Figure 2 v2.jpg

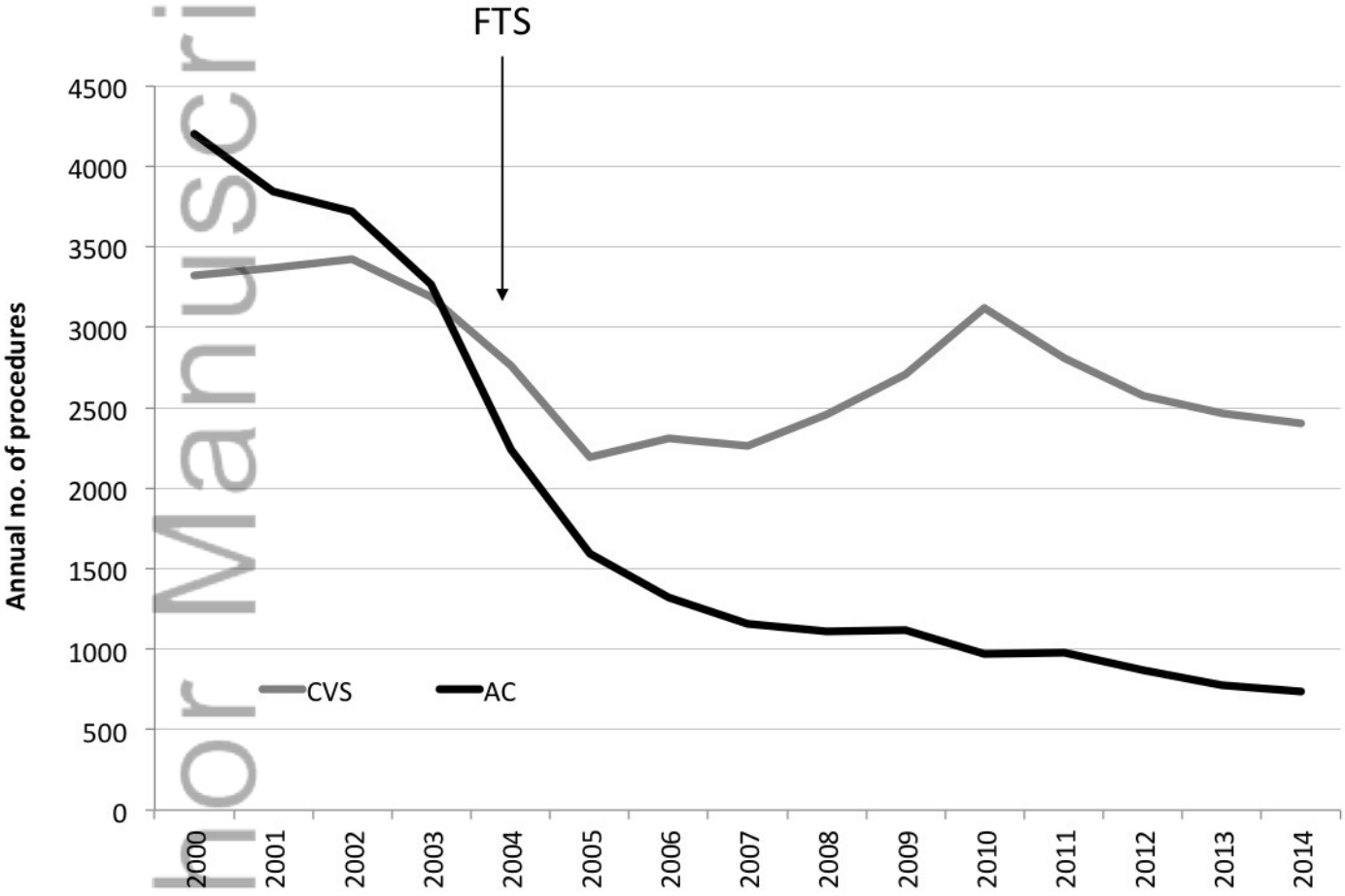

Figure 3.jpg