

Online Research @ Cardiff

This is an Open Access document downloaded from ORCA, Cardiff University's institutional repository: <http://orca.cf.ac.uk/118278/>

This is the author's version of a work that was submitted to / accepted for publication.

Citation for final published version:

Piña-Aguilar, Raul E., Simpson, Sheila A., Alshatti, Abdulrahman, Clarke, Angus, Craufurd, David, Dorkins, Huw, Doye, Karen, Lahiri, Nayana, Lashwood, Alison, Lynch, Colleen, Miller, Claire, Morton, Sally, O'Driscoll, Mary, Quarrell, Oliver W., Rae, Daniela, Strong, Mark, Tomlinson, Charlotte, Turnpenny, Peter and Miedzybrodzka, Zosia 2019. 27 years of prenatal diagnosis for Huntington disease in the United Kingdom. *Genetics in Medicine* 21 , pp. 1639-1643. 10.1038/s41436-018-0367-z file

Publishers page: <http://dx.doi.org/10.1038/s41436-018-0367-z> <<http://dx.doi.org/10.1038/s41436-018-0367-z>>

Please note:

Changes made as a result of publishing processes such as copy-editing, formatting and page numbers may not be reflected in this version. For the definitive version of this publication, please refer to the published source. You are advised to consult the publisher's version if you wish to cite this paper.

This version is being made available in accordance with publisher policies. See <http://orca.cf.ac.uk/policies.html> for usage policies. Copyright and moral rights for publications made available in ORCA are retained by the copyright holders.



27 Years of Prenatal Diagnosis for Huntington Disease: Still an Important Option despite the Increasing Use of Pre-implantation Genetic Diagnosis

Raul E. Piña-Aguilar^{1,2}, Sheila Simpson², David Craufurd³, Daniela Rae^{1,2}, Abdulrahman Ahlshatti^{1,*}, Angus Clarke⁴, Huw Dorkins⁵, Karen Doye⁶, Nayana Lahiri^{7,8}, Alison Lashwood⁹, Collen Lynch¹⁰, Claire Miller¹¹, Sally Morton¹², Mary O'Driscoll¹³, Oliver W. Quarrell¹⁴, Mark Strong¹⁵, Charlotte Tomlinson⁹, Peter Turnpenny¹⁶, on behalf of the UK HD Predictive Testing Consortium, Zosia Miedzybrodzka^{1,2}

¹School of Medicine, Medical Sciences and Nutrition, University of Aberdeen, Aberdeen, UK

²North of Scotland Regional Genetics Service, Aberdeen Royal Infirmary, Aberdeen, UK

³University of Manchester, Manchester, UK

⁴Institute of Cancer and Genetics, University of Cardiff, Cardiff, UK

⁵Leicester Royal Infirmary, Leicester, UK

⁶The Centre for Reproductive & Genetic Health, London, UK

⁷St George's University of London, London, UK

⁸St George's University Hospitals NHS Foundation Trust, London, UK

⁹Clinical Genetics, Guy's Hospital, London, UK

¹⁰CARE Fertility Centre, Nottingham, UK

¹¹Liverpool Women's Hospital, Liverpool, UK

¹²South East of Scotland Genetics Services, Molecular Medicine Centre, Western General Hospital, Edinburgh, UK

¹³Clinical Genetics Unit, Birmingham Women's NHS Foundation Trust, Birmingham, UK

¹⁴Department of Clinical Genetics, Sheffield Children's Hospital, Sheffield, UK

¹⁵School of Health and Related Research (SchARR), University of Sheffield, Sheffield, UK

¹⁶Clinical Genetics, Royal Devon & Exeter Healthcare NHS, Exeter, UK

*Current address: Kuwait Medical Genetics Center

Correspondence to: Prof. Zosia Miedzybrodzka, Clinical Genetics Centre, Ashgrove House, Foresterhill, Aberdeen, AB25 2ZA Tel: 01224552120

Email zosia@abdn.ac.uk

Abstract

Objective

To examine trends in prenatal diagnosis and pre-implantation diagnosis for Huntington disease (HD) in United Kingdom since services commenced.

Design

Long term UK wide prospective case record based service evaluation.

Setting

23 UK Regional Genetic Centres 1988-2015, and four UK PGD centres 2002-2015

Participants

479 couples undergoing prenatal diagnosis (PND) for HD and 305 cycles of pre-implantation diagnosis (PGD) for HD.

Main outcome

Annual rates of PND and PGD for HD.

Results

From 1988 – 2015, 479 prenatal diagnoses were performed in the UK for HD, an exclusion approach was used in 150 (31%). The annual number of PND for HD has remained in the order of 18 cases per year since testing began, a rate of 3.5 per million of UK population.

Since UK licensing of PGD for HD in 2002, more than 300 cycles of PGD for HD have been performed. The annual rate of prenatal diagnosis has remained similar over 27 years, despite a steady increase in the use of PGD for HD.

Conclusions Although increasing number of couples are choosing either direct or exclusion PGD to prevent HD in their offspring, both direct and exclusion prenatal diagnosis remain important options in a health system where both PGD and PND are state funded. At risk couples, should continue to be informed of all options available to them, preferably pre-pregnancy.

What is already known on this topic

HD is a late-onset neurogenetic disorder with autosomal dominant inheritance. Whilst not all choose to intervene; families at risk have the option of testing an established pregnancy or conceiving with preimplantation genetic diagnosis for the disorder. With both methods, direct mutation testing or linkage analysis are used to distinguish between high- and low- risk conceptions.

Few studies have reported a long-term, prospective survey of prenatal diagnosis for HD. The effect of the availability of PGD on decisions made by families about conventional prenatal diagnosis is not known.

What this study adds

Our study is the longest series of PND and PGD for a neurogenetic disorder. It shows that, despite an important increase in the use of PGD, the number of prenatal diagnoses has remained stable for 27 years. PGD has not replaced PND, our results suggest a new group of patients have been tested. Families at risk of HD in UK should be offered both options pre-pregnancy.

Introduction

HD is an autosomal dominant neurodegenerative disease characterised by cognitive decline, movement disorder and frequent psychopathology, leading to death over 10 – 25 years. Onset is most often in a person's 30s - 50s, but may be earlier or later¹. Growing-up with an affected parent can present a significant psychological burden for those at risk². Those at risk of HD have a number of reproductive options³. Many choose to accept the 50% risk of each child being affected, some choose to remain childless, adopt a child or use gamete donors. The identification by linkage to the HD locus resulted in the additional option of prenatal diagnosis (PND) and termination of affected pregnancies, or increasingly, the possibility of pre-implantation genetic diagnosis (PGD) to select mutation-negative embryos conceived by in-vitro fertilisation (IVF).

Pre-symptomatic predictive testing and prenatal diagnosis (PND) in HD serve as paradigms for testing in other late-onset genetic neurodegenerative disorders, such as familial early-onset Alzheimer Disease. Family based linkage studies have been used to offer PND in the UK since 1988. Direct mutation testing became possible in 1993 with the discovery that a triplet repeat expansion within exon 1 of the gene *Huntingtin* causes the disease⁴. Fetal DNA samples for PND can be taken using chorionic villus sampling (CVS) from 11 weeks' gestation, and from around 15 weeks by amniocentesis. However, couples with a fetus who is at a high risk have can only undergo termination of pregnancy if they are to avoid the birth of an affected child. As the majority of individuals at risk of HD choose not to undergo predictive testing and it is typically a late onset condition, prenatal testing is not offered for information only and couples are carefully counselled around this aspect when making reproductive decisions. In preimplantation genetic diagnosis (PGD), couples avoid the need for termination through embryo biopsy and genetic testing of pre-implantation embryos created using *in vitro* fertilisation⁵. PGD for HD was first reported in 1996⁶.

Some couples who use reproductive technologies to avoid having a child affected by HD have undergone predictive testing and know that they carry the HD gene. In such cases, PND is typically performed using "direct" testing of the pregnancy for the HD gene mutation. Those at risk who wish to avoid passing on the gene but do not wish to find out their own HD status, can use "exclusion" or "indirect" testing. DNA markers linked to the HD gene are used to establish which grandparent contributed the HD gene passed to the fetus from the at-risk parent: the affected grandparent or their spouse. If the fetus has not inherited the gene from the affected grandparent, this excludes the mutated HD gene in the pregnancy or embryo. Exclusion testing, whether applied through PND or PGD, allows the at-risk parent to avoid discovery of their genetic risk. However, this means that parents who do not in fact have the mutated HD gene, may then terminate an unaffected pregnancy or discard unaffected embryos that happens to share the **affected** grandparental haplotype, as there is a 50% chance that this haplotype harbours the mutated gene, and a 50% chance that it harbours the normal copy.

In the UK access to PND is overseen by NHS boards/trusts and professional networks, but access to PGD is regulated by the Human Fertilisation and Embryology Authority (HFEA).

Before 1993, prenatal diagnosis for HD was performed using linkage analysis. Both direct and exclusion PND have been available in the UK since 1993, free at the point of care through NHS public funded healthcare. Direct PGD for HD was licensed in the UK from 2002, and exclusion PGD from 2009. NHS funding for direct and exclusion PGD testing for HD is now widely available free of charge to couples at risk across the UK who do not already have a child and fulfil other NHS funding criteria for PGD.

With better awareness of reproductive risks and options within families, and increasing optimism driven by global research efforts in HD treatment, we hypothesised that the request rate for PND might be in decline.

Data on HD PND has been systematically retrospectively collected from 23 regional genetic centres on an annual basis since testing began 27 years ago. Results from the first years 1994-1998 has been reported⁷. Here we describe the trends in PND in the UK since inception of these services, and compare these with available data on UK PGD uptake.

Methods

Participants and exposures

Members of the UK predictive testing consortium retrospectively submitted annual anonymous data on prenatal diagnosis uptake from 1987 to 2015, using the same core data format for most of that time.

The number of PGD cycles performed each year for HD reported by Guy's Hospital, the Centre for Reproductive and Genetic Health in London, University College London, the Western General Hospital in Edinburgh and the CARE centre in Nottingham.

Endpoints

Numbers of cases and the types of test were recorded annually and presented at the annual HD Consortium meetings. Additional data were gathered on age, sex of the at-risk partner, predictive testing status of the at-risk partner, timing of predictive testing with respect to the pregnancy, mode of prenatal diagnosis (direct or exclusion testing), results of prenatal diagnosis and pregnancy outcome. Available PGD data included the number of couples undergoing treatment and the total number of cycles commenced.

Statistical analysis

Analysis of case frequency was performed in all cases. Detailed information was available for 411 PND cases. Data were analysed using IBM SPSS version 23, and the Chi squared test of proportions.

Patient involvement

Patient representatives from the Huntington's Disease Association attended and contributed to discussions about study design and data interpretation at UK predictive testing group meetings.

Results

From 1988 to 2015, 479 prenatal studies were performed across 23 UK centres. An indirect (exclusion) approach was used in 144 (31.2%; Figure 1). Testing rates were low before the identification of the gene in 1993, and 1994 saw the highest number of tests requested (37). From 1995 – 2015, the rate of PND has remained modest but steady, with a mean of 21 pregnancies per year being tested.

Detailed case information was available for 411 PND pregnancies. The at-risk parent was female in 51% (Figure 3). The majority of at-risk PND parents had undergone pre-symptomatic predictive testing (84%), only 15.8% of these predictive tests were performed during pregnancy.

Direct mutation testing was performed in 62.5% of PND, with the exclusion approach being used in 37.5%. The fetus was found to be affected by HD in 53% of direct PND cases, and 90.2% of these pregnancies underwent termination. The remaining 12 (9.8%) were continued, resulting in the parents being aware that the child would one day develop HD. Only one HD unaffected pregnancy was reported to have been terminated (Figure 4). Of the exclusion tested pregnancies, termination was performed in 87.5% with a high-risk result, and the remaining 9 (12.5%) continued. None of the low risk exclusion pregnancies underwent termination. In these 21 continued affected and high-risk pregnancies, the at risk/affected parent was more often the mother (56.3% vs 43.7%), whereas in terminated pregnancies the at-risk parent was more often the father (52.9% vs 47.1%) (Figure 5), however neither of these differences reached statistical significance (two tailed Chi-square, $p=0.1616$).

From 2002 to 2015, 305 IVF-PGD cycles were performed in the UK for HD. The annual number of PGD cycles has increased steadily over time (Figure 2).

Discussion

Principal findings

PND has been available in the UK since 1988. Other than a peak in the year the HD gene was identified, the rate of uptake of PND is modest and has remained remarkably similar over more than two decades. The annual number of PGD cycles has steadily increased since UK licensing of the procedure in 2002.

Exclusion testing remains an important option for couples at risk, with around one third of PND in the UK using this method. Intriguingly, available data suggests that exclusion testing is used more often in PGD (personal communication; data not shown as not available for all centres).

Both at risk men and at-risk women choose PND and PGD. Around 15% of parents are symptomatic at the time of reproductive testing.

During our 27-year study period, the UK population grew from 56.93 million to 65.11 million, thus the annual rate of HD PND has fallen from 0.316 per million to 0.276 per million. The rate of HD PGD cycles was 0.463 per million in 2015. Taking into account the prevalence and incidence of HD, we have estimated that the order of magnitude for the uptake of PND and PGD in 2015 was at least 3.4% of at risk pregnancies (see Supplementary Info). Despite the rising uptake of PGD for HD, the vast majority of UK pregnancies at risk of HD continued to remain untested.

Access to PND and PGD funding varies worldwide. In the UK, both PND and PGD for HD is fully publicly funded for couples by the NHS and is generally co-ordinated through Genetic Regional Centres. Although in some areas (e.g. Scotland) PGD access is limited to couples without a child, we propose that this data indicate couples' behaviour in an environment where at least some real choice is available.

Strengths and limitations of the data

Here we report on more than 27 years' use of prenatal and preimplantation diagnosis across the UK. This is by far the longest longitudinal study of HD reproductive choices worldwide, and demonstrates, on a national scale, the impact reproductive technologies like PND and PGD.

Although testing rates have been captured reliably through the course of the study, detailed data for 12% of cases is missing due to the challenges of data collection in a nationwide study over three decades and without specific funding. Only minimal and anonymous data were collected, to maintain participation, but PND rates may be slightly under reported. PGD data were^{was} obtained directly from all UK centres currently offering PGD. The number of PGD cycles are not equivalent to PND rates as they do not always result in a clinical pregnancy. The likely level of under ascertainment does not alter our conclusions.

Comparison with previous studies

As genetic diagnosis of HD is only provided in the UK by the NHS (I am uncertain this is the case as I know of people diagnosed through private neurologists and patients who have seen private geneticist about prenatal) our data represent a true nationwide picture, in contrast to other countries where a market in private genetic testing limits data access. A small part of UK cases has been reported in a European context⁹; but only a few studies have reported national experience of prenatal diagnosis for HD, with reports from Canada¹⁰, Australia¹¹ and the Netherlands¹² but these reports did not capture the transition to PGD.

Van Rijj et al.¹² reported a series of 126 Dutch HD prenatal diagnoses. 82% of affected pregnancies in that series resulted in termination, in contrast to 90% in our UK series. They estimated that in the Netherlands 22% of at risk couples used PND when pregnant. An adjunct paper analysing the uptake of PGD found that couples opting for PGD after

pregnancy were more likely to have terminated a previous affected pregnancy than those undergoing PND alone (87% vs 55%)¹³.

. In the present study, other factors may play a role. In the UK, patient access to both PND & PGD is covered by the NHS; although the support for PGD is more limited. NHS funding for PGD is limited to 3 cycles or one successful pregnancy and, if couples had an existing child together that is unaffected or status unknown they would be unable to access PGD on the NHS. In addition, some people may feel the option of PGD in the UK is restricted due to the geographical location of the few centres that are licenced to offer NHS funded PGD. In the Netherlands, 'non-disclosure' PGD is banned by law, so that those who wish to use this approach must travel to a different country such as Belgium, while in UK the majority of PGD cycles are exclusion diagnoses.

Regional differences impact the use of prenatal/preimplantation diagnosis. There is no European registry of prenatal diagnosis for genetic disorders, but the European Society of Human Reproduction (ESHRE) maintains a PGD registry. The latest report from 2010 found that, of 1574 cycles performed for monogenic disorders, 158 (10%) were for HD. Across the ESHRE dataset, the pregnancy rate for PGD was 22%; 2 of 10 couples for whom embryo transfer is performed are achieving a pregnancy¹⁴. In the UK, HD has become the most common indication for monogenic PGD, and pregnancy rates are 34% per cycle, with a live birth rate of 23% for fresh embryo transfer and 18% for frozen from 1999-2012¹⁵. The latest data available from HFEA reported a 25.6% live birth per initiated cycle for 2013¹⁶. In the UK, there are restrictions for NHS funding of PGD cycles including the female partner's age, body mass index, the smoking status, alcohol and illegal drug use of both partners. NHS funding criteria are limited to couples who do not have an unaffected child. This excludes those who have **had successful** PGD/PND previously but also those who have chosen not to have a test and therefore do not know the genetic status of their current child. Therefore, PGD is not freely available to all couples at risk.

Clinical and research implications

In choosing between PND and PGD couples balance personal, ethical, cultural and health issues. Many couples consider the concept of PGD as more attractive than PND when planning a future pregnancy, as it avoids termination of affected pregnancies and the procedure-associated loss of a normal pregnancy. However, the risks and stresses of IVF also bring their own burdens, coupled with a lower chance of a successful pregnancy outcome¹⁷. IVF and PGD put extra risks in a woman **compared to those interested** in prenatal diagnosis, amniocentesis or chorionic villi sampling, that generate primary a pregnancy loss risk.

Patterns of CVS and amniocentesis usage are changing rapidly with the advent of non-invasive prenatal testing (NIPT) for screening Down syndrome and other aneuploidies and non-invasive prenatal diagnosis (NIPD) for some de novo paternal monogenic disorders using fetal free DNA. A case of NIPD for HD was recently reported¹⁸. Although Van den Oever¹⁸ demonstrated the proof of principle that free fetal DNA can be used for the diagnosis of HD, the intrinsic technical challenges of sequencing for a triplet repeat disorder means that this technique is not available in the UK and majority of countries. A linkage-based

approach may be preferred, as often used in PGD for HD and other monogenic disorders. Funding is not currently available for NIPD in the UK.

Further studies of the social and health economic consequences of PND and PGD are required to understand the full effect of these reproductive technologies for the burden of disease in families affected by HD. Our data suggest that a long-term policy of making reproductive technologies available on a population basis free at the point of care has led to a significant reduction in HD births in the UK but the principal motivation for service provision has to remain the wish to support patients and families in facing and coping with this disease. Families with HD require support to face the challenges of this disease and to lead lives, as individuals and families, that are as full and rewarding as can be achieved.

The cost of PND is around £210 plus clinic costs and of PGD is around £12,000 (only compared with an IVF cycle costs of around £7,500). These costs are easily outweighed by the lifetime medical and social care costs of HD that may be averted by the decisions to avoid having a child who may be affected. The UK health care funding model offers couples the opportunity to choose between PND and PGD, and thus we propose that our results reflect couples' wishes for testing when largely unencumbered by financial considerations.

Conclusions

This is the longest running study reporting national rates of prenatal and preimplantation diagnosis for a neurogenetic disorder. Prenatal diagnosis, by both direct and exclusion test methods, is as popular in the UK now as a generation ago. The rate of pre-implantation genetic diagnosis for HD is rising, with many couples seeking exclusion testing. Thus, many more at-risk couples are seeking to give birth only to children whom they know will not be affected by HD compared with 20 years ago. Couples including one partner at risk of HD should be offered non-directive information about the reproductive options, pre-pregnancy advice and access to both direct and exclusion PND and PGD.

Acknowledgements

We are grateful to UK genetics centres for supplying the data, and Kirsty Mathieson, Vivien Vaughan and Stella Sihlabela for collating data. The NHS Grampian Huntington's disease endowments research fund made a contribution to the running costs of the study.

Authors contributions.

Contributors: ZM led the collation of 27 years of data, analysed the data, drafted and revised the paper with REPA. She is the guarantor. SS, and DC established the prospective data collection, collected data in their centres and co-ordinated the group to collect data annually for 27 years, contributed to data interpretation and commented on the paper. KD, AL, CL, SM, CL provided the data on PGD, contributed to data interpretation and commented on the paper. DR, AA, collated annual data submission, contributed to data interpretation and commented on the paper. MS provided data interpretation. HD, MO, OQ, CT, PT, NL and

members of the UK HD predictive testing consortium supplied annual data for their centre, contributed to data interpretation and commented on the paper.

References

1. Ross CA, Aylward EH, Wild EJ, Langbehn DR, Long JD, Warner JH, Scahill RI, Leavitt BR, Stout JC, Paulsen JS, Reilmann R, Unschuld PG, Wexler A, Margolis RL, Tabrizi SJ. Huntington disease: natural history, biomarkers and prospects for therapeutics. *Nat Rev Neurol*. 2014;10(4):204-16.
2. Forrest Keenan K, Miedzybrodzka Z, van Teijlingen E, McKee L, Simpson SA. Young people's experiences of growing up in a family affected by Huntington's disease. *Clin Genet*. 2007;71(2):120-9.
3. de Die-Smulders CE, de Wert GM, Liebaers I, Tibben A, Evers-Kiebooms G. Reproductive options for prospective parents in families with Huntington's disease: clinical, psychological and ethical reflections. *Hum Reprod Update*. 2013;19(3):304-15.
4. The Huntington's Disease Collaborative Research Group. A novel gene containing a trinucleotide repeat that is expanded and unstable on Huntington's disease chromosomes. *Cell*. 1993;72(6):971-83.
5. Brezina PR, Kutteh WH. Clinical applications of preimplantation genetic testing. *BMJ*. 2015;350:g7611.
6. Schulman JD, Black SH, Handyside A, Nance WE. Preimplantation genetic testing for Huntington disease and certain other dominantly inherited disorders. *Clin Genet*. 1996;49(2):57-8.
7. Simpson SA, Harper PS; United Kingdom Huntington's Disease Prediction Consortium. Prenatal testing for Huntington's disease: experience within the UK 1994-1998. *J Med Genet*. 2001;38(5):333-5.
8. Evans SJ, Douglas I, Rawlins MD, Wexler NS, Tabrizi SJ, Smeeth L. Prevalence of adult Huntington's disease in the UK based on diagnoses recorded in general practice records. *J Neurol Neurosurg Psychiatry*. 2013;84(10):1156-60.
9. Simpson SA, Zoetewij MW, Nys K, Harper P, Dürr A, Jacopini G, Yapijakis C, Evers-Kiebooms G. Prenatal testing for Huntington's disease: a European collaborative study. *Eur J Hum Genet*. 2002;10(11):689-93.
10. Creighton S, Almqvist EW, MacGregor D, Fernandez B, Hogg H, Beis J, Welch JP, Riddell C, Lokkesmoe R, Khalifa M, MacKenzie J, Sajoo A, Farrell S, Robert F, Shugar A, Summers A, Meschino W, Allingham-Hawkins D, Chiu T, Hunter A, Allanson J, Hare H, Schween J, Collins L, Sanders S, Greenberg C, Cardwell S, Lemire E, MacLeod P, Hayden MR. Predictive, pre-natal and diagnostic genetic testing for Huntington's disease: the experience in Canada from 1987 to 2000. *Clin Genet*. 2003;63(6):462-75.

11. Tassicker RJ, Marshall PK, Liebeck TA, Keville MA, Singaram BM, Richards FH. Predictive and pre-natal testing for Huntington Disease in Australia: results and challenges encountered during a 10-year period (1994-2003). *Clin Genet.* 2006;70(6):480-9.
12. van Rij MC, de Koning Gans PA, Aalfs CM, Elting M, Ippel PF, Maat-Kievit JA, Vermeer S, Verschuuren-Bemelmans CC, van Belzen MJ, Belfroid RD, Losekoot M, Geraedts JP, Roos RA, Tibben A, de Die-Smulders CE, Bijlsma EK. (2014a). Prenatal testing for Huntington's disease in the Netherlands from 1998 to 2008. *Clin Genet.* 2014;85(1):78-86. doi: 10.1111/cge.12090.
13. van Rij MC, de Koning Gans PA, van Belzen MJ, Roos RA, Geraedts JP, De Rademaeker M, Bijlsma EK, de Die-Smulders CE. (2014b). The uptake and outcome of prenatal and pre-implantation genetic diagnosis for Huntington's disease in the Netherlands (1998-2008). *Clin Genet.* 2014;85(1):87-95.
14. De Rycke M, Belva F, Goossens V, Moutou C, SenGupta SB, Traeger-Synodinos J, Coonen E. ESHRE PGD Consortium data collection XIII: cycles from January to December 2010 with pregnancy follow-up to October 2011. *Hum Reprod.* 2015;30(8):1763-89.
15. Sharpe A, Avery P, Choudhary M. Reproductive outcome following pre-implantation genetic diagnosis (PGD) in the UK. *Hum Fertil (Camb).* 2017:1-8. doi: 10.1080/14647273.2017.1336259.
16. Human Embryology Fertility Authority. 2016. Fertility treatment 2014: Trends and Figures. Available at: http://www.hfea.gov.uk/docs/HFEA_Fertility_treatment_Trends_and_figures_2014.pdf
17. Miedzybrodzka Z, Templeton A, Dean J, Haites N, Mollison J, Smith N. Preimplantation diagnosis or chorionic villus biopsy? Women's attitudes and preferences. *Hum Reprod.* 1993;8(12):2192-6.
18. van den Oever JM, Bijlsma EK, Feenstra I, Muntjewerff N, Mathijssen IB, Bakker E, van Belzen MJ, Boon EM. Non-invasive prenatal diagnosis of Huntington disease: detection of the paternally inherited expanded CAG repeat in maternal plasma. *Prenat Diagn.* 2015;35(10):945-9.

Figures Legends

Figure 1. Number of prenatal diagnosis cases for HD in UK, in the period of the study (1988-2015). *Red bars refer to direct testing and blue bars to exclusion testing.*

Figure 2. Comparison of prenatal diagnosis (PND) vs preimplantation genetic diagnosis (PGD) since 2002. *Red line refers to PND direct testing, blue line exclusion testing, black line the total, and dotted line the trend during the period. Green line displays the number of PGD-in vitro fertilisation cycles.*

Figure 3. Type of testing in the affected parent. *Yellow shows patients with pre-symptomatic testing, green symptomatic (diagnostic) and blue not tested.*

Figure 4. Follow-up of pregnancies with prenatal diagnosis. Top. Indirect testing. Bottom. Direct testing. *Blue bar shows number of terminated pregnancies and green continued pregnancies.*

Figure 5. Results of follow-up of pregnancies with prenatal diagnosis according the sex of the parent at risk. *Blue bar shows number of terminated pregnancies and green continued pregnancies.*

Fig. 1

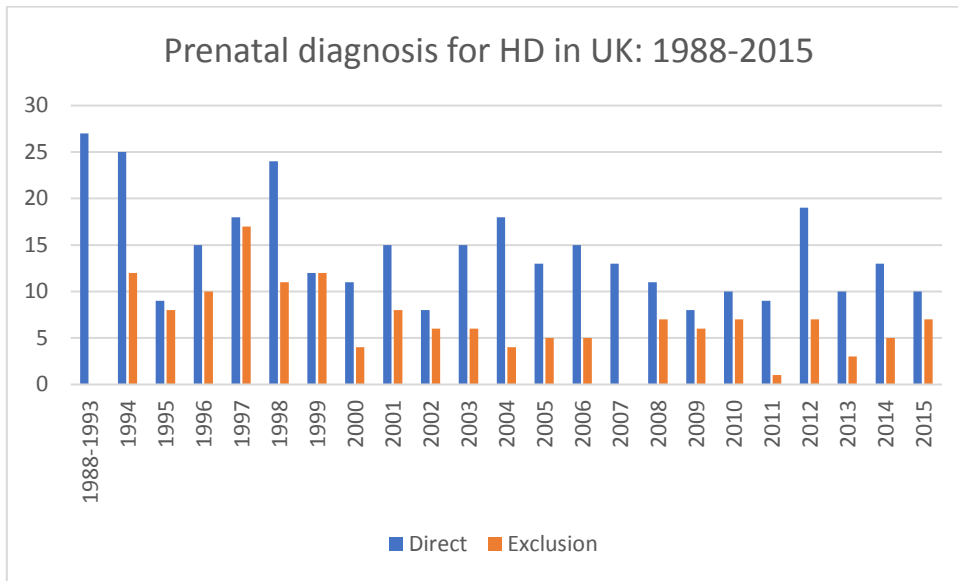


Fig. 2

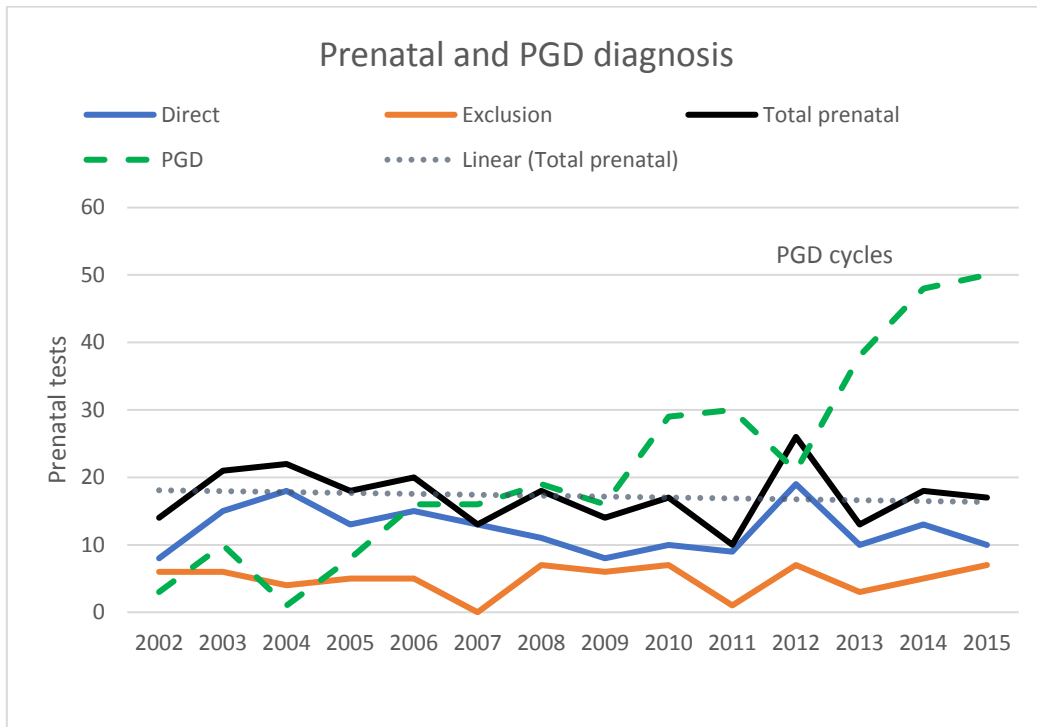


Fig. 3

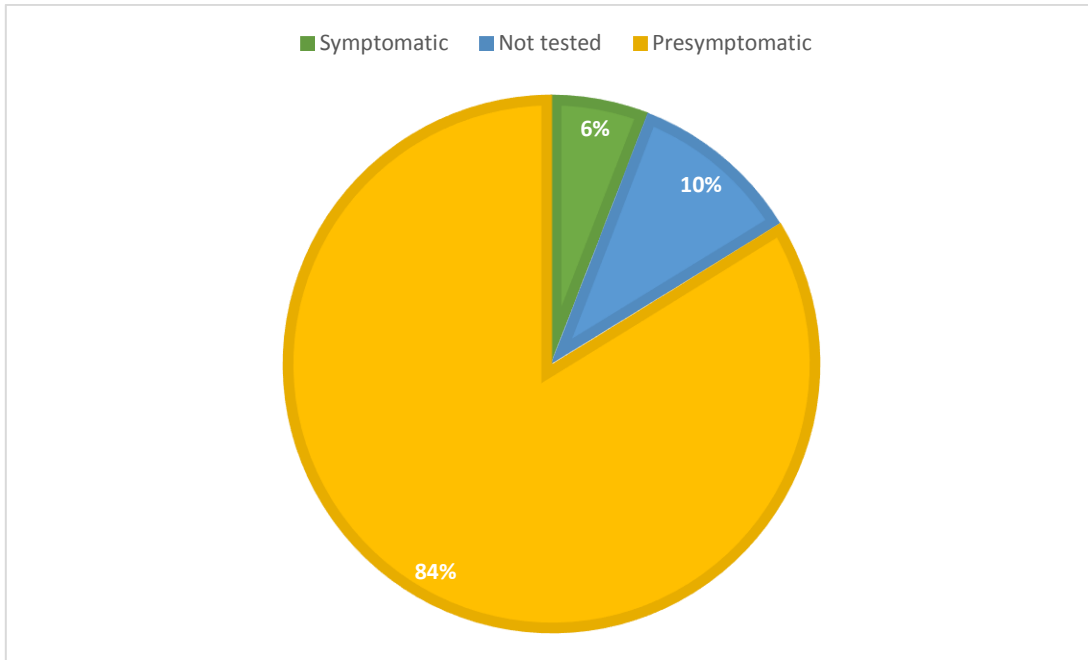


Fig. 4

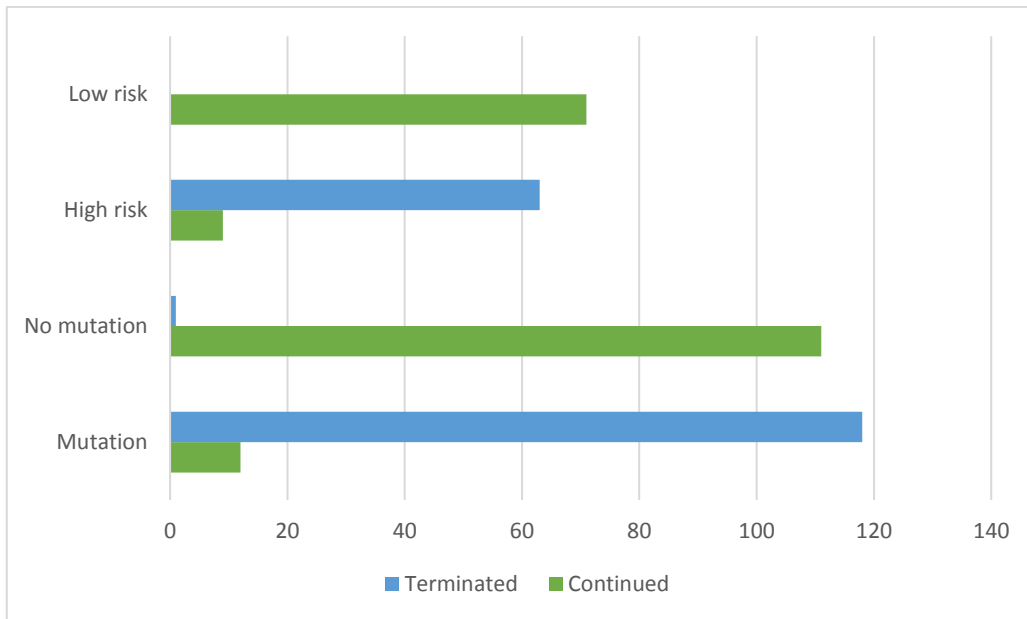
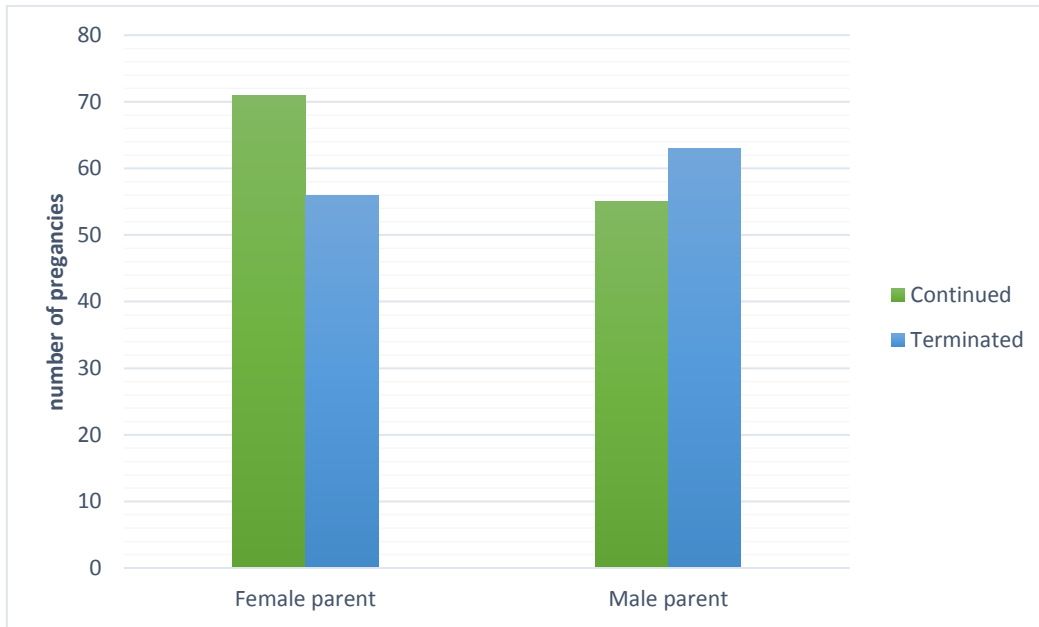


Fig. 5



Supplementary Info

Estimation of PND/PGD uptake in 2015.

An estimate of the percentage of HD at risk births undergoing prenatal diagnosis or PGD was estimated based upon:

1) The denominator number of 12-week pregnancies at 50% risk:

The UK population in 2015 = 65,110,000

Assuming a prevalence of 10 / 100,000 gives 6511 cases

Assuming a disease duration of 18.8 years gives an incidence of 346.3 per year in the UK

A distribution for the age of onset was assumed as reported in Harper & Newcombe 1992.¹ Standard life tables were used to estimate that there would need to be 365.3 births per year to maintain this incidence. Using a pregnancy loss rate of 4 % at 12 weeks (Avalos et al 2012) it would require 380.5 twelve week embryos, and therefore 761.1 embryos were at 50% risk

2) The numerator for the prenatal tests:

The number of direct tests is 10. The number of exclusion tests is 7, but half of these would have been unnecessary if the parents had all been tested - so we have 3.5 tests of pregnancies at 50% risk. So, the total number of prenatal tests is 13.5.

3) The numerator for the PGD tests:

the numerator for direct PGD tests is $36 / 80$ (based on PGD data collected for this study) x 52 PGD tests = 23.4 tests.

The numerator for the exclusion PGD tests is $44 / 80 \times 52$ PGD tests = 28.6 tests (which means that $28.6 / 2 = 14.3$ tests were for pregnancies at 50% risk).

The total number of PGD tests at 50% risk was $23.4 + 14.3 = 37.7$

We could not assume that those having PGD would have had pre-natal diagnosis so the number of PGD cases was reduced by 1/3 based on an approximation of the success rate of PGD per cycle started at Guy's Hospital (Lashwood A personal communication).

This gives a numerator for the PGD cycles of 12.6

Overall, the testing proportion is thus around $(13.5 + 12.6) / 761.1 = 3.4$

We cannot assume that all those undertaking a pregnancy were aware of their risk. There are no estimates for this but, if half of those undertaking a pregnancy were aware of their risk, the uptake would be 6.8%. If estimates of those aware of their risk were closer to 25% or 75% then the uptake would be of the order of magnitude of 13.6% and 4.5% respectively.

Supplementary references

1. Harper PS and Newcombe RG. Age at onset and life table risks in genetic counselling for Huntington's disease. *J Med Genet* 1992; 29: 239-242
2. Ammon Avalos L, Galindo C, Li DK. A systematic review to calculate background miscarriage rates using life table analysis. *Birth Defects Res A Clin Mol Teratol*. 2012 ;94(6):417-23.