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ORIGINAL ARTICLE

Genomic analysis in the clinic: benefits and challenges for health care professionals and patients in Brazil

Patrícia Ashton-Prolla[1,2,4] · **José Roberto Goldim**[2,3,4] · **Filippo Pinto e Vairo**[1] · **Ursula da Silveira Matte**[2,4] · **Jorge Sequeiros**[5,6,7]

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Abstract Despite significant advances in the diagnosis and treatment of genetic diseases in the last two decades, there is still a significant proportion where a causative mutation cannot be identified and a definitive genetic diagnosis remains elusive. New genome-wide or high-throughput multiple gene tests have brought new hope to the field, since they can offer fast, cost-effective and comprehensive analysis of genetic variation. This is particularly interesting in disorders with high genetic heterogeneity. There are, however, limitations and concerns regarding the implementation of genomic analysis in everyday clinical practice, including some particular to emerging and developing economies, as Brazil. They include the limited number of actionable genetic variants known to date, difficulties in determining the clinical validity and utility of novel variants, growth of direct-to-consumer genetic testing using a genomic approach and lack of proper training of health care professionals to adequately request, interpret and use genetic information. Despite all these concerns and limitations, the availability of genomic tests has grown at an extremely rapid pace and commercially available services include initiatives in almost all areas of clinical genetics, including newborn and carrier screening. We discuss the benefits and limitations of genomic testing, as well as the ethical implications and the challenges for genetic education and enough available and qualified health care professionals, to ensure the adequate process of informed consent, meaningful interpretation and use of genomic data and definition of a clear regulatory framework in the particular context of Brazil.

Keywords Genomic analysis · NGS · Genetic testing · Genetic counselling · Informed consent · Ethical issues

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✉ Patrícia Ashton-Prolla
pprolla@gmail.com

[1] Serviço de Genetica Medica, Hospital de Clínicas de Porto Alegre, Porto Alegre, RS, Brazil

[2] Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil

[3] Serviço de Bioética, Hospital de Clinicas de Porto Alegre, Porto Alegre, RS, Brazil

[4] Centro de Pesquisa Experimental, Hospital de Clinicas de Porto Alegre, Porto Alegre, RS, Brazil

[5] i3S- Instituto de Investigação e Inovação em Saúde, Universidade do Porto, Porto, Portugal

[6] IBMC - Institute for Molecular and Cell Biology, Universidade do Porto, Porto, Portugal

[7] ICBAS, Universidade do Porto, Porto, Portugal

Challenges, benefits and limitations of genomic testing in the clinic

In the last years, the development of high-throughput, massive parallel DNA sequencing technologies, also known as "next generation sequencing" (NGS), resulted in a significant decline in cost and time needed to sequence entire human genomes (Collins et al. 2003; Cadwalladr 2013; Wetterstrand 2014). An immediate consequence of this technological breakthrough was its increased accessibility to research and the medical community. The simultaneous analysis of multiple genes (multi-gene panels), whole-exome sequencing (WES) or whole-genome sequencing (WGS) are all now within the reach of a growing number of researchers and physicians. Several NGS platforms also include protocols for the analysis of the transcriptome and epigenetic alterations (Lin et al. 2015). In the clinic, one of the immediate benefits of the introduction of NGS was a more efficient genetic diagnosis of

conditions with significant locus heterogeneity, i.e. disorders in which mutations in one of multiple genes may cause that phenotype. Thus, in the area of disease-targeted sequencing, we moved from a time-consuming, sequential, gene-by-gene approach to the simultaneous analysis of multiple or all genes known to be related to a given phenotype. Currently, instead of cost, time of analysis and amount of DNA needed, the major limiting factor for genetic testing became the pace of discovery of genes potentially relevant to a phenotype (Rehm 2013).

Thus, clinicians are often faced with the question whether they should start a diagnostic workup with a disease-targeted test or directly with a genomic analysis (WES or WGS), for the sake of time, cost and efficiency. Although there seems to be a cost-benefit advantage in favour of WES or WGS, analysis of ethical and technical aspects may still favour the disease-targeted gene approach, at least in most situations. There will be situations where a genomic approach will yield the highest diagnostic effectiveness, while, in others, WES/WGS will add very little to multi-gene panel testing. For instance, excellent results have been obtained with WES/WGS for investigation of seemingly genetic disorders that present with atypical manifestations, are difficult to confirm using simple clinical or laboratory criteria or otherwise require extensive or costly evaluation; these are usually disorders with high clinical and genetic heterogeneity, such as intellectual disability, congenital malformations and mitochondrial dysfunctions (Need et al. 2012; Dixon-Salazar et al. 2012; Pinxten and Howard 2014). Usage of WES/WGS in cancer genetics and prenatal diagnosis is less favourable (Gracia-Aznarez et al. 2013; Filges and Friedman 2014). This is reflected in practical terms in the proportion of different subspecialties requesting genomic testing in the clinic. In a recent report of interviews of 221 genetic counsellors in the USA, about a third of participants had already offered WES and/or WGS; among these, 52.5 % spent at least half of their time in paediatrics, contrasting to only 5 % of those in prenatal counselling and 11.25 % in cancer genetics (Macchini et al. 2014). Apart from WES and WGS, genomic strategies used in the field of molecular cytogenetics (i.e. array comparative genomic hybridization—aCGH) to identify unbalanced chromosomal abnormalities and copy number variants (CNV) are increasingly common in dysmorphology and in prenatal diagnosis; for certain disorders (as intellectual disability, autism and multiple congenital anomalies), aCGH is considered an appropriate first-tier diagnostic test (Xu et al. 2014; South et al. 2013). Finally, current technical limitations of NGS make it inadequate for disorders caused by expansion of oligonucleotide repeats, CNV and alterations in highly repetitive DNA regions (Bras et al. 2012).

Genomic testing has also been considered a promising strategy for population screening of genetic disorders (e.g. newborn or carrier screening). Several cost-effectiveness studies are underway, including an NIH-funded 5-year study comparing WGS with the current standard of care for newborn screening (Dorey 2013; Knoppers et al. 2014; Beckmann 2014). Nevertheless, greater ethical challenges can be expected for screening healthy persons. The benefits of introducing genomic testing in the clinic are summarized in Table 1.

Thus, NGS has proved to be an important diagnostic tool and has come to stay. It has changed the approach, pace and success of molecular diagnosis of several genetic conditions. Nevertheless, this technology is still under development and has several technical limitations and practical challenges for its wider use in the clinic. The major technical limitations and practical challenges of the introduction of WES and WGS in the clinic, expected to be universal, are summarized in Tables 2, 3 and 4.

Specificities of the application of NGS and genomic testing in Brazil

Differently from the aforementioned, regulatory, educational and health policy challenges are particular to each country. In Brazil, there are some specificities that will differ from most European and North American countries, but also from other countries in Latin America.

Brazil is the largest country in Latin America (8,515, 762 km^2). Its total population of 200.4 million is quite diverse, with many Brazilians having a multi-ethnic origin, with predominance of southern and northern European, as well as African ancestry, and, to a lesser degree, Indigenous and Asian contribution; however, when markers of ancestry are studied, there is a predominance of European alleles (60–80 %) in all five regions of the country (Pena et al. 2011; Leite et al. 2011). The Human Development Index (HDI) is 0.74 (world ranking 70/180) and the nominal gross domestic product (GDP) per capita is USD 12,079 (UNDP 2013). Brazil shows a very large social and economic disparity between north and south, as well as between rich and poor areas within each region. The Gini coefficient, a measure of economic inequality, although declining, is still one of the highest in the world—52.7 in 2012 (The World Bank 2014). The vast majority of the population relies on the Brazilian National Health System (Sistema Único de Saúde, SUS), established by the Constitution of 1988, and based on the "Organic Law of Health" of 1990, which includes the values of universality, comprehensiveness and equity of access, and principles of hierarchy, decentralization, regionalization and popular participation (Paim et al. 2011).

In Brazil, public and private medical genetics services are mainly located in large urban centres, the needs of the rural populations remaining largely uncovered. Until very recently, molecular genetic testing was accessible only through a few commercial laboratories, for patients able to pay out-of-pocket, or through research projects in reference centres (Toledo et al. 2012; Melo and Sequeiros 2012; Horovitz et al. 2013; Passos-Bueno et al. 2014). Additional significant limitations

Table 1 Benefits of genomic testing in the clinic

Benefit	Examples
Identification of new genes in Mendelian disorders, advances in the understanding of the causes and natural history of rare and common diseases	Rabbani et al. 2012; Zhang 2014; Boycott et al. 2013; Hechtman et al. 2015; Bonnefond and Froguel 2013
More efficient diagnostic work-up (time and cost benefit, especially in conditions with significant genetic heterogeneity), improved diagnostic rates	Zhu et al. 2015; Soden et al. 2014; Jacob et al. 2013; Nigro and Piluso 2012; Schnekenberg and Németh 2014; Newman and Black 2014
Guidance about treatment choices (group stratification for therapy)	van Allen et al. 2014; Lebofsky et al. 2014
Avoidance of adverse drug reactions (concomitant pharmacogenetic testing)	Apellániz-Ruiz et al. 2015; Moreira and Eng 2014; Abul-Husn et al. 2014; Guchelaar et al. 2014; Drögemöller et al. 2013
Refinement of prognostic predictions and risk counselling	Macchini et al. 2014; Vrijenhoek et al. 2015; Prior 2014

are that genetic counselling is mainly provided by physicians (clinical geneticists or other MDs); there is no formal genetic education for non-MD health care professionals; and genetic counsellors are not yet recognized.

Clinical genetics was approved as a medical specialty in Brazil, in 1983. There are currently ten (3-year) residency programmes, forming an average of 17 clinical geneticists per year (SBGM 2014). The total number of board-certified clinical geneticists in the country is 260 (SBGM 2015, personal communication), approximately 1 for every 770,000 citizens, who are mainly bound to academic centres in the south and southeast regions. This reflects on a limited amount of qualified services with multidisciplinary teams and expertise in genomic analysis and counselling. Furthermore, although most medical schools include topics about clinical genetics in their curricula, not all have formal disciplines in the field. It was only in 2014 that the Ministry of Education included genetic diagnosis and counselling in the mandatory topics for every medical school (BRASIL 2014a, b).

Two important steps for clinical genetics were taken in Brazil, in 2012 and 2014. The National Supplementary Health Insurance Agency (ANS, *Agência Nacional de Saúde Suplementar*), the regulatory agency for private health care plans, was established in January 2012 and determined that coverage of genetic testing by private health organizations was mandatory. This regulatory act benefited an estimated 20–30 % of the Brazilian population with private health care coverage (Pietrobon et al. 2008). It has also restricted the prescription of genetic tests to clinical geneticists, to assure that genetic counselling is performed. Two years later, in January 2014, molecular diagnostic technologies and genetic counselling were formally incorporated in the list of procedures of SUS in Brazil, in a law proposed by the Ministry of Health, to allow integral access to health care for persons with rare diseases, 80 % of which are genetic in nature (BRASIL 2014a, b; Passos-Bueno et al. 2014). This landmark for clinical genetics included, for the first time, access to genetic testing to patients in the SUS. With the exception of aCGH, however, no other genomic approaches were included in the new list of procedures covered by SUS or private health care plans.

Thus, genomic testing is offered in Brazil by commercial laboratories and research consortia from some academic centres. Most laboratories offer disease-targeted gene panels for specific groups of diseases, and only a handful performs WES locally or sends samples for sequencing abroad. The lack of regulation of genetic testing in SUS has also generated situations where the public health system was forced, by court order, to reimburse a test performed at a private laboratory, based on the principles of universality, comprehensiveness and equity of access to health, regardless of it being really useful, appropriate or a priority. This practice tends to increase, as the population and medical community become better informed about the potential benefits of genomic testing and while this remains excluded from the procedures reimbursed by ANS or SUS (Melo and Sequeiros 2012; Biehl et al. 2012). Finally, the increase in offer of direct-to-consumer genetic tests over the last few years in Brazil is very concerning. Contrarily to what happened in Europe and North America (Borry et al. 2012; Annas and Elias 2014), and again due to the lack of regulation, the offer by commercial companies of genomic testing for physical and intellectual performance, cosmetics (predisposition to baldness, skin wrinkles), nutrition profiles, among other of dubious validity and utility, is increasing.

Another important barrier to the more widespread implementation of genomic testing in Brazil is the shortage of qualified health care professionals to appropriately request testing, interpret its results and provide pre- and post-test genetic counselling. This shortage of qualified professionals in the field is exacerbated by the absence of non-MD genetic counsellors and by the limited training in genetics and counselling in medical schools. In combination with lack of regulatory policies regarding genetic and genomic testing in the country, the lack of qualified professionals creates a permissive scenario where any physician may order genomic testing, without any proper genetic counselling. It is not uncommon that physicians with limited knowledge of clinical and molecular

Table 2 Technical and practical challenges of genomic testing in the clinic

Technical
Accurate and efficient analytic assessment of genomic variants (increase its clinical validity and utility)
Better coverage of certain genomic regions (<50 %)
Need for result confirmation (i.e. by Sanger sequencing)
Handling of variants of uncertain significance (VUS) and novel variants
(when reporting to clinicians and disclosing results to patients)
Need for expert knowledge on each gene and disease, improved information on rare gene variants freely available in public databases
Practical/operational
Disclosure of "incidental findings" and its familial implications[a]
Segregation studies in families to investigate the pathogenicity of novel and VUS
Complexity of data analysis: equitable access and reimbursement feasible for everyone
Proper classification of variants (clinically valid and actionable, clinically valid but not directly actionable, or of unknown significance) and constant updating of this knowledge[b]
Data management (IT) in the laboratory (data tracking, handling and storage; and quality control)[c]
Data management (physicians) in the clinic (lack of background genetics education and training to properly manage and report genomic results)
Lack of consensus on data return (what results must be generated, returned to the physician and the patient, and to what extent and how the return of unfavourable or potentially harmful results should be prevented)
Genomic data availability and accessibility in medical records and databases (privacy and confidentiality)
Definition of the need to recontact periodically to reassess significance of novel variants and VUS
Genetic counselling: increase in the amount of time needed and training of professionals on communication strategies with patients and families

[a] Also called secondary, unsolicited, unexpected or unanticipated variants

[b] EuroGentest has published recommendations on NGS where variants are classified in different categories: "It is recommend the use of a variant classification into these 5 levels, namely: pathogenic (5), likely pathogenic (4), unclassified UVs (3), likely benign (2) and benign (1) variants." (Eurogentest—Guidelines for Diagnostic Next Generation Sequencing 2015 [in press])

[c] WGS is expected to reveal three to four million variants, WES is expected to reveal about 20,000 variants (Johansen Taber et al. 2014)

Table 3 Social, economic, ethical and psychological challenges of genomic testing

Validity and risk-benefit of a hypothesis-free approach to genetic testing and screening
"Information-seeking bias" (out of curiosity)—how clinically relevant and how important is it in a given society
Avoid psychological harm
Develop and harmonize informed consent guidelines
Develop recommendations for data handling and return of results
Address patient autonomy (right-to-know vs. right-not-to-know)
Revisit and rediscuss genetic counselling models
Obtain meaningful health economic data
Data sharing: allow knowledge-enabled analytical pipelines to support more readily the broad community of clinical genetic laboratories
Address more rapidly expanding, demand-driven practices in clinical care (e.g. some commercial labs reporting all variants, regardless of their validity and utility and of having been requested or not)
Consolidate the responsible translation of genomic testing from the research laboratories to the clinic

genetics order WGS, WES or multi-gene panels with no clear indication, no interpretation of the results and no adequate pre- or post-test counselling.

Unfortunately, in Brazil, this scenario is not limited to genomic testing but also applies to conventional genetic testing. In most European and North American countries, the introduction of genetic tests in the clinic led to an extensive discussion on the limitations and benefits of molecular diagnosis and the establishment of clear regulation (Becker et al. 2011; Rogowski et al. 2009; European Society of Human Genetics 2010; Claustres et al. 2014; Richards et al. 2008; Rehm et al. 2013; ACMG Board of Directors 2013). In addition, concern about genetic literacy among health care professionals resulted in major educational efforts in the field with support from governmental agencies and professional societies (Farndon and Bennett 2008; Kirk et al. 2008; Guttmacher et al. 2007). As the reimbursement for genetic testing by the private and public sectors was almost inexistent in Brazil until not long ago, this discussion was limited to clinical geneticists and research groups working in the area. In 2012, Melo and Sequeiros published a report on the challenges of incorporating genetic testing in Brazil's the Unified National Health System (SUS) (Melo and Sequeiros 2012).

The current legislation regarding genetics in Brazil is restricted to Law 11.105/1995, which rules about genetic modified organisms and the use of embryonic stem cells for research, and by a few specific resolutions of the National Health Council regarding research in human genetics (BRASIL 1995; BRASIL 2012). The contemporary Brazilian law offers a wide set of normative devices aiming to protect the right to privacy and human personality, beginning with the respect for fundamental rights, as expressed in the Republic's Constitution and specified in infra-constitutional laws, such as the Civil Code (Brasil 2002). The Constitution of the Federative Republic of Brazil (Brasil 1988) provides, in section X, protection regarding the right to privacy. This is also strictly ruled on Article 21 of the Brazilian Civil Code. Although Brazil is a member of the United Nations Economic and Social Council, which emphasizes the need of all signatory nations to have a specific law on privacy and genetic information (United Nations Economic and Social Council (ECOSOC)

Table 4 Current limitations and challenges for genomic testing in Brazil and needs regarding genetic testing and counselling

Limitations and challenges	Needs
Medical genetics services are concentrated in few urban areas	Decentralization of medical genetics services
Genetic counselling is provided mainly by medical geneticists	Training of genetic counsellors and regulamentation of the profession
One clinical geneticist for every 770,000 citizens	Increase in the number of training centres in clinical genetics
Lack of formal disciplines in the field of genetics	Inclusion of genetics in curricula of medical schools and health-related specialties
Genomic approaches (except aCGH) are not covered by public or private health care systems	Coverage of NGS and WES by the public health care system and private health insurance companies
Lack of regulation on genomic testing (test requisition, testing, disclosure of results, quality control)	Establishment of guidelines by the Brazilian Medical Genetics and Clinical Pathology Societies and regulation/quality control by the Ministry of Health
Lack of information on genetic variation in the Brazilian population (absence of public databases)	Creation of a national variation database curated by a regulamented system and site

2004), such specific law does not yet exist in the country. There is also no specific law on privacy of genetic/genomic data.

A few directives, however, have been produced in the last decades. In 2001, a guideline from the Federal Council of Medicine (CFM) and the Brazilian Association of Medicine (AMB) specifically addressed predictive genetic testing in three scenarios: presymptomatic testing for late-onset diseases for which there is no treatment, predictive testing for diseases for which therapeutic or preventive measures are available and susceptibility testing for complex diseases where multiple low penetrance variants are involved (Lopes-Cendes et al. 2001). Regarding the former, tests are only performed in adults who spontaneously seek genetic services and are evaluated and followed by a multidisciplinary team including psychologists. In diseases for which preventive or therapeutic measures are available, the test can be performed at any age (provided the result would change management), but a multidisciplinary approach is still needed. For the latter, since the risk related to each of multiple genetic variants is not precisely known, testing cannot be considered predictive, as it has doubtful clinical validity and utility. In 2004, CFM and AMB published a directive (www.cfm.org.br; 12/12/11) stating that diagnostic genetic testing should be conducted whenever the result could impact on clinical management (Raskin et al. 2004). But, decisions about performing genetic testing were actually left to the physician and the patient, with non-existing regulation. Nevertheless, in 2004, the Brazilian Society of Genetics (SBG) produced a document entitled "Guide to good laboratory practices in human cytogenetics and molecular genetics" that aims at increasing reliability of genetic test results and improving communication between laboratories and physicians, although it does not thoroughly addresses accreditation or quality assessment of the laboratories (Borovik et al. 2004). In 2014, both the updated diagnostic regulations of the private health care regulatory agency (ANS 2013; BRASIL 2013) and the law for Integral Care of Persons with Rare Disorders (BRASIL 2014), published by the Ministry of Health, stated that genetic counselling should be an integral part of genetic testing. There are still no comprehensive regulatory guidelines for clinical molecular laboratories and especially not for reporting results of genetic tests in general. Commercial laboratories are free to adopt their own rules regarding, for instance, which results must be reported or how information will be handled. In general, most choose to follow (more often) North American or European guidelines, but they are not compelled to do so by any external source.

This is a matter of significant concern for the Brazilian Society of Medical Genetics (SBGM), well aware of the need of national guidelines and of the consequences and limitations of genetic and genomic testing. The SBGM, however, suffers the pressure of a growing and unregulated market against any limitations on who really has the expertise to request, interpret and provide results of genomic tests. At the same time, the society also has to deal with the limited number of geneticists and poor genetic training of medical professionals. Finally, together with other stakeholders, whose goal is to use genetic and genomic data wisely and responsibly, SBGM has to participate in the delineation and implementation of a regulatory framework that does not increase inequality of access, created by the existing economic disparities. Despite all these major concerns and challenges for medical genetics and the inclusion of genetic and genomic testing in the clinic, one can envisage an opportunity from this situation: the current lack of any major regulation may allow the development of a regulatory framework that takes into account the previous experience in other countries.

Ethical challenges for the clinical implementation of genomic testing in Brazil

Many of the ethical issues regarding genomic analysis derive from the lack of adequate knowledge to deal with the amount of information generated, especially polymorphic variants, variants that are not related to the phenotype, still under

investigation or of unknown significance (VUS). These challenges are not new to clinical geneticists, especially those working within admixed populations, such as Brazil. Often, Sanger sequencing reveals previously unreported variants, which cannot be easily classified as to their relevance to disease, due to differences in genetic background. As more genes are simultaneously probed, the chance of finding novel variants or VUS increases. Depending on its mode of inheritance, an association with disease may be very difficult to determine.

One of the strategies to investigate VUS is segregation analysis. When a VUS is identified, testing family members may become important to clarify the significance of results. In these situations, health care professionals discuss with the proband, in the genetic counselling process, the potential implications of that information and the importance of testing of relatives to understand significance of a given variant. During counselling, patients are encouraged to inform their relatives about what they have learned and additional counselling is made available to the family. Relatives may then seek counselling services. Although this may limit the number of consultants (either because relatives are not properly informed or at all), it is not considered an adequate practice for a physician to directly contact a patient's relative.

An additional difficulty in the analysis of VUS is that although most public genetic variation databases include variants found in Brazilians, none is based in Brazil. Thus, information on genetic variability of the Brazilian population is not easily accessible. Local regulations limiting sharing of genetic data make it even more difficult to make this information easily available for diagnosis and research. Also, regulatory restrictions to collaborative research with international groups and restricted funding for long-term projects (which could potentially clarify the impact of genetic variability in diseases with incomplete or low penetrance) contribute to the lack of that knowledge. Lack of robust data on the genomic variability in Brazilians, and consequent limitations that arise in VUS interpretation, poses an extra challenge for informed consent in genomic analyses in Brazil.

Informed consent in medical assistance is a communication process, in which patient and physician or counsellor discuss risks, benefits, implications and limitations of a given procedure, before it is undertaken. As its name implies, it comprises information sharing, understanding and agreement. Therefore, a fundamental basis of informed consent is that at least the physician/counsellor is well informed of all that may result from the procedure, and the patient, after acknowledging properly the information, is then able to make a decision regarding a given procedure. Ideally, both parts should discuss freely whatever is at stake. Although this discussion should also occur when genomic NGS testing approaches are at stake, there is often significant uncertainty about what will be encountered (unsolicited findings) and the implications of variants of unknown clinical significance (Ormond and Cho 2014; Clarke 2014). Often, there is so much uncertainty involved that it is questionable whether *truly informed* consent can be obtained. Therefore, the whole process becomes very complex and has to be completely redefined in different terms.

Several papers in the last few years have addressed these ethical issues related to informed consent in NGS. Several authors have suggested different models of consent but no consensus has yet been reached within the international community. Appelbaum et al. (2014), for instance, describe four different models of consent to return of incidental findings: traditional consent, staged consent, mandatory return and outsourcing. The former recommendations of the American College of Medical Genetics and Genomics (ACMG) toward the obligatory return of 'incidental' findings on a small list of conditions and genes, based on their high penetrance, possible early onset and potential for medical intervention (preventive, follow-up or treatment measures) (Green et al. 2013), were considered highly controversial, as they alienate the patient's choice and recommend the return of results to all persons, including minors (Ormond and Cho 2014; Clarke 2014). In Brazil, with still dominant paternalistic views of medicine and lack of regulation, the decision on which results are to be reported is often left to the laboratory and the clinician. Laboratories performing WES may determine, in conjunction with the patient's doctor, which genes will be analysed and results reported. This practice has been described in other countries, but is likely exacerbated in Brazil, for social, cultural and economical reasons (Townsend et al. 2013). In this context, a decision on which results will be reported does not consider the patient's right-to-know or not-to-know and becomes a decision of the laboratory and/or clinician, who may or may not act according to international guidelines and best practices.

Anyway, to enable duly informed consent for genomic testing in the clinical care setting, extensive and time-consuming counselling is required prior to sequencing (time needed has been estimated at 6–8 h) (Johansen Taber et al. 2014). Obviously, the availability and quality of counselling depends on the qualified staff and funds available for such activity. Again, we need better tools to support the decision-making process, based on genomic information generated locally, and better instruction in genetics (i.e. educating medical doctors and students on the genetic determinants of health and disease, and proper training of clinical geneticists and genetic counsellors) to be able to improve this situation.

Conclusion

In spite of some technical limitations still existing and, more importantly, insufficient addressal of the ethical and regulatory issues, genomic testing is rapidly entering our clinical practice as an important diagnostic tool. In a very short period,

NGS has already been changing the pace, approaches and success rate of molecular diagnosis for many genetic conditions. This will not happen differently in Brazil or in other Latin American countries. Nevertheless, its current limits and challenges need to be urgently attended, and the specificities of each country considered, so as to increase better and more informed access to genomic testing, in a scientifically sound, ethically meaningful and socially responsible manner. Hopefully, the advances in genetic testing technologies may drive more health care professionals into the field, and clinical genetics and counselling will experience the growth it needs to face the challenges ahead of us.

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