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RESEARCH

Implementation of personalized medicine in Central-Eastern Europe: pitfalls and potentials based on citizen's attitude

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Abstract

Objective Next-generation sequencing is increasingly utilized worldwide as a research and diagnostic tool and is anticipated to be implemented into everyday clinical practice. Since Central-Eastern European attitude toward genetic testing, especially broad genetic testing, is not well known, we performed a survey on this issue among Hungarian participants.

Methods A self-administered questionnaire was distributed among patients and patient relatives at our neurogenetic outpatient clinic. Members of the general population were also recruited via public media. We used chi-square testing and binary logistic regression to examine factors influencing attitude.

Results We identified a mixed attitude toward genetic testing. Access to physician consultation positively influenced attitude. A higher self-determined genetic familiarity score associated with higher perceived genetic influence score, which in turn associated with greater willingness to participate in genetic testing. Medical professionals constituted a skeptical group.

Conclusions We think that given the controversies and complexities of the next-generation sequencing field, the optimal clinical translation of NGS data should be performed in institutions which have the unique capability to provide interprofessional health education, transformative biomedical research, and crucial patient care. With optimization of the clinical translational process, improvement of genetic literacy may increase patient engagement and empowerment.

Relevance of the article for predictive, preventive, and personalized medicine The paper highlights that in countries with relatively low-genetic literacy, a special strategy is needed to enhance the implementation of personalized medicine.

Keywords Next-generation sequencing · Hungary · Survey · Counseling · Ethic · Predictive genetic tests · Predictive preventive personalized medicine · Direct to consumer genetic tests · Genetic literacy

Background

Understanding genetics is an especially important factor in predictive, preventive, and personalized medicine (PPPM) [1]. In recent years, next-generation sequencing (NGS) has become increasingly utilized worldwide as a genetic research and diagnostic tool [2, 3]. The introduction of this technique in the study of human diseases has made the diagnosis of many diseases easier and faster [4]. However, the rapid spread of this technology has also raised many questions from a regulatory and ethical point of view. Clinical geneticists face the problem of reporting and interpreting a large amount of information on a greater scale than ever before [5]. Direct-to-consumer testing is available in many countries, which also raises questions about the role and method of genetic counseling before and after these services. Because next-generation sequencing can generate many potential output, preparing patients before actual testing is complex. The quantitative change in the magnitude of genetic results may also mean a qualitative change from an ethical point of view [6]. Many important questions have been raised in the literature regarding genetic counseling and next-generation sequencing technologies in recent years, such as reporting incidental findings [3] and reporting variants of uncertain

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significance [7]. Further problems arise from the blurring line between research and clinical practice [8] and the necessity of reanalysis of results [9]. Sharing genetic test results among researchers and with the patient's family members raises questions [10]. Additionally, special circumstances may arise when children are involved in NGS studies [11]. Based on a non-systemic search of the literature available in PubMed, attitudes toward genetic testing and opinions on the abovementioned questions have not been previously assessed in detail in Central-Eastern European countries (as defined by OECD). As next-generation sequencing is increasingly available in this part of Europe, it is critical to collect opinions on these issues.

Methods

Instrumentation

The survey was distributed in Hungarian language. It contains 37 questions (Q1-Q37) with 72 items (42 single choice, six open-ended, three multiple choice, 21 rating scale). The survey was broken up into five parts. The first part asks for the respondent's sociodemographic information. The second part focuses on genetic knowledge and concepts in genetics. The third part asks questions about attitudes toward ordering genetic tests. The fourth part inquires about genetic test results and incidental findings, and the fifth part is about sharing genetic test results as well as genetic material.

We created two scoring systems from items in questions Q10 and Q12 for further analysis. Question 10 asked the respondents to read nine phrases and rate how well she or he understands the given phrase on a 1–10 scale (score 10 if totally understood, score 1 if not understood at all). We summed the scores from these nine phases, so that a total score ranges from 10 to 90. We named this summary score "self-rated genetic familiarity score." We did not adopt previously used objectives and perceived genetic knowledge measures [12–15] because the purpose of this study was to measure the respondent's familiarity with the phrases used frequently in relation to the subject.

Question 12 asked respondents to rate on a scale of 1–4 how much a given trait is influenced by genetics in their viewpoint (1, no effect at all; 2, slight effect; 3, strong effect; 4, completely determined by genetics). Some of the traits in question are scientifically known to be influenced strongly or determined completely by genetics, but some of the traits are more controversial. We decided not to take into consideration whether responses were correct or incorrect; instead, we summed the scores for these ten questions, which we named the "perceived genetic influence score." This score ranges from 10 to 40. We used a cutoff score of 30 to create two groups of respondents for further statistical hypothesis testing. A score of 30 or above means that a respondent rated all the traits as influenced strongly or determined completely by genetics.

Participants

We distributed the paper-based survey to patients and patient's relatives at our neurogenetic outpatient clinic. The same version of the questionnaire was available online, and the web link to the questionnaire was sent out by email to patients who had previously provided their email addresses to us. The web link to the questionnaire was also shared on social media. The survey was distributed among medical students who attended our genetic lectures, as well as the general population who attended our annual open lecture for those interested in genetic science. The study was approved by an institutional ethical committee (Semmelweis University Regional and Institutional Committee of Science and Research Ethics, SE TUKEB 194/2015). The questionnaire started with an informed consent about the survey. Consent was given by filling out the survey because the survey was anonymous.

Data analysis

We used IBM-SPSS 21.0 for Windows for all analyses. Individuals refusing to answer specific questions were excluded only from evaluation of the question concerned. Prevalence was measured as a percentage. Binary data (either as collected or collapsed) was analyzed using the chi-square test and binary logistic regression analysis with odds ratios (ORs) with 95% CIs at a significance level of $p < 0.05$. The influence of education and profession (health related or not) on the self-rated genetic familiarity score was determined using the Kruskal-Wallis test and Mann-Whitney U test, respectively. The Mann-Whitney U test was also used to determine if the distribution of the self-rated genetic familiarity score was the same across respondents with perceived genetic influence score above 30 or under 30. To assess predictors for positive attitude toward direct to consumer (DTC) testing, a multivariate binary logistic regression model was used for three questions, which were identified as relevant questions for DTC testing: (1) Q16: Do you think it is acceptable to have the opportunity to purchase genetic tests commercially? (2) Q18: Would you ask for comprehensive genetic testing just out of curiosity? (3) Q19.4: Would you ask for a genetic test if you are in good health, without a medical consultation in order to learn about your ancestry for curiosity?

Results

Respondents

In total, 657 people filled out the survey (463 female, 177 male, 17 people did not indicate their gender). Five hundred fifty-nine people filled out the survey completely. Mean age of the respondents was 41 ± 14.6 years (41.6 ± 14.8 for males and 40.89 ± 14.49 for females). 49.2% of the respondents had either a university or college degree. Seventy-two respondents worked in healthcare (28 of which were physicians), and 14 respondents studied a healthcare-related profession (11 of which were medical students). 47% of the respondents are from the capital city, Budapest.

Self-rated genetic familiarity score

The distribution of the self-rated knowledge score is represented in Fig. 1. Mean score was 64.96 ± 22.38. The self-rated familiarity score was significantly higher among respondents who worked in healthcare (Mann-Whitney U $p < 0.01$) compared to respondents not working or studying in a healthcare-related profession and was significantly higher with higher educational status (Kruskal-Wallis $p < 0.01$) (Table 1). There was no correlation with age (Spearman's rho: − 0.040).

Perceived genetic influence score

Responses on perceived genetic influence are represented in Fig. 2. The total score ranged from 1 to 40. One hundred nine people (18.5%) had a score greater than or equal to the cutoff value of 30 (a score of 3 or 4 on all the questions). Respondents with a greater self-rated genetic familiarity score were more likely to have high-perceived genetic influence (Mann-Whitney U $p = 0.007$). Respondents with a high-perceived genetic influence score were more likely to ask for whole genome testing (with or without medical consultation option) for later use than those with a perceived genetic influence score below 30 [49 (48.5%) vs 172 (37.7%) $p = 0.056$; 63 (63.6%) vs 231 (50.9%) $p = 0.026$, respectively]. Respondents with a high score were also more likely to request genetic testing with consultation to detect common risk modifier variants [87 (87.0%) vs 335 (73.1%) $p = 0.003$] or if a serious but manageable disease might be discovered, even if they are currently healthy [99 (97.1%) vs 396 (85.9%) $p = 0.001$].

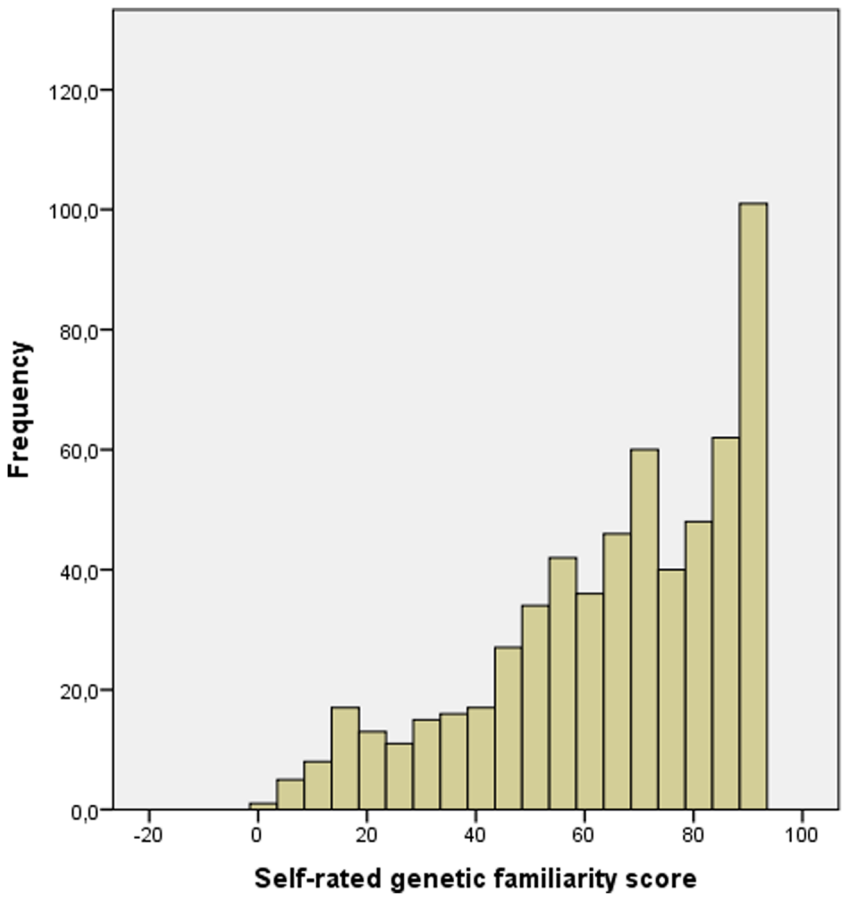

Fig. 1 Distribution of self-rated genetic familiarity scores. Legend: Frequency of self-rated genetic familiarity scores divided by five points. High scores were relatively frequent, which could be explained by the overrepresentation of respondents with college or university degrees

Table 1 Self-rated genetic familiarity score with different educational status

Educational status	*N*	Mean	95% confidence interval for mean
Vocational training	20	45.35	32.78–57.92
Middle school	26	50.04	40.84–59.24
Vocational school	51	61.69	56.10–67.28
High school	141	63.57	59.81–67.32
College	100	64.65	60.43–68.87
University	197	70.21	67.15–73.26
National qualification registered Training	10	70.80	59.01–82.59
Total	599	64.96	63.17–66.76

Number of respondents (*N*) with different educational status and the mean self-rated genetic familiarity score, with 95% confidence intervals. National qualification registered training is a diverse group of trained professionals in Hungary. Generally, higher educational status associated with higher self-rated genetic familiarity score

Factors influencing attitude toward genetic testing and related questions

Bivariate analyses

We performed bivariate analyses to investigate the effect of different demographic parameters on attitude toward genetic testing, incidental findings, and sharing genetic test results. Gender, profession, self-rated genetic familiarity, and perceived genetic influence scores significantly affected more than one outcome variable as outlined below. Besides these, consultation with a physician also influenced some of the outcome variables.

Gender Male respondents were more likely to request genetic testing with or without consulting a medical doctor in some conditions. This is presented in Table 2. However, a greater percentage of female than male respondents had a high-perceived genetic influence score (21.9 vs. 11.4% $p = 0.003$).

Working in healthcare Healthcare providers and respondents not working or studying in healthcare differed somewhat in attitude toward genetic testing. While there was no significant difference when requesting tests without a physician consultation, there were significant differences when physician consultation was indicated in the question (Table 3).

If respondents are currently healthy but there is potential to detect a serious untreatable disease, those who are healthcare workers would less frequently ask for genetic testing compared to non-healthcare workers. There was a marginally significant difference between the two groups if a serious but manageable disease might be discovered [40 (54.1%) vs 310 (70.5%) $p = 0.007$; 60 (80.0%) vs 387 (88.6%) $p = 0.058$].

Consultation with a physician The opportunity to consult with a doctor increases motivation to participate in genetic testing in multiple ways (Table 4). Significant differences were present in motivation for detecting rare diseases, screening for serious diseases, and screening for common risk variants and for later use in whole genome analysis. Interest in ancestry and certain physiological features remained low regardless of the option of consultation with physician.

Predictors for a positive attitude toward direct to consumer genetic testing

The results of the logistic regression are presented in Table 5. Age and gender had the greatest influence on attitude toward genetic testing. Male respondents were more likely to request a genetic test just for curiosity or for ancestry purposes. Younger respondents were more likely to request a genetic test for medical purposes and participate in commercially available genetic testing.

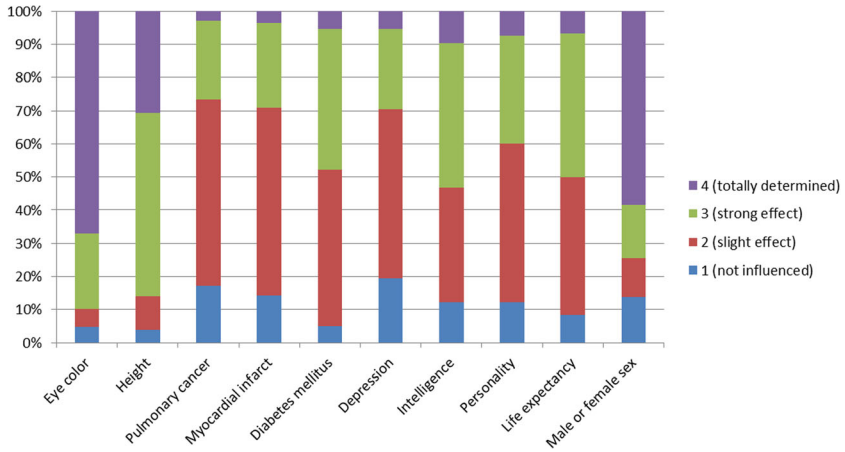

Fig. 2 Distribution of perceived genetic influence scores. Legend: Distribution of perceived genetic influence scores on different traits. Patients were asked to rate on a scale of 1–4 how much a given trait is influenced by genetics in their viewpoint, where 1 means that a given trait is not influenced by genetics and 4 is that the trait is totally determined by genetics. It can be seen that even traits which are biologically determined by genetic factors (such as eye color) could be perceived as non-genetic, and complex traits could be perceived as strongly influenced by genetics

Table 2 Differences between male and female respondents in motives for genetic testing when in good health

	Male	Female	*P* value
Q19. Would you ask genetic test without consulting a doctor in a healthy condition for			
4. Interest in ancestry	84 (51.5%)	149 (38.9%)	0.008
5. Determine certain body features	60 (36.8%)	69 (18.2%)	< 0.001
6. Whole genome for future use	85 (51.2%)	135 (35.0%)	< 0.001
Q20. Would you ask genetic test with consulting a doctor in a healthy condition for			
3. Gene defects that slightly increase the possibility of common diseases	131 (81.2%)	282 (73.2%)	0.051
4. Interest in ancestry	90 (54.5%)	145 (38.4%)	0.001
5. Determine certain body features	63 (38.2%)	81 (21.5%)	< 0.001
6. Whole genome for later use	105 (63.6%)	186 (48.8%)	0.002

Number of respondents and percentages (in parentheses) of male and female respondents who answered "yes" for the given questions. Only significant differences were included in the table. For certain motives, male respondents had more positive attitudes toward testing

Educational status also affected certain attitudes, but not in a consequent manner. Respondents who identified themselves as religious expressed lower acceptance toward commercial genetic tests, with borderline significance. The model could explain 8.0–11.0% of total variance for the questions included in the analysis.

Discussion and conclusion

Discussion

Attitude toward genetic testing when in good health

There are a variety of different motives for broad genetic testing when in good health [16]. Health-related motives may include the potential for early detection and intervention, prevention, and closer monitoring [17]; for adoptees, it can be a source of familial medical history [18]. Non-health-related motives may include curiosity, desire to learn ancestry information, participation in research, and recreation-related motives [16].

Our respondents expressed mixed attitudes toward genetic testing when in good health. Health-related tests were more likely indicated as a motivation for testing, especially when physician consultation was an option. After consulting a physician, 73.5% of the respondents would request a genetic test to screen for genetic defects causing serious diseases, and 65.3% would ask for a genetic test to detect genetic risk factors for common diseases. Without a consultation, only 47.6 and 46.9%

Table 3 Differences in genetic attitude of respondents employed in healthcare and non-healthcare-related fields

	Healthcare respondents	Non-healthcare respondents	*P* value
Q19. Would you ask genetic test without medical consultation in a healthy condition for			
1. Define the risk for certain rare diseases	30 (41.1%)	213 (48.4%)	0.257
2. Find out gene defects causing serious diseases	33 (45.2%)	242 (55.0%)	0.13
3. Gene defects that slightly increase the possibility of common diseases	35 (47.3%)	237 (54.0%)	0.315
4. Interest in ancestry	31 (41.9%)	185 (43.0%)	0.899
5. Determine certain body features	16 (21.6%)	110 (25.7%)	0.561
6. Whole genome for later use	22 (30.1%)	178 (40.7%)	0.093
Q20. Would you ask genetic test with medical consultation in a healthy condition for			
1. Define the risk for certain rare diseases	46 (61.3%)	351 (80.1%)	*0.001*
2. Find out gene defects causing serious diseases	54 (72.0%)	372 (85.1%)	*0.007*
3. Gene defects that slightly increase the possibility of common diseases	46 (62.2%)	339 (78.3%)	*0.005*
4. Interest in ancestry	30 (41.1%)	188 (43.7%)	0.703
5. Determine certain body features	18 (24.3%)	121 (28.3%)	0.574
6. Whole genome for later use	31 (41.9%)	234 (54.4%)	*0.058*

Number of respondents and percentages (in parentheses) of those employed in healthcare or non-healthcare fields who answered "yes" on the given question. Significant *p* values are in italics. For question Q20.1, Q20.2, and Q20.3, healthcare workers were significantly less likely to respond positively, while for Q20.6 a marginally significant difference was detected, which shows a greater interest in genetic test among non-healthcare-related workers

Table 4 Differences of attitude toward testing with availability of physician consultation

	Q19. Without medical consultation		Q20. With medical consultation		OR (95% CI)	*P* value
	Yes	No	Yes	No		
Would you ask genetic testing in a healthy state for						
1. Define the risk for certain rare diseases	277 (48.3)	296 (51.7)	446 (78)	126 (22)	*3.78 (2.92–4.89)*	*< 0.001*
2. Find out gene defects causing serious diseases	313 (54.7)	259 (45.3)	483 (84.3)	90 (15.7)	*4.4 (3.36–5.86)*	*< 0.001*
3. Gene defects that slightly increase the possibility of common diseases	308 (53.8)	264 (46.2)	429 (75.8)	137 (24.2)	*2.7 (2.08–3.45)*	*< 0.001*
4. Interest in ancestry	242 (43)	320 (57)	240 (42.9)	319 (57.1)	1 (0.78–1.26)	1
5. Determine certain body features	134 (24)	425 (76)	147 (26.4)	410 (73.6)	1.1 (0.86–1.49)	0.35
6. Whole genome for later use	224 (39.5)	343 (60.5)	299 (53.2)	263 (46.8)	*1.7 (1.37–2.2)*	*< 0.001*

Attitude toward different motives for testing with physician consultation availability. Significant *p* values are in italics. The results show that in the case of genetic tests with a clear medical utility, the availability of medical consultation associates with a greater desire to test

of respondents would request such tests, respectively. Interest in ancestry information and certain physiological features (such as determining eye color from genetic data) was generally lower regardless of the option for consultation (36.8% for ancestry information and 22.4% for physiological features with consultation; 36.5 and 22.4% respectively without consultation). This is different from the findings of Baptista et al. in a cohort from the USA [18], where 80 adoptees and 1527 non-adopted adults expressed a high interest in ancestry information (73% of the non-adoptees and 83% of the adoptees were "very interested" in learning ancestry information). Although we have no information on the cause of this discrepancy, we speculate that the different history of the two countries regarding immigration could give an explanation.

A mixed attitude was also detected in a hypothetical situation when a serious genetic disease is present in the family, but the respondent is healthy. In this case, 51.9% of the respondents would like to know if he or she is carrying the pathogenic mutation in every case, 9% only if it is treatable, and 15.5% only if the respondent would like to have a child. In a separate question, we asked if the respondent would like to be contacted if some genetic findings related to their health emerge later in a research project. 61.9% would like to be contacted in every case, 18.1% only if there is a chance to intervene for the given condition, and 4.9% did not want to be contacted at all. It has been shown previously in the literature that disease severity and ability to treat the disease positively correlated with a positive attitude toward testing [19], but our respondents expressed a high interest regardless. A similarly high interest in incidental findings from diagnostic sequencing was also found in other studies [20].

The concept of direct to consumer testing has changed somewhat in recent years. Previously, it meant ordering a genetic test and receiving results without clinician involvement, but nowadays it is viewed more as a spectrum with various levels of physician involvement [21]. There were directly and indirectly connected questions on DTC included in our questionnaire. It was stated by 44.7% of our respondents that it is acceptable for them to buy genetic tests commercially, and 48.9% stated that she or he would use such service. US-based studies found a similar rate of potential interest in DTC genetic testing [22]. There is less information from European countries on potential consumers for nonspecific testing. In our cohort, the interest in genetic testing for different motives showed that this is mostly relevant for health-related testing.

Factors influencing attitude toward genetic testing and DTC testing

Differences between males and females and healthcare and non-healthcare workers emerged in bivariate analyses. According to the logistic regression model, age and gender were the most relevant factors influencing attitudes. Educational status and religious devotedness also had a mild effect. Male respondents were more likely to be interested in genetic testing with or without medical consultation for ancestry information, to determine certain physiological features, and whole genome testing for later analysis. They were also more interested in identifying genetic risk factors for common

Table 5 Predictors for positive answers for questions related to direct to consumer genomic testing

Predictors		Would you ask for a comprehensive genetic testing just out of curiosity? (Q18)		Would you ask for a genetic testing in a good health condition, without a medical consultation in order to learn about your ancestry? (Q19.4)		Do you think it is acceptable to purchase genetic test commercially? (Q16)	
		OR (CI_{95})	*P* value	OR (CI_{95})	*P* value	OR (CI_{95})	*P* value
Educational level (ref: university)	Middle school	0.931 (0.325–2.665)	0.894	0.884 (0.299–2.606)	0.822	*0.326 (0.107–0.989)*	*0.048*
	Vocational training	*5.953 (1.231–28.788)*	*0.027*	0.469 (0.129–1.712)	0.252	1.61 (0.379–4.193)	0.705
	Vocational school	0.921 (0.450–1.885)	0.821	0.598 (0.278–1.289)	0.189	0.585 (0.286–1.198)	0.143
	High school	1.392 (0.811–2.390)	0.230	0.883 (0.508–1.535)	0.660	*0.489 (0.284–0.844)*	*0.010*
	National qualification registered training	2.137 (0.516–8.839)	0.295	0.761 (0.199–2.913)	0.690	1.603 (0.387–6.641)	0.515
	College	*2.240 (1.232–4.072)*	*0.008*	1.156 (0.641–2.087)	0.630	0.963 (0.541–1.714)	0.899
Gender (ref: women)		*1.761 (1.112–2788)*	*0.016*	*1.761 (1.125–2.758)*	*0.013*	1.358 (0.869–2.124)	0.180
Age		*0.981 (0.964–0.999)*	*0.035*	*0.980 (0.962–0.998)*	*0.029*	*0.979 (0.962–0.997)*	*0.021*
Has child (ref: yes)		1.302 (0.762–2.223)	0.334	1.210 (0.712–2.057)	0.481	0.866 (0.510–1.471)	0.596
Profession (ref: healthcare)		1.547 (0.876–2.732)	0.133	1.147 (0.644–2.043)	0.642	1.173 (0.668–2.059)	0.579
Religious (ref: religious)		1.143 (0.758–1.724)	0.524	0.888 (0.586–1.345)	0.575	*0.703 (0.468–1.056)*	*0.090*
Self-rated familiarity score		0.999 (0.990–1.009)	0.919	0.994 (0.984–1.004)	0.241	1.002 (0.992–1.012)	0.677
Perceived genetic influence (ref: score ≥ 30)		0.799 (0.467–1.368)	0.413	0.908 (0.527–1.567)	0.729	0.993 (0.583–1.693)	0.980
Living area (ref: non-capital)		0.903 (0.587–1.387)	0.640	1.171 (0.759–1.807)	0.474	1.147 (0,751–1752)	0.525
Nagelkerke R^2 (%)		11.0		8.1		8.0	

The table is showing the impact of various factors (such as age and gender) on positive answers. Odds ratios (OR), 95% confidence intervals, and significance level (*p*) are indicated. Significant *p* values and marginally significant *p* values and marginally significant p values are in italics. Based on the logistic regression model, age and gender were the most relevant factors influencing attitude toward direct to consumer genetic tests. Educational status and religious devotedness also had a mild effect

diseases if medical consultation was an option. However, fewer male than female respondents had a high-perceived genetic influence score (11.4 vs. 21.9% $p = 0.003$). Healthcare workers and students seemed to be more skeptical toward genetic testing; for almost every motive, they were less likely to request a genetic test with medical consultation. We do not think that the reason for this is that they view themselves as qualified to request a genetic test and for this reason felt the medical consultation was unnecessary. Overall, the percentage of respondents who would ask for a genetic test was still increased when medical consultation was an option, but it was significantly higher for non-healthcare workers. A likely explanation is that the opportunity for medical consultation increased interest in testing among non-healthcare workers on a greater scale compared to healthcare workers. The more skeptical view of genetic professionals was also captured in a study by Middleton et al. [19]. Other studies have also shown that more knowledge on genetics may be associated with a lower perceived benefit of testing [23], which might reflect a more realistic view of genetic testing utility. The captured skepticism of physicians might be explained by the current limitations of genetic data interpretation and often unclear translation into the clinical setting. Even in well-defined Mendelian disorders, the diagnostic rate of clinical exome sequencing is around 30% [24]. Genomic risk prediction in multifactorial diseases is an even more complex task and even with improved prediction models clinical validity and clinical utility has yet to be proven [25]. One way to improve the predictive capacity of genomic information is to capture the complexity of an individual's biological system by simultaneous analysis of "multiple omes" (e.g., genome, epigenome, transcriptome, proteome), and creating a personal omics profile [26]. However, to gain meaningful clinical information from this multilayer data is not trivial. Different multi-omics data integration methodologies are now available, but the field is still in development [27].

The effect of age on attitude toward genetic testing is complex according to the literature. In general, younger people show a more positive attitude and willingness to participate in genetic testing [23]; this was supported by our study as well. However, increasing age might be associated with greater awareness of genetic testing opportunities [28], and younger people may express more concerns related to testing [29] according to literature.

Perceived genetic influence also affected attitude toward genetic testing, which was mostly noticeable when the medical utility of the genetic test was less obvious. Those respondents who had a high-perceived genetic influence score (≥ 30) were more likely to be interested in testing for common risk modifier variants and in submitting samples for whole genome sequencing for later analysis. Interestingly, a higher percentage of female than male respondents had a high-perceived genetic influence score (21.9 vs 11.4% $p = 0.003$), but more male respondents would request a genetic test for ancestry purposes, for determining certain physiological features, and for whole genome analysis at a later time. This could be because females are generally more skeptical toward genetic testing when the medical utility is uncertain, but a group of female respondent has a high-perceived genetic influence score, and they are more likely to ask these tests. According to previous studies, men may have a more positive attitude toward testing, but women may have more knowledge of genetics [23]. It is also noteworthy that respondents with a greater self-rated genetic familiarity score were more likely to have a high-genetic influence score, as well as healthcare workers. However, healthcare workers generally had a more skeptical view of genetic tests, which indicate that they see the utility of these tests differently.

There are some available measures for determining objective and perceived genetic knowledge as well as genetic self-efficacy in the literature [12, 15, 30–32]. However, these are heterogeneous and in Hungary there is no validated measure for determining objective genetic knowledge or self-efficacy currently available. Instead, we measured familiarity with genetic phrases, which is different from knowledge but helps estimate how likely a respondent has heard about issues raised in the questionnaire. We showed that the familiarity score was higher among more educated respondents, similar to genetic literacy, and genetic knowledge [12, 14, 15]. Additionally, healthcare related workers also had higher genetic familiarity scores in our study. More knowledge associates with more positive attitude toward genetics according to literature, but also with more concerns [15]. However, high familiarity does not mean high level of knowledge [14]. It has also been shown that confidence in genetic knowledge may even decrease after receiving direct-to-consumer personal genomic test results [12], which might be addressed by clinical genetic counseling.

Study limitations

One limitation of our study is that most respondents were well educated. Additionally, the study population either has a personal connection to a genetic disease, is interested in genetics, or is a medical professional. However, according to the literature, individuals seeking genetic susceptibility testing are usually highly educated

[33] and have high level of genetic knowledge [12]. It can also be assumed that people interested in genetics or those with a personal connection to a genetic disease are more likely to use such a service [34]. The larger representation of medical professionals allowed us to compare the public and medical viewpoint. Response rate could not be measured, since we do not have an estimation of the number of people reached through public media. Objective genetic knowledge was not measured, because validated measures in Hungary are still lacking. In future work, it will be important to validate such a measure in the Hungarian population and also compare the genetic familiarity score with objective knowledge. Regarding predictors for a positive attitude toward DTC testing, 8–11% of the total variation could be explained by our model, thus other relevant factors need to be identified.

Conclusions and and expert recommendations

In this study, we showed a mixed attitude toward broad genetic testing in a Hungarian cohort. Interest was higher for health-related indications and for tests with more obvious medical utility. Most relevant factors influencing attitude toward testing were medical education, availability of medical consultation, gender, and age. Respondents with a higher genetic familiarity score also had a higher perceived genetic influence score, which in turn positively influenced attitude toward testing with a less clear medical utility. However, medical professionals who had a high-genetic familiarity score, constituted a skeptical group, which might be explained by the current limitations of NGS data interpretation. Respondents expressed a higher interest in testing if medical consultation was an option. Previous studies show that patients prefer to receive genetic information from physicians they already know [7, 15, 35], but it is also shown that physicians generally receive limited training in genetics [36]. Meanwhile, clinical genetic counseling is becoming more complex [36]. Thus we advocate for a model where clinical and research use of next-generation sequencing is linked to clinical follow-up with the patients, preferentially performed in institutes with a dual role as genetic research and clinical institutes. This fits into the dynamic model of managing exome and genome sequencing results [37], but acknowledges that technology is developing rapidly and public as well as medical professional's knowledge in genomics is limited. Our findings are consistent with the Action Plan of the International Consortia of Personalized Medicine (ICPerMed) [38] which identify as actionable research activity for the implementation of the personalized medicine of the following:

1. Introduce curricula reforms to create new models of genomic-based healthcare for patients and citizens and broaden the focus on basic and clinical sciences to include health systems sciences in the education of all healthcare professionals
2. Build sustainable resources for educating and training citizens, patients, and patient advocates on involvement of patients and patient organizations across the entire research and development lifecycle of personalized medicine
3. Develop the tools and modus operandi of a knowledge network for enhancing health (genomic) and digital literacy
4. Develop and share best practices of patient engagement approaches for the needs of a variety of European citizens
5. Develop the instruments for the evaluation of the effectiveness and impact of public engagement initiatives in personalized medicine

Our results serve as a basis for a national roadmap of personalized medicine regarding citizen's engagement and pave the way for action plans to enhance patient engagement and empowerment.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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