Research Article

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Personalized Medicine

Medical student preparedness for an era of personalized medicine: findings from one US medical school

Aim: The objective of this research was to assess medical student preparedness for the use of personalized medicine. **Materials & methods:** A survey instrument measuring attitude toward personalized medicine, perceived knowledge of genomic testing concepts and perceived ability to apply genomics to clinical care was distributed to students in medical school (MS) years 1–4. **Results:** Of 212 participants, 79% felt that it was important to learn about personalized medicine, but only 6% thought that their medical education had adequately prepared them to practice personalized medicine. Attitude did not vary across years; knowledge and ability increased after MS1, but not after MS2. **Conclusion:** While medical students support the use of personalized medicine, they do not feel prepared to apply genomics to clinical care.

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With the recent presidential announcement of a Precision Medicine Initiative [1], an era of personalized medicine is imminent. In broad terms, personalized (or precision) medicine is an approach emphasizing unique patient characteristics to improve the prevention, diagnosis and management of disease [2]. Personalized medicine is largely fueled by advances in genomics and informatics, including the ability to deliver genomic content to healthcare providers through the electronic health record at the point of care [3,4]. The growing public and federal support of personalized medicine raises an important question: does the next generation of healthcare providers feel prepared to integrate genomics into clinical care and practice personalized medicine?

Recent surveys of current healthcare providers across different specialties have revealed a general lack of knowledge, preparedness and even willingness to use genomics in clinical care [5–8]. This has mostly been observed in the field of pharmacogenomics (PGx), which implicates genetic variants in interindividual drug response variability and was one of the first aspects of personalized medicine to be translated to clinical care [9]. A nationwide survey of US physicians found that many felt inadequately educated in PGx, and that early or future adopters were more likely to have received PGx training and to feel informed about genetic test availability and applications [7]. A separate survey of US primary care physicians similarly found that the majority did not feel comfortable ordering PGx tests [10]. Comparable results have been observed in other countries: almost half of surveyed physicians in Greece felt that their knowledge of PGx and personalized medicine was poor [11], and the vast majority of residents and specialized physicians surveyed in Italy believed that PGx should be taught more extensively during the course of studies in medicine and surgery [12]. Recent findings

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from a PGx implementation program at the Icahn School of Medicine at Mount Sinai (ISMMS; NY, USA) [13] have highlighted that providers, including resident trainees and physician attendings in internal medicine, lack familiarity and comfort in interpreting and utilizing genomic information [6]. Overall, this poses a significant barrier to widespread personalized medicine implementation.

The increasing pervasiveness of genomics in clinical practice underscores the need to improve genomics knowledge and familiarity in future healthcare providers [14–16]. In the last 10 years, medical schools have evolved their curricula to include genomics education [17]. To enhance personalized medicine competency, some medical schools are offering students the opportunity to analyze their own genotyping or sequencing information [18–20]. Despite these efforts, few studies have assessed whether medical students feel adequately prepared for the integration of genomics into clinical care. In order to address this, we conducted a cross-sectional study of ISMMS medical students in all years of schooling, surveying their attitudes toward genomic medicine, their perceived knowledge of genomic testing concepts and their perceived ability to apply genomics to clinical care. This study provides significant insight into medical student willingness and preparedness for the practice of personalized medicine.

Table 1. Medical student quantitative measures.

Concept and definition	Survey items
Attitude:	Eight items: please indicate the extent to which you agree with each item[†]:
– Attitude toward adoption of genome-guided prescribing and personalized medicine	– Openness: I would be willing to use new types of therapy/interventions to help my patients; I would be willing to use a patient's genetic information to guide my decisions in clinical practice; I would be willing to try genome-guided prescribing tools that are developed by researchers; I would be willing to use genome-guided prescribing in my career even if more senior physicians around me were not – Divergence: clinical experience is more important than using a patient's genetic information to make decisions; I would not be willing to prescribe different medications or doses of medications. Clinicians know better than academic researchers how to treat patients based on a patient's genetic information; research-based genome-guided prescribing tools are not clinically useful Rating scale ranges from 1 to 5: – 1 = not at all – 2 = to a slight extent – 3 = to a moderate extent – 4 = to a great extent – 5 = to a very great extent
Knowledge:	Four items: how comfortable are you in your knowledge about:
– Perceived knowledge of genomic testing concepts	– Basic genomic testing concepts and terminology; pharmacogenomics; genetic variation predisposing to common diseases (such as diabetes, kidney and heart disease); next-generation sequencing? Rating scale ranges from 1 to 5: – 1 = not at all comfortable – 2 = not very comfortable – 3 = neither comfortable nor uncomfortable – 4 = comfortable – 5 = very comfortable
Ability:	Four items: how comfortable are you in your ability to:
– Perceived ability to apply genomics to clinical care	– Recommend genomic testing options to patients; understand genomic test results; explain genomic test results to patients; make treatment recommendations based on genomic test results? Rating scale ranges from 1 to 5: – 1 = not at all comfortable – 2 = not very comfortable – 3 = neither comfortable nor uncomfortable – 4 = comfortable – 5 = very comfortable

[†]Adapted from the Evidence-Based Practice Attitude Scale – Genome-Informed Interventions [6].

Materials & methods

Setting

The study was conducted at ISMMS, a medical school integrated into the Mount Sinai Health System in New York City. All ISMMS medical students in the 2014–2015 academic year (n = 520) were eligible to participate. Hard copy questionnaires were distributed to students in medical school (MS) years 1–4 during class meetings held between June 2014 and September 2014. Incoming students were surveyed during an orientation session delivered at the beginning of their first year (MS1). Second year students were surveyed at the beginning of the academic year (MS2). Third and fourth year students were also surveyed at the beginning of the academic year (combined as MS3+). Participation was voluntary, and the study was granted exemption by the Mount Sinai Institutional Review Board. Surveys were not linked to participant name and results were aggregated to assure confidentiality.

Survey development

A survey instrument was developed to capture attitude toward genomic medicine, perceived knowledge of genomic testing concepts and perceived ability to apply genomics to clinical care. Table 1 summarizes these constructs and corresponding questions in the survey. Definitions were provided for the following terms: genomics, next-generation sequencing (NGS), PGx, genome-guided prescribing, direct to consumer (DTC) genetic testing and personalized medicine.

Attitude questions were primarily based on the Evidence-Based Practice Attitude Scale (EBPAS) [21], which was previously adapted to measure attitudes toward adopting genome-informed interventions (EBPAS-GII) [6]. Here, we used a subset of the EBPAS-GII scale, focusing on two of its three subscales: openness to new practices and divergence of usual practice with research-based/academically developed GII. The third subscale (appeal of GII) was not included in the present study because it would not pertain to medical students who have not yet been exposed to genomic medicine implementation. Four items on each of the openness and divergence subscales were measured on a 5-point scale, depending on the extent of agreement with each statement, which ranged from 'Not at all' to 'To a very great extent' (Table 1). Items from the divergence subscale were reverse scored. The modified EBPAS-GII, referred to as the attitude summary score, is the sum of the two subscale scores.

In a similar manner, additional 5-point scale questions were developed and were scaled to two constructs: perceived knowledge of genomic testing concepts (knowledge; four items), and perceived ability to apply genomics to clinical care (ability; four items).

Table 2. Medical student demographics (n = 212).

Characteristics	Medical students, n (%)
Gender:	
– Male	109 (51)
– Female	101 (48)
– Not given	2 (1)
Medical school year:	
– 1	65 (31)
– 2	64 (30)
– 3	64 (30)
– 4	17 (8)
– Not given	2 (1)
Research interest:	112 (53)
– Clinical	101 (48)
– Translational	59 (28)
– Basic science	22 (10)
– Don't know	65 (31)
Dual degree program:	34 (16)
– MD/PhD	17 (8)
– MD/MPH	7 (3)
– MD/MSCR	10 (5)

Responses were measured on a 5-point scale, ranging from 'not at all comfortable' to 'very comfortable' (Table 1). A score was computed for each of these constructs separately.

Four additional items related to education were developed and were measured on the same 5-point scale as the attitude questions. These items were analyzed separately. Questions about attitudes toward DTC testing and comfort with technology were adapted from a previous study [6]. Data were collected on general demographics, interest in a research career and additional degrees being pursued including PhD, Masters of Public Health (MPH) or Masters of Science in Clinical Research (MSCR).

Statistical analysis

Cronbach's alpha was computed for the attitude, knowledge and ability items separately [22]. When Cronbach's alpha for a scale exceeds 0.7, the scale is considered to consistently assess the same underlying concept.

The sample distributions of attitude, knowledge and ability summary scores were approximately normal. One-way analysis of variance (ANOVA) with *post hoc* Tukey honest significant difference tests was used to examine significant associations between attitude, knowledge and ability scores with our collected

Table 3. Attitude, knowledge and ability scores.

Summary score	Number of items	n	Mean	SD	Range	Alpha
Attitude:	8	195	24.80	3.51	16–36	0.7
– Openness	4	195	15.09	2.95	5–20	0.8
– Divergence	4	195	9.71	2.56	4–18	0.6
Knowledge	4	211	11.90	4.06	4–20	0.9
Ability	4	211	9.21	4.01	4–20	0.9

SD: Standard deviation.

sample covariates. ANOVA p-values were controlled for multiple testing with the Benjamin–Hochberg false discovery rate (BH-FDR) method at a 5% rate. BH-FDR p-values are reported as adjusted p-values (p_{adj}). All results reported as significant are $p < 0.05$ after correction for multiple testing.

Answers for questions on attitudes toward DTC testing, comfort using technology and agreement with the statement "I think that it is important to learn about personalized medicine" were collapsed into binary values and tested for an association with the attitude summary score using *t*-test analyses. Multiple testing was corrected for with the BH-FDR method.

Each of the four education-related questions was tested for an association with MS year using the Kruskal–Wallis (KW) test, a nonparametric test similar to one-way ANOVA. Significant KW test results were further examined with Dunn's *post hoc* test of rank sums, controlling for FDR at the 5% rate.

Software

All statistical analyses were performed in the R statistical software environment [23]. The R package 'ggplot2' [24] was used to construct figures, 'psych' [25] was used to compute Cronbach's alpha and 'dunn.test' [26] was used to compute the Dunn's test.

Results

Participant characteristics

Of the 520 eligible ISMMS medical students in MS years 1–4, 212 (41%) participated in this study. The demographics of the 212 study participants are shown in Table 2. In total, 51% of participants were male, 53% were interested in a career involving research and 16% were enrolled in a dual degree program (including MD/PhD, MD/MPH and MD/MSCR programs).

ISMMS adheres to a traditional curriculum where the first two years of medical school are primarily didactic and third and fourth years are primarily clinical. MS1 consists of students just beginning their schooling (students were given surveys during orientation). MS2 consists of students undergoing classroom-based learning. MS3 and MS4 consist of students in the clinical clerkships. Given the low volume of responses from MS4 students (17 students), and the absence of any significant curriculum changes between MS years 3 and 4, these two groups were combined for analysis as MS3+. In total, quantitative analyses were performed on survey data from 65 MS1, 64 MS2 and 81 MS3+ participants (212 total; two students declined to provide their MS year and were excluded from certain analyses).

Attitude, knowledge & ability

To analyze students' overall attitudes toward genomic and personalized medicine, an attitude summary score was calculated (Table 3). The attitude score comprised two subscales, openness and divergence (see Table 1 & Figure 1), totaling eight items with a combined Cronbach's alpha of 0.7. The mean attitude score across all respondents was 24.8 (out of a maximum possible score of 40), indicating overall positive attitudes toward personalized medicine (Table 3). Summary scores for perceived knowledge of genomic testing concepts and for perceived ability to apply genomics to clinical care were calculated similarly, using four items for each (see Tables 1 & 3; Cronbach's alpha 0.9 each). The mean knowledge and ability scores across all respondents were 11.9 and 9.2, respectively (out of a maximum possible score of 20 for each). Subsequent analyses were performed using the attitude, knowledge and ability summary scores. All items tested for association with the attitude summary scores were also tested for association with the openness subscale of the attitude score alone, which produced identical results.

Table 4 presents the attitude, knowledge and ability scores by medical student characteristics. The scores across MS years are also represented in Figure 2. There were no significant associations between attitude scores and medical student characteristics, including MS year (Figure 2A), interest in a career involving research or pursuit of a dual degree program. Male students had significantly higher perceived knowledge scores than female students ($p < 0.01$). MS1 students had significantly lower knowledge scores than either MS2 or MS3+ students (Figure 2B; $p < 0.001$). There were no significant differences in knowledge scores between MS2 and

MS3+ students, between students interested or not in a career involving research or between students enrolled or not in dual degree programs. However, MD/PhD students had significantly higher knowledge scores than either MD/MPH or MD/MSCR students ($p < 0.01$ and $p < 0.05$, respectively). MS1 students had significantly lower perceived ability scores compared with MS2 and MS3+ students (Figure 2C; $p < 0.001$). There were no significant associations between ability scores and interest in a career involving research or pursuit of a dual degree.

Table 5 presents attitude scores by medical student familiarity with DTC genetic testing and comfort using technology. The majority of medical students surveyed had heard of DTC genetic testing companies (79%) and had used or would consider using these services (63%). However, most students (64%) did not feel that they knew enough about genetics and genomics to understand DTC genetic test results. There was a significant association between attitude scores and whether students had used or would consider using DTC services ($p < 0.05$), and whether they felt that they could understand the results ($p < 0.01$). The majority of medical students were comfortable using technology, including computers (95%) and the local electronic health system, Epic (52%). There was no association between attitude scores and comfort using technology (Table 5).

Education

The majority (79%) of ISMMS medical students agreed with the statement 'I think it is important to learn about personalized medicine' (Table 6). MS1 stu-

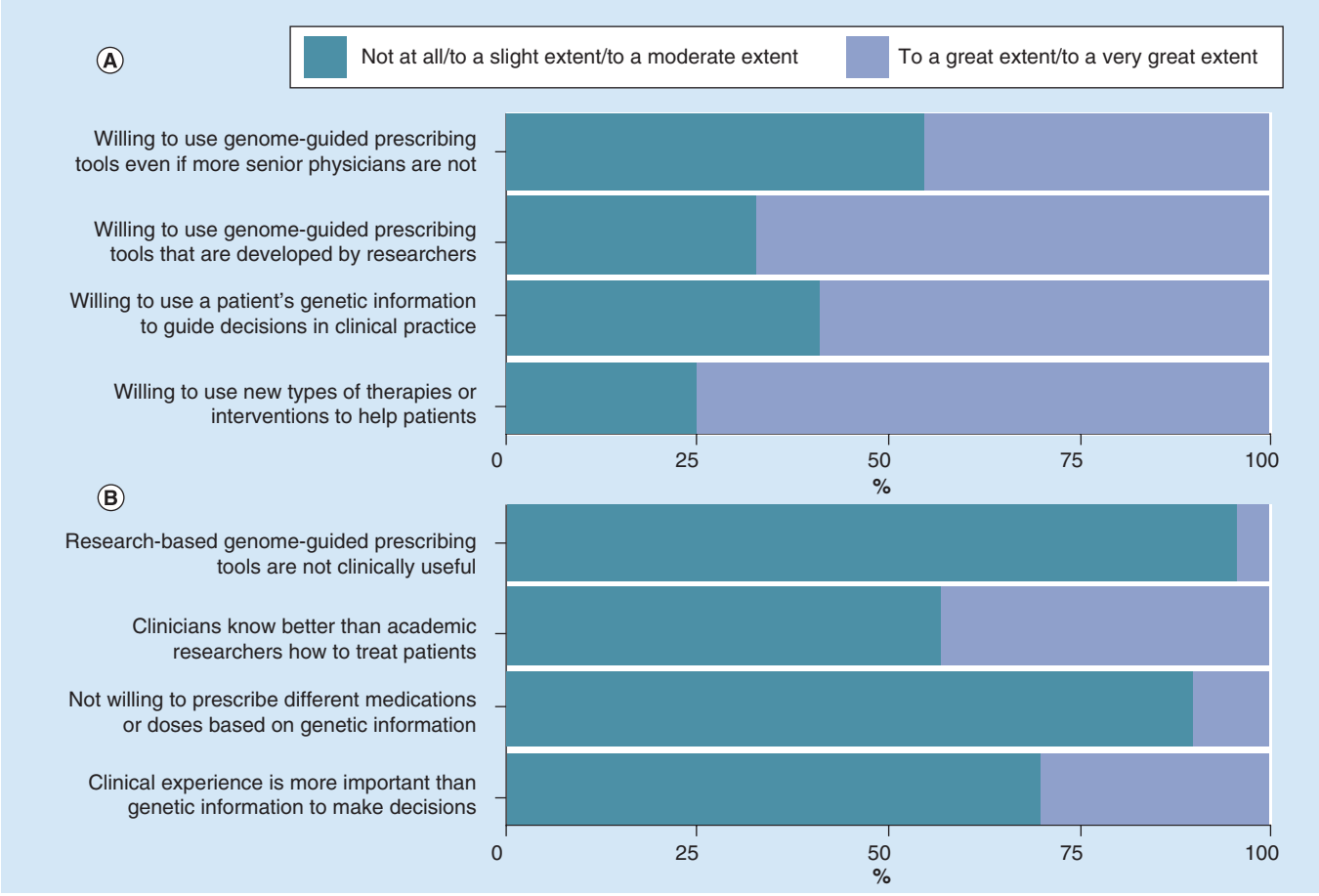

Figure 1. Attitudes toward adoption of genomic and personalized medicine. **(A)** Four openness and **(B)** four divergence items comprise the attitude score (Cronbach's alpha 0.7). Pooled responses (n = 210) were collapsed into binary values as 'not at all/to a slight extent/to a moderate extent' and 'to a great extent/to a very great extent'. **(A)** In the openness items, the majority disagreed with the statement: I am willing to use genome-guided prescribing tools even if more senior physicians are not (55%). The majority agreed with the statements: I would be willing to use genome-guided prescribing tools that are developed by researchers (67%); I would be willing to use a patient's genetic information to guide decisions in clinical practice (60%); and I would be willing to use new types of therapies or interventions to help patients (75%). **(B)** In the divergence items, the majority of students disagreed with all four statements: research-based genome-guided prescribing tools are not clinically useful (96%); clinicians know better than academic researchers how to treat patients (57%); I would not be willing to prescribe different medications or doses based on genetic information (90%); and clinical experience is more important than genetic information to make decisions (70%).

Table 4. Attitude, knowledge and ability scores by medical student characteristics.

Characteristics	Attitude				Knowledge				Ability			
	n	Mean	SD	p_{adj}	n	Mean	SD	p_{adj}	n	Mean	SD	p_{adj}
Age range (years):				NS				NS				NS
– 23 or younger	58	25.00	3.53		65	11.51	4.65		65	8.55	4.34	
– 24–25	75	24.89	3.43		83	11.59	3.63		83	9.05	3.77	
– 26 or older	61	24.56	3.61		63	12.65	3.90		63	10.05	3.90	
Gender:				NS				$p < 0.01$				NS
– Male	103	25.04	3.45		109	12.72	3.86		109	9.85	4.16	
– Female	90	24.58	3.59		101	10.98	4.10		101	8.52	3.77	
Medical school year:				NS				$p < 0.001$				$p < 0.001$
– 1	51	24.76	3.46		65	9.569	4.75		65	6.97	4.16	
– 2	63	25.11	3.72		64	12.79	2.95		64	9.72	3.71	
– 3+	79	24.49	3.38		81	13.25	3.19		81	10.65	3.32	
– 1 vs 2				NS				$p < 0.001$				$p < 0.001$
– 1 vs 3+				NS				$p < 0.001$				$p < 0.001$
– 2 vs 3+				NS				NS				NS
Dual degree:				NS				NS				NS
– No	164	24.81	3.46		178	11.71	4.01		178	9.07	4.12	
– Yes	29	24.93	3.82		32	13.19	4.07		32	10.03	3.30	
Type of dual degree:				NS				$p < 0.05$				NS
– MD/PhD	16	25.63	3.42		17	15.29	2.80		17	11.35	3.10	
– MD/MPH	6	25.33	4.27		7	10.14	3.67		7	9.57	2.30	
– MD/MSCR	9	22.22	3.96		10	11.8	4.18		10	9.30	4.14	
– PhD vs MPH				NS				$p < 0.01$				NS
– PhD vs MSCR				NS				$p < 0.05$				NS
– MPH vs MSCR				NS				NS				NS
Interest in research:				NS				NS				NS
– No/unsure	90	24.78	3.76		98	11.42	4.07		98	9.64	4.37	
– Yes	104	24.90	3.19		112	12.36	3.97		112	8.81	3.59	

NS: Not statistically significant; P_{adj}: Adjusted p-value; SD: Standard deviation.

dents were significantly more likely to agree with the statement than MS3+ students (Figure 3A; $p < 0.05$). Students who were interested in a career involving research were more likely to agree than students who were not or were unsure (Figure 3A; $p < 0.01$). Students who agreed with this statement were more likely to have higher attitude scores (Figure 3B; $p < 0.001$).

Table 6 shows responses to additional education-related questions. Overall, only 6% of medical students agreed with the statement "My medical education has adequately prepared me to practice personalized medication," 7% agreed with "I know whom to ask questions regarding genomic testing" and 18% agreed with "My professors have encouraged the use of personalized medicine." MS2 and MS3+ students were significantly more likely than MS1 students to agree with these statements. MS2 students were also more likely to agree with the last statement than MS3+ students.

Discussion

Until recently, most genomic advances were only relevant to a small subset of patients and an even smaller subset of healthcare providers. Today's providers are gaining more experience with testing for genetic diseases, specific applications of personalized cancer

therapy and a handful of clinically relevant drug–gene interactions [2]. Future generations of providers will likely make even broader use of genomics and personalized medicine approaches in routine clinical care across most if not all subspecialties. However, relative to the pace of genomic discovery, the adoption of genomics and personalized medicine among healthcare providers has been slow. At this stage, it is therefore crucial to identify and address potential barriers to the widespread implementation of personalized medicine, such as future providers' attitudes, knowledge and abilities [27].

This study assessed these constructs by means of a survey instrument distributed to 520 medical students at ISMMS, a US medical school maintaining a standard medical education curriculum with didactic learning in the first two years and clinical training in the third and fourth years. There were 212 respondents (41%), with the lowest number of respondents (8%) coming from MS4, and 53% expressing interest in a career involving

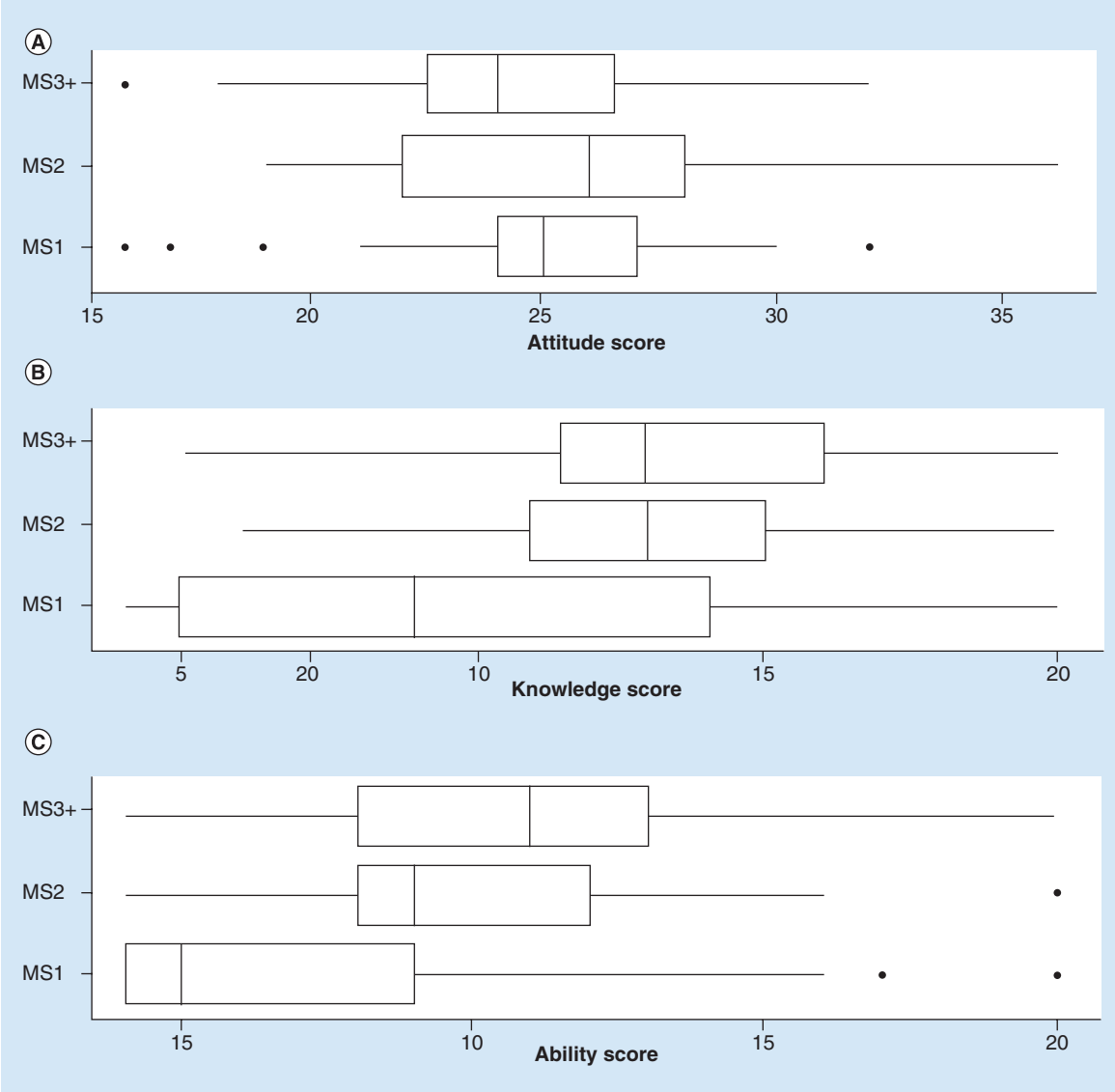

Figure 2. Attitude, knowledge and ability scores by medical school year. **(A)** Attitude scores: MS1 (mean: 24.76; standard deviation [SD]: 3.46), MS2 (mean: 25.11; SD: 3.72) and MS3+ (mean: 24.49; SD: 3.38). There were no significant associations between attitude scores and MS year. **(B)** Knowledge scores measured perceived knowledge of genomic testing concepts: MS1 (mean: 9.57; SD: 4.75), MS2 (mean: 12.79; SD: 2.95) and MS3+ (mean: 13.25; SD: 3.19). MS1 students had significantly lower knowledge scores than either MS2 or MS3+ students ($p < 0.001$). **(C)** Ability scores measured perceived ability to apply genomics to clinical care: MS1 (mean: 6.97; SD: 4.16), MS2 (mean: 9.72; SD: 3.71) and MS3+ (mean: 10.65; SD: 3.32). MS1 students had significantly lower ability scores than either MS2 or MS3+ students ($p < 0.001$).
MS: Medical school year.

Table 5. Attitude scores by other predictor variables: familiarity with direct to consumer testing and comfort with technology.

Survey items	n (%)	Mean	SD	p_{adj}
DTC testing				
Have you heard of DTC companies such as 23andme?				NS
– No	40 (21)	24.95	4.34	
– Yes	155 (79)	24.76	3.27	
Have you used/would you consider using DTC services?				$p < 0.05$
– Would not use	69 (37)	23.91	3.73	
– Would use/did use	120 (63)	25.27	3.37	
I know enough about genetics and genomics to understand DTC test results:				$p < 0.01$
– Definitely false/mostly false/don't know	124 (64)	24.27	3.39	
– Mostly true/definitely true	69 (36)	25.74	3.58	
Comfort with technology				
How comfortable are you with using computers?				NS
– Neither comfortable or uncomfortable/not comfortable	10 (5)	24.20	3.49	
– Comfortable/very comfortable	185 (95)	24.83	3.51	
How comfortable are you with using Epic?				NS
– Neither comfortable or uncomfortable/not comfortable	93 (48)	25.00	3.48	
– Comfortable/very comfortable	102 (52)	24.62	3.53	

DTC: Direct-to-consumer; NS: Not statistically significant; P_{adj}: Adjusted p-value; SD: Standard deviation.

research. Using an adapted attitude score [6] comprised of openness and divergence items, we determined that students had overall positive attitudes toward personalized medicine and were open to using genetic and genomic information in clinical care even when this diverged from usual practice. Attitudes toward personalized medicine did not vary across MS year, interest in research or type of training program. Almost all respondents (96%) felt that research-based genome-guided prescribing tools were clinically useful, and most (90%) were willing to prescribe different medications based on genetic information. In comparison, a previous survey study at ISMMS revealed that 53% of general internal medicine physicians perceived genotype information to be useful for making prescribing decisions [6].

Perceived knowledge of genomic testing (including basic concepts, PGx, genetic predisposition to common disease and NGS) was lower in MS1 students than in other years. Perceived ability to apply genomics to clinical care (including recommending, understanding and explaining genomic tests and using genomic information to guide treatment) was also lower in MS1 students. There were no differences in knowledge or ability between MS2 and MS3+ students. These findings are consistent with the ISMMS didactic curriculum, as genetics and genomics education was recently incorporated earlier into the first year curriculum, and MS1 students are now routinely offered the opportunity to participate in a PGx study. MS2 students were more likely to agree that their professors had encouraged the use of personalized medicine than other groups, which may also be a reflection of this curriculum change. The finding that there were no differences in perceived genomic knowledge or ability between MS2 and MS3+ students could suggest insufficient integration or emphasis of personalized medicine approaches in the later clinical curriculum.

Most ISMMS medical students (79%) were aware of personal genome testing via DTC companies, although only 36% felt comfortable interpreting DTC test results. This is in contrast to earlier findings that only 41% of ISMMS physicians were aware of these services, whereas 59% felt comfortable interpreting results [6]. We found significantly higher attitude scores in medical students who were willing to use DTC services and were comfortable interpreting results; this association was not observed in the previous ISMMS physician study [6]. Interestingly, at Stanford School of Medicine, nearly all students taking a genomics and personalized medicine course felt that most physicians do not have enough knowledge to interpret results of personal genome tests [28].

Although the majority (79%) of medical students surveyed agreed that it was important to learn about person-

Table 6. Items related to education.

Survey items	Total (n = 193); n (%)	MS1 n = 51; (%)	MS2 (n = 63); n (%)	MS3+ (n = 79); n (%)	p_{adj}	p-value (*post hoc*)		
						MS1 vs MS2	MS1 vs MS3+	MS2 vs MS3+
I think that it is important to learn about personalized medicine:					$p < 0.05$	NS	$p < 0.05$	NS
– Not at all/to a slight extent/to a moderate extent	41 (21)	9 (18)	11 (17)	21 (27)				
– To a great extent/to a very great extent	152 (79)	42 (82)	52 (83)	58 (73)				
My medical education has adequately prepared me to practice personalized medicine:					$p < 0.001$	$p < 0.001$	$p < 0.001$	NS
– Not at all/to a slight extent/to a moderate extent	181 (94)	48 (94)	59 (94)	74 (94)				
– To a great extent/to a very great extent	12 (6)	3 (6)	4 (6)	5 (6)				
I know whom to ask questions regarding genomic testing:					$p < 0.001$	$p < 0.001$	$p < 0.01$	NS
– Not at all/to a slight extent/to a moderate extent	180 (93)	48 (94)	58 (92)	74 (94)				
– To a great extent/to a very great extent	13 (7)	3 (6)	5 (8)	5 (6)				
My professors have encouraged the use of personalized medicine:					$p < 0.001$	$p < 0.001$	$p < 0.001$	$p < 0.01$
– Not at all/to a slight extent/to a moderate extent	158 (82)	45 (88)	43 (68)	70 (89)				
– To a great extent/to a very great extent	35 (18)	6 (12)	20 (32)	9 (11)				

MS: Medical school year; NS: Not statistically significant; P_{adj}: Adjusted p-value.

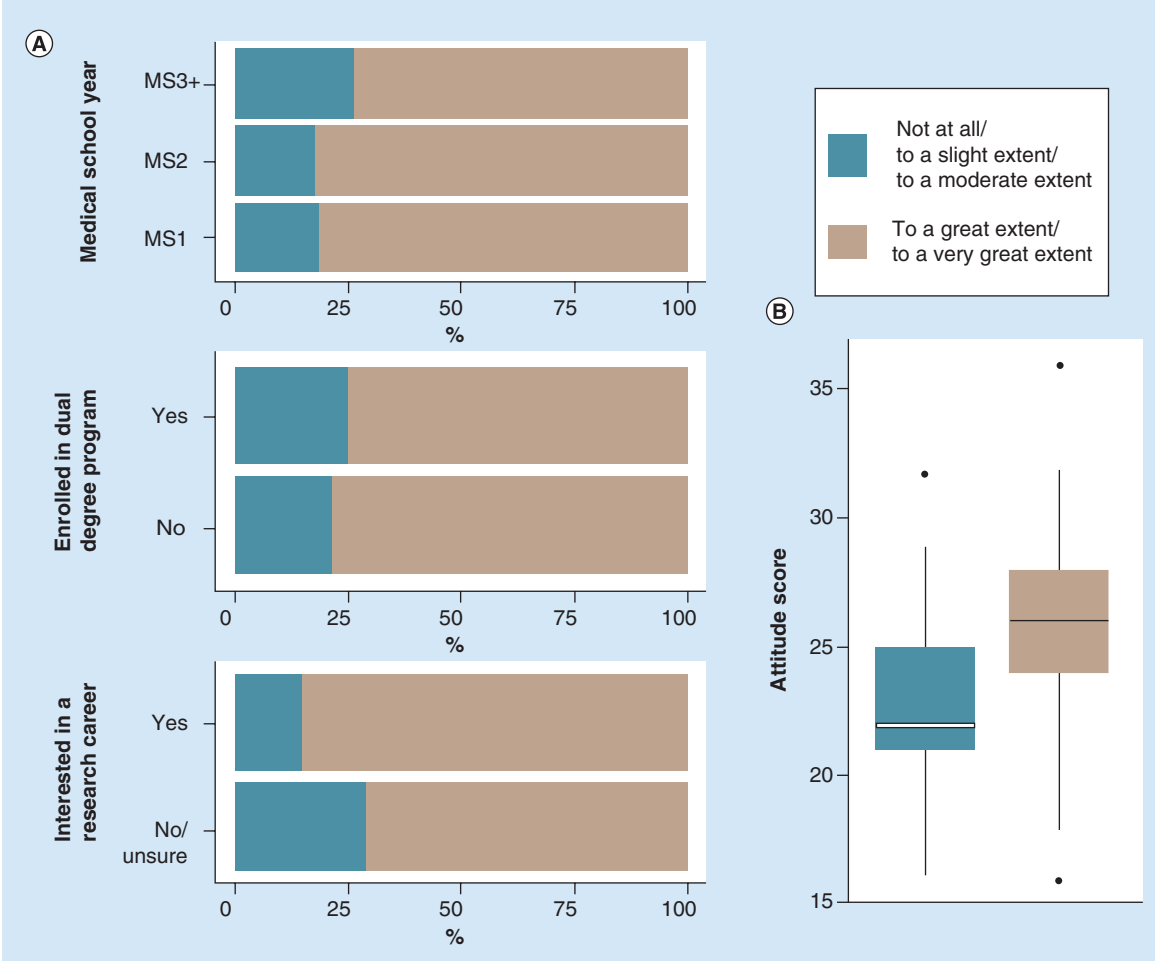

Figure 3. Extent of agreement with the statement "I think that it is important to learn about personalized medicine." Responses were collapsed into binary values as 'not at all/to a slight extent/to a moderate extent' and 'to a great extent/to a very great extent'. **(A)** Responses are shown according to MS year, dual degree program and interest in a research career. In total, 82% of MS1 versus 83% of MS2 versus 73% of MS3+ students agreed with the statement. MS1 students were significantly more likely to agree than MS3+ students ($p < 0.05$). There was no significant difference in agreement between students enrolled (79%) or not enrolled (76%) in a dual degree program (MD/PhD, MD/MPH or MD/MSCR). Students interested in a career involving research were significantly more likely to agree with the statement than students who were not or were unsure (86 vs 71%, respectively; $p < 0.01$). **(B)** Students who agreed with the statement had significantly higher attitude scores (mean: 25.34; standard deviation: 3.37) than those who did not agree (mean: 22.87; standard deviation: 3.39; $p < 0.001$). MS: Medical school year.

alized medicine, only 6% of students felt that their medical education had adequately prepared them to practice personalized medicine. Students interested in research were more likely to agree that it was important to learn about personalized medicine, and MD/PhD students were the most confident in their knowledge of genomic testing concepts. This suggests that personalized medicine remains most accessible to research-oriented individuals, which is congruent with the way genomic and technological advances transformed biomedical research long before their tentative reach into clinical practice.

A limitation of this study is that the survey instrument was distributed to a single US medical school. ISMMS is an early adopter of personalized medicine with several educational genomic initiatives [18,29] and translational genomic medicine research programs in place [13]; this emphasis on genomics and personalized medicine may not be reflective of other medical schools in the USA or in other countries. Thus, the study would benefit from additional assessment of the survey instrument in other settings. Additionally, 59% of eligible ISMMS students did not respond to the survey. It is possible that those who responded may have been more interested in genomics and personalized medicine and did not represent the study body as a whole. Another limitation is that the survey was designed to measure perceived (or self-reported) knowledge and ability in genomics. The knowledge and ability constructs were developed

specifically for this study, and it is not known how well they correlate with actual knowledge and skills. Finally, the cross-sectional design of the study limits the ability to draw conclusions as to whether differences in knowledge and ability between MS1 and MS2/MS3+ students can be attributed to general medical education or to specific genomics education.

A general theme with biomedical progress is that there are often delays in translating new technologies into clinical practice, and the way to tackle this discrepancy is by further educating the medical community [15]. To prepare for an era of personalized medicine, genomics education will need to go beyond the standalone basic science coursework of medical school [16]; the question remains what the most effective educational model will be. Personal genome testing has been implemented at some institutions, including ISMMS, as a mechanism to enhance genomics education. At ISMMS, personal whole-genome sequencing is incorporated into an advanced laboratory-style genome analysis course [18], in which students who analyzed their own genomes (including five MD or MD/PhD students) were found to have a significant increase in objectively assessed genomics knowledge [29]. Similarly, Stanford students who analyzed their own DTC genotyping data in a genomics and personalized medicine course had a significant increase in their objective knowledge of genetics and personal genome testing, while non-genotyped students did not show any improvement [28]. Several professional organizations and societies, including the Association of American Medical Colleges and the Association of Professors of Human and Medical Genetics, have developed or are in the process of developing guidelines and core competencies for genomics education [17,30]. A framework for developing genomic medicine competencies, put forth by the National Human Genome Research Institute's Inter-Society Coordinating Committee for Physician Education in Genomics, provides a starting point to implement genomic approaches in clinical care [31]. The framework focuses on a basic set of genomic skills – family history, genomic testing, treatment based on genomic results, somatic genomics and microbial genomic information – that can be used to guide medical education and residency training. Ongoing efforts to improve education and adoption among currently practicing healthcare providers at all stages are also needed, as their attitudes and mentorship will likely influence uptake of personalized medicine by future providers.

Conclusion

The promise of personalized medicine is soon to be a reality, and providers will have unprecedented access to genomic and other data to incorporate into their medical decision-making. Future providers will play a significant role in promoting and applying genetic testing, as well as critically evaluating and interpreting genetic test results; without a firm grasp of genomics, they may be overlooking a fundamental aspect of their job [14]. There is a definitive need for genomics to be embedded in medical education as a means to equip providers with the attitude, knowledge and skills required to practice personalized medicine. As a first step, the expansion of educational content and hands-on infrastructure is needed to expose medical students to genomics and personalized medicine approaches in their didactic and clinical curricula. Practical applications of personalized medicine, such as PGx, could be integrated into clinical training as a mechanism to appeal broadly to all medical students. This will allow future providers to harness the power of genomics in a way that best serves their patients.

Future perspective

Personalized medicine has the potential to pervade all aspects of clinical care from prevention and early diagnosis to management of disease. To realize its full potential, however, it needs to be understood and accepted by the medical community at large. While the precise impact of personalized medicine on the future practice of medicine is difficult to predict, it is clear that tomorrow's healthcare providers would benefit from enhanced familiarity with genomics and its applications. Expanding the genomic footprint of medical education is the first key step to ensuring the widespread implementation and success of personalized medicine.

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Ethical conduct of research

The authors state that they have obtained appropriate institutional review board approval or have followed the principles outlined in the Declaration of Helsinki for all human or animal experimental investigations. In addition, for investigations involving human subjects, informed consent has been obtained from the participants involved.

Executive summary

- Current medical students are entering an era of personalized medicine and will likely make broad use of genomics and personalized medicine approaches in clinical care.
- In this study, medical student preparedness for personalized medicine was assessed by means of a survey instrument measuring attitude toward personalized medicine, perceived knowledge of genomic testing concepts and perceived ability to apply genomics to clinical care.

Attitude, knowledge & ability

- Medical students had overall positive attitudes toward personalized medicine, and attitudes did not vary across medical school years, research interests or types of training programs.
- First year medical students had lower perceived knowledge of genomic testing concepts and lower perceived ability in genomics than other students. There were no differences in knowledge or ability among medical students in years 2 or above, suggesting a need for increased emphasis of personalized medicine approaches in the later clinical curriculum.

Education

- While the majority (79%) of medical students agreed that it was important to learn about personalized medicine, only 6% of students felt that their medical education had adequately prepared them to practice personalized medicine.
- Students with research interests were more likely to attribute importance to learning about personalized medicine, suggesting that personalized medicine remains more accessible to research-oriented individuals.

Conclusion

- Although interest in genomics and personalized medicine is high among medical students, they do not feel prepared to practice personalized medicine.
- There is a need for increased attention to the application of clinical genomics in medical student education, particularly in the clinical curriculum, as a means to equip providers with the attitude, knowledge and ability to practice personalized medicine.

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