A Systematic Evaluation of Different Methods for Calculating Adolescent Vaccination Levels Using Immunization Information System Data

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ABSTRACT

Objective. Immunization information systems (IISs) are valuable surveillance tools; however, population relocation may introduce bias when determining immunization coverage. We explored alternative methods for estimating the vaccine-eligible population when calculating adolescent immunization levels using a statewide IIS.

Methods. We performed a retrospective analysis of the Michigan State Care Improvement Registry (MCIR) for all adolescents aged 11–18 years registered in the MCIR as of October 2010. We explored four methods for determining denominators: (1) including all adolescents with MCIR records, (2) excluding adolescents with out-of-state residence, (3) further excluding those without MCIR activity ≥ 10 years prior to the evaluation date, and (4) using a denominator based on U.S. Census data. We estimated state- and county-specific coverage levels for four adolescent vaccines.

Results. We found a 20% difference in estimated vaccination coverage between the most inclusive and restrictive denominator populations. Although there was some variability among the four methods in vaccination at the state level (2%–11%), greater variation occurred at the county level (up to 21%). This variation was substantial enough to potentially impact public health assessments of immunization programs. Generally, vaccines with higher coverage levels had greater absolute variation, as did counties with smaller populations.

Conclusion. At the county level, using the four denominator calculation methods resulted in substantial differences in estimated adolescent immunization rates that were less apparent when aggregated at the state level. Further research is needed to ascertain the most appropriate method for estimating vaccine coverage levels using IIS data.

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Immunization information systems (IISs) are an important use of health information technology for conducting population-based surveillance,¹ having been in place for nearly two decades and well established in most states.^{2–5} IISs are able to create reminder-and-recall systems, aid in the surveillance of immunization efforts, and help evaluate public health responses to outbreaks of vaccine-preventable diseases.⁶

The comprehensiveness of information warehoused in IISs can affect their usefulness as a surveillance tool. Incomplete information can potentially lead to underestimated coverage levels and undermine recall efforts.^{7–9} Similarly, inaccurately determining the appropriate denominator population due to in- and out-migration can introduce bias when calculating vaccination levels. To address this issue, IIS users can manage individual-level data by using patient status indicators (e.g., moved or gone elsewhere [MOGE]) or special flags to identify those who have moved out of state or receive care from an out-of-state provider.¹⁰ However, such status indicators are provider-derived and may have varying levels of accuracy. Moreover, not all out-migrated individuals are identified by these means, and IISs may not be able to accurately account for individuals who have moved into the state but not yet received vaccines, or who still reside in the state but have changed providers. Consequently, these challenges could impact estimates of vaccination coverage levels. These challenges may be especially applicable when assessing adolescent immunization, as individuals may be “counted” (i.e., assessed for immunization status) as eligible in the registry because of one or two doses that were provided during infancy.

We explored whether different methods of estimating the vaccine-eligible adolescent population in an IIS resulted in substantial variation (defined as a >10 percentage-point change) in calculated adolescent vaccine coverage levels. We specifically evaluated alternative denominator calculation mechanisms that were likely to be available to most IISs to identify vaccine-eligible adolescent populations.

METHODS

Study population

We used data from the Michigan Care Improvement Registry (MCIR) to assess coverage levels for four adolescent vaccines: tetanus-diphtheria-acellular pertussis (Tdap), meningococcal conjugate vaccine (MCV4), seasonal influenza (flu), and human papillomavirus (HPV) vaccine (among females only).¹¹ Providers are mandated to report all school-exclusionary vaccination

doses administered to Michigan children ≤ 18 years of age. The MCIR is used by more than 95% of Michigan providers and had vaccination doses recorded for 2,589,182 children aged ≤ 18 years as of October 2010.¹²

We extracted vaccination records of all adolescents aged 11–18 years as of September 21, 2010, from the MCIR ($n=1,386,003$). We excluded deceased adolescents and those without a valid Michigan county of residence recorded, as well as duplicate and opt-out records ($n=133,348$), for a total of 1,252,655 adolescents with records available for analysis.

Alternative denominator definitions

We used four methods to estimate the population of adolescents eligible for vaccination (Figure 1), of which the first three also had a minor impact on the number of immunizations counted in the numerator of our calculations. This change in numerator accounted for <4% of the total immunization given for each denominator calculation method. The most inclusive denominator calculation method incorporated all adolescents in the sample with unique records in MCIR (hereafter, MCIR Inclusive). The second method excluded adolescents who were flagged MOGE at the user level (hereafter, Exclude Flagged).¹⁰ This population also excluded those who received immunizations by out-of-state health-care providers as well as migrants who were not considered state residents. (Of note, from 2002 to 2011, the MOGE flag in MCIR was not functional at the jurisdictional level or compliant with the Modeling of Immunization Registry Operations Workgroup [MIROW]⁴ standards for managing patient status at the provider level, having instead only two business rules: (1) to notify an end user of an incomplete or incorrect address and (2) to eliminate MOGE records from reminder-and-recall queries.)

The third method sought to further identify adolescents who likely had moved out of state but were not flagged as such. For this method, we eliminated from the Exclude Flagged population those adolescents whose MCIR records showed no activity for ≥ 10 years from the abstraction date (hereafter, Exclude Flagged and Inactive). We defined MCIR record inactivity as having no updates or modifications to the demographic profile or vaccination data. As a fourth method, we extrapolated county-specific U.S. Census Bureau estimates from 2007,⁶ the most recent year for which age- and gender-specific distributions were available at the county level, to estimate the population of 11- to 18-year-olds in 2010. Specifically, the population of 8- to 15-year-olds in 2007 was carried forward to represent the population of 11- to 18-year-olds in 2010.

Figure 1. The different adolescent (11–18 years of age) vaccine-eligible populations used to estimate coverage levels for four vaccines:^a Michigan, 2010

^aThe four vaccines were tetanus-diphtheria-acellular pertussis, meningococcal conjugate, seasonal influenza, and human papillomavirus (HPV) vaccine. (HPV was evaluated among females only.)

^bMCIR Inclusive refers to the total number of adolescents with an MCIR record containing valid county information. Exclude Flagged refers to the number of adolescents with an MCIR record containing valid county information, excluding those flagged as having moved out of state. Exclude Flagged and Inactive refers to the number of adolescents with an MCIR record containing valid county information, excluding those flagged as having moved out of state or with ≥ 10 years of MCIR inactivity. U.S. Census refers to the total number of adolescents in Michigan using 2007 U.S. Census estimates (Source: Census Bureau [US]. Estimated population of Michigan by age, race, and sex: 2000–2008 [cited 2013 May 29]. Also available from: URL: http://www.michigan.gov/cgi/0,4548,7-158-54534_51713_51714-214745--,00.html).

MCIR = Michigan Care Improvement Registry

MOGE = moved or gone elsewhere

Adolescent vaccination status determination

The primary outcome assessed was a comparison of the estimated proportion of eligible adolescents who had received each of the four vaccines studied. Detailed vaccine eligibility criteria are provided in the digital Appendix, Figure 1A, which is available online only.¹³ We estimated vaccine coverage levels by calculating the proportion of eligible adolescents who had received all of the recommended doses for that vaccine. Only valid vaccine doses were included. For MCV4, valid vaccine doses included adolescents ≥ 11 years of age who had received ≥ 1 dose of either the conjugated or polysaccharide meningococcal vaccines. For HPV, females had to be ≥ 11 years of age and have received all three vaccine doses. For Tdap, eligibility and vaccine coverage were dependent on the child's age, completion of the diphtheria-tetanus-acellular pertussis primary series during early childhood, and timing of most recent tetanus-diphtheria booster. Because the flu vaccine is recommended annually from approximately September to February, vaccine coverage was

estimated by identifying whether a single dose of the 2009–2010 seasonal flu vaccine had been received as of February 28, 2010.

County characteristics

We hypothesized several characteristics that could potentially contribute to the variation in estimated vaccine coverage levels, including total adolescent population size (using 2007 U.S. Census data¹¹), median annual household income, and distribution of uninsured children. We obtained county-specific median annual household incomes for 2009 from the U.S. Department of Agriculture Economic Research Service.¹⁴ We obtained the distribution of uninsured children < 19 years of age among Michigan counties from the Census Bureau Small Area Health Insurance Estimates, which were available most recently for 2007.¹⁵

Analyses

We assessed estimated coverage levels for each of the four vaccines using the four different denominator

determination methods for the state overall and also disaggregated by county. For analyses using the Census estimates as the denominator, we used vaccination data derived from the MCIR Inclusive population as the numerator to maximize the likelihood of capturing all administered doses. For each of the 83 counties in Michigan, we determined the difference between the highest and lowest coverage levels (of the four coverage levels calculated for each vaccine, defined as the “maximal difference” in coverage levels) and generated descriptive statistics. We also calculated the relative difference in estimated coverage levels for each vaccine and county by dividing the maximal difference by the mean coverage level (across the four calculation methods). We created state maps to look for possible patterns between the variation in calculated coverage levels and county characteristics. We also created quartile categories of vaccination levels (categorized as <25th, 25th to <50th, 50th to <75th, and ≥75th percentiles) across vaccines and methods, and determined the number of counties that moved across quartiles (either to the next highest or lowest quartile) using different calculation methods.

RESULTS

The vaccine-eligible populations varied substantially in size by denominator calculation method (Figure 1). The MCIR Inclusive population contained 1,252,655 adolescents, nearly 12% larger than the population calculated using Census estimates (1,112,200 adolescents). The populations further decreased after accounting for adolescents who may have migrated out of state (Exclude Flagged = 1,201,218) and had inactive records (Exclude Flagged and Inactive = 988,100).

At the state level, there was some variability in estimated vaccination levels by denominator calculation method for each of the vaccines assessed (Table 1). For all four vaccines assessed, the lowest and highest vaccine coverage levels corresponded to the largest (MCIR Inclusive) and smallest (Exclude Flagged and Inactive) populations, respectively.

When we studied vaccination coverage at a county level, we found substantially more variation among the different denominator calculation methods. Estimated vaccine-specific coverage levels calculated using all four methods are provided for each county in the digital Appendix, Table 1A, which is available online only. Within a given county, maximal differences ranged from approximately 7–21 percentage points for the

Table 1. State and county examples of adolescent (11–18 years of age) vaccine coverage levels calculated using four different denominator calculation methodologies: Michigan, 2010

Vaccine	Denominator calculation method			
	MCIR Inclusive ^a Percent	Exclude Flagged ^b Percent	Exclude Flagged and Inactive ^c Percent	U.S. Census ^d Percent
Michigan				
Tdap	45.3	46.0	55.9	50.9
MCV4	45.7	46.5	56.6	51.2
HPV	15.0	15.3	18.5	16.2
Influenza	8.1	8.3	10.1	9.1
Example county X				
Tdap	38.6	39.0	46.5	44.6
MCV4	36.1	36.7	43.7	41.8
HPV	18.1	18.4	21.8	20.2
Influenza	7.1	7.3	8.6	8.2

^aMCIR Inclusive was defined as all adolescents with a record in the MCIR that had valid county information.

^bExclude Flagged was defined as all adolescents with an MCIR record with valid county information after excluding those that may have out-migrated.

^cExclude Flagged and Inactive was defined as all adolescents with an MCIR record with valid county information after excluding those that may have out-migrated or with records that were inactive for ≥10 years.

^dU.S. Census was defined as the total number of adolescents in each county using 2007 U.S. Census estimates.

MCIR = Michigan Care Improvement Registry

Tdap = tetanus-diphtheria-acellular pertussis

MCV4 = meningococcal conjugate vaccine

HPV = human papillomavirus

Tdap and MCV4 vaccines, 2–9 percentage points for the HPV vaccine, and 1–5 percentage points for the flu vaccine (digital Appendix, Table 2A, which is available online only).

Of the 83 Michigan counties, the majority had maximal differences in estimated coverage levels of ≥ 11 percentage points for the Tdap and MCV4 vaccines, whereas no counties had maximal differences of > 10 percentage points for the HPV and flu vaccines (Figure 2a). For the Tdap and MCV4 vaccines, approximately 10% of counties had ≥ 16 percentage points of variation. For the HPV vaccine, 22% of counties had maximal differences of 6–10 percentage points, and the remaining counties had maximal differences of ≤ 5 percentage points. In comparison, the least variability was seen among the flu vaccine, with all counties having < 5 percentage points of variation in coverage levels. Looking at the proportions of the total Michigan adolescent population living in counties with different maximal levels of variation, there were approximately 57% and 55% of adolescents residing in the counties with ≤ 10 percentage points of variation in Tdap and MCV4 vaccine coverage levels, respectively (Figure 2b).

We examined whether the denominator calculation methods that resulted in the lowest and highest estimated coverage levels for each vaccine were consistent across counties. For most of the counties, vaccine-specific coverage levels were the lowest when using the MCIR Inclusive population and highest when using the Exclude Flagged and Inactive population (Table 1). When a county deviated from this pattern, the Census population resulted in either the highest or lowest coverage levels in almost all cases. The Census population resulted in the lowest Tdap coverage levels in 16 counties (19%) and the highest coverage levels in six other counties (7%) (Table 2). Using Census estimates to calculate the denominator produced vaccine coverage levels that were at one extreme of the range (either highest or lowest) in more than 20 counties for each vaccine studied.

We explored how quartile rankings of estimated coverage levels might vary based on the calculation method used by comparing the quartile distributions of counties (Table 3). Most movement across quartile categories occurred when comparing coverage levels calculated using MCIR Inclusive vs. Census denominators (27–39 counties moved up or down at least one quartile category, depending on vaccine). At times, this variation was extreme. For example, between the two methods, one county could move from the lowest quartile category to being ranked in the top half of counties for Tdap coverage. Vaccines with the greatest variation in calculated coverage levels (i.e., Tdap and

MCV4) had the highest number of counties (12–39) and greatest proportion of adolescents (15%–51%) that migrated across quartiles when comparing the different methods.

We assessed the characteristics of the counties with the greatest and least variation in estimated vaccination levels (digital Appendix, Figure 2A, which is available online only). In general, the least populous counties had the greatest variability across all vaccines and calculation methods, while the most populous counties typically had the least variability. A similar pattern was apparent when we looked at county-specific median annual household income, whereby counties whose median income fell below that of the state average had the greatest variation in coverage levels across methods. The distribution of uninsured children across counties did not appear to correlate with degree of variation in coverage rates.

DISCUSSION

We systematically assessed the impact of different denominator calculation methods on estimating both absolute and relative vaccination levels among Michigan adolescents. While the different calculation methods produced some variability at the state level in estimates of the proportions of adolescents estimated to have received recommended vaccines, greater differences in vaccination coverage were noted at the county level for three of the four vaccines assessed. For some counties and vaccines, variability was as high as 21 percentage points, indicating that substantial differences in data interpretation can arise based on the methodology used and may need to be considered when evaluating immunization programs and policies.

When comparing counties based on vaccine coverage levels, we found that the calculation method used led to notable differences in coverage rates, which has important policy implications for local public health officials. For the Tdap and MCV4 vaccines, nearly 50% of counties (36 and 39 counties, respectively) migrated either up or down into a different quartile when comparing values derived from the MCIR Inclusive vs. Census denominators. For HPV and flu vaccines, approximately one-third of counties moved into a different quartile category. Taken together, these results demonstrate that there can be substantial differences, depending on the denominator used, in the estimation of a county's immunization coverage or the identification of areas that would potentially benefit from future interventions.

A major contributor to the observed variation in estimated vaccine coverage levels calculated using the

Figure 2a. Proportion of counties with different levels of maximal variation^a in adolescent (11–18 years of age) vaccine coverage levels: Michigan, 2010

Figure 2b. Distribution of the total Michigan adolescent (11–18 years of age) population in 2010,^b by level of variation in calculated vaccine coverage and by vaccine

^aMaximal variation is defined as the largest difference in estimated vaccine coverage levels among the four different calculation methods assessed.

^bComparison among the four different calculation methods: MCIR Inclusive, Exclude Flagged, Exclude Flagged and Inactive, and U.S. Census. The total Michigan adolescent population using U.S. Census estimates was 1,112,200. For HPV, only the female adolescent population ($n=565,754$) was used to calculate results.

Tdap = tetanus-diphtheria-acellular pertussis

MCV4 = meningococcal conjugate vaccine

HPV = human papillomavirus

Flu = influenza

Table 2. Percentage of counties with the lowest and highest vaccine coverage levels for adolescents (11–18 years of age) estimated using the U.S. Census denominator: Michigan, 2010

Vaccine	Counties with Census denominator resulting in lowest vaccine coverage level Percent (N)	Proportion of total Michigan adolescent population ^b living in these counties Percent	Counties with Census denominator resulting in highest vaccine coverage level Percent (N)	Proportion of total Michigan adolescent population ^b living in these counties Percent
Tdap	19 (16)	10	7 (6)	11
MCV4	19 (16)	10	6 (5)	6
HPV ^c	22 (18)	18	6 (5)	4
Influenza	19 (16)	10	6 (5)	4

^aPercentages are determined out of the 83 counties in Michigan.

^bThe total Michigan adolescent population using U.S. Census estimates was 1,112,200 adolescents in 2010.

^cFor HPV, the percentages of the total Michigan adolescent female population ($n=565,754$ based on U.S. Census data) are provided.

Tdap = tetanus-diphtheria-acellular pertussis

MCV4 = meningococcal conjugate vaccine

HPV = human papillomavirus

different methods was the degree of variation in the size of eligible populations. For example, one-fifth of the adolescents identified in the MCIR Inclusive population were reclassified as possibly having migrated out of the state due to being flagged MOGE at the provider level or lacking any activity on their records for ≥ 10 years. Additionally, the population derived using Census estimates was $>10\%$ smaller than that of the MCIR Inclusive population. At the county level, the MCIR Inclusive population was the largest and the Exclude Flagged and Inactive population was the smallest for most of the counties, subsequently contributing to the maximal variation in calculated vaccine coverage levels. However, for a notable number of counties, Census estimates produced either the largest or smallest coverage levels.

While it remains to be determined which method provides the most accurate assessment of immunization coverage, these data suggest that differences in how the eligible adolescent population is determined at the county level, especially for less populous counties, can lead to different conclusions about the success or failure of county-level immunization efforts. Of note, one limitation to the study was that the MOGE flag used to define two of the eligible populations in this study (Exclude Flagged and Exclude Flagged and Inactive) was not compliant with MIROW standards for managing patient status at the provider level and did not function at the jurisdictional level, as was modeled in this study.¹⁰ As of May 2011, the process for designating Inactive-MOGE patient status at the jurisdictional level was modified by mandating follow-up activities and supporting documentation to more accurately identify out-migrated individuals in MCIR.

Thus, future efforts should use the new patient status designations to determine eligible populations and assess the variation in immunization coverage analyses.

Less variation was evident at the state level, due in part to the fact that county-level variability could be absorbed within the larger population of eligible adolescents, and that some adolescents may move among counties but remain in state. The degree of variation in coverage calculated at the state level (2–11 percentage points) was not as substantial as county-specific variation (1–21 percentage points, depending on the vaccine), indicating that there may be greater flexibility in the methodology allowable for statewide assessments. Coverage levels calculated using Census estimates were also within the range obtained for state-level assessments. Thus, given the consistent methodology used by the U.S. Census across jurisdictions, Census data may reasonably be used to estimate the denominator when comparing vaccination coverage among states.

An additional contributor to the observed maximal variation in estimated coverage levels was the difference in the actual level of vaccination. Vaccines with low coverage levels (e.g., the flu and HPV vaccines) had less variation in the estimated coverage levels calculated when compared with the Tdap and MCV4 vaccines, although the relative differences in coverage levels were nearly identical for the four vaccines (digital Appendix, Table 2A, which is available online only). Because the wide variation in coverage levels for vaccines with higher point estimates can result in greater variability in their assessment, it is important to consider point estimates of vaccine coverage when evaluating calculation methods.

Table 3. Counties that change quartile category^a for vaccinations, by different calculation methods:^b Michigan, 2010

Comparison between methods		Tdap				MCV4				≥3 HPV ^c doses				Influenza			
		≥1 quartile ^d N (percent) ^e	≥2 quartiles ^d N (percent) ^e	≥1 quartile ^d N (percent) ^e	≥2 quartiles ^d N (percent) ^e	≥1 quartile ^d N (percent) ^e	≥2 quartiles ^d N (percent) ^e	≥1 quartile ^d N (percent) ^e	≥2 quartiles ^d N (percent) ^e	≥1 quartile ^d N (percent) ^e	≥2 quartiles ^d N (percent) ^e	≥1 quartile ^d N (percent) ^e	≥2 quartiles ^d N (percent) ^e	≥1 quartile ^d N (percent) ^e	≥2 quartiles ^d N (percent) ^e	≥1 quartile ^d N (percent) ^e	≥2 quartiles ^d N (percent) ^e
MCIR Inclusive	vs.	12 (51)	1 (0.1)	17 (15)	1 (0.1)	1 (0.1)	1 (0.1)	6 (6)	0 (0)	9 (4)	0 (0)	9 (4)	0 (0)	9 (4)	0 (0)	9 (4)	0 (0)
MCIR Inclusive	vs.	17 (50)	1 (0.1)	22 (24)	1 (0.1)	0 (0)	0 (0)	20 (9)	0 (0)	15 (8)	0 (0)	15 (8)	0 (0)	15 (8)	0 (0)	15 (8)	0 (0)
MCIR Inclusive	vs.	36 (30)	6 (4)	39 (47)	6 (4)	5 (4)	5 (4)	29 (11)	0 (0)	27 (15)	0 (0)	27 (15)	0 (0)	27 (15)	0 (0)	27 (15)	0 (0)

^aThe number of counties (out of 83 counties total) that move quartiles. Quartiles were defined as <25th, 25th to <50th, 50th to <75th, and ≥75th percentile.

^bMCIR Inclusive refers to the total number of adolescents with an MCIR record containing valid county information. Exclude Flagged refers to the number of adolescents with an MCIR record containing valid county information, excluding those flagged as having moved out of state. Exclude Flagged and Inactive refers to the number of adolescents with an MCIR record containing valid county information, excluding those flagged as having moved out of state or with ≥10 years of MCIR inactivity. U.S. Census refers to the total number of adolescents in Michigan using 2007 U.S. Census estimates.

^cFor HPV, the percentages of the total Michigan adolescent female population (n=565,754) were used.

^dMove to the next highest or lowest quartile

^eThe total Michigan adolescent population (aged 11–18 years) using U.S. Census estimates was 1,112,200 in 2010.

Tdap = tetanus-diphtheria-acellular pertussis

MCV4 = meningococcal conjugate vaccine

HPV = human papillomavirus

MCIR = Michigan Care Improvement Registry

Limitations

This study was subject to several limitations. For one, although Michigan requires all school-exclusionary childhood vaccinations to be reported to MCIR, the IIS relies on health-care providers to submit vaccination information. As such, the available data in the MCIR may be incomplete. Second, with the relatively recent introduction of school mandates for Tdap and MCV4 vaccines in Michigan in 2010, there may have been less reporting of adolescent vaccines than of early childhood immunizations. Third, while the different denominator calculations in this study attempted to address population movement out of state using available flags and assessing record inactivity, none were able to adjust for adolescents who have migrated into the state but not yet received any vaccines in Michigan. Fourth, due to limitations in data availability when determining Census denominators, we had to extrapolate 2007 U.S. Census estimates to approximate the adolescent population in 2010, which may have contributed to inaccuracy for this method. Finally, this study was not intended to provide recommendations for the way to calculate vaccination coverage levels; rather, it was intended to highlight the notion that different methods of denominator calculation can result in differences in conclusions about the success of vaccination efforts. What constitutes meaningful differences in vaccination levels among counties or by various methods is not well established.¹⁶ Further studies are needed to develop guidelines for how to select the most appropriate calculation method, while also considering how county characteristics can affect vaccination rate calculations.

CONCLUSIONS

In this study, we found substantial differences in estimated vaccine coverage levels based on whether the state IIS or U.S. Census data were used to determine the eligible population. These differences were more apparent at the county level than at the state level and could impact conclusions made at the county level about adolescent immunization coverage. Variability was most notable among the least populous counties and the vaccines with higher coverage levels. These results suggest that individual-level changes that are not adequately tracked in IISs (i.e., in- or out-migration) can lead to disparate assessments of adolescent immunization levels. Researchers should be particularly mindful of the methodology used when studying immunization efforts at a more fragmented (i.e., county) level, where the potential impact can be greater.

All study activities were approved by the Institutional Review Boards at the University of Michigan and the Michigan Department of Community Health. Also, since June 2009, Amanda Dempsey has served as an advisory board member for Merck, providing advice on human papillomavirus vaccination in the U.S. However, this company had no role in the design or analysis of this study and is unaware of the study's results. Further, Dr. Dempsey does not receive research support from Merck.

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