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Overview of Global, Regional, and National Routine Vaccination Coverage Trends and Growth Patterns From 1980 to 2009: Implications for Vaccine-Preventable Disease Eradication and Elimination Initiatives

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Abstract

Background—Review of the historical growth in annual vaccination coverage across countries and regions can better inform decision makers' development of future goals and strategies to improve routine vaccination services.

Methods—Using the World Health Organization (WHO) and the United Nations Children's Fund estimates of annual national third dose of diphtheria-tetanus-pertussis–containing vaccine (DTP3) and third dose of polio vaccine (POL3) coverage for 1980–2009, we calculated the mean absolute annual rate of change in national DTP3 coverage among all countries (globally) and among countries within each WHO region, as well as the number of years taken by each region to reach specific regional coverage levels. Last, we assessed differences in mean absolute annual rate of change in DTP3 coverage, stratified by baseline level of DTP3 coverage.

Results—During the 1980s, global DTP3 coverage increased a mean of 5.3 percentage points/year. Annual rate of change decreased to 0.5 percentage points/year in the 1990s and then increased to 0.9 percentage points/year during the 2000s. Mean annual rate of change in coverage across all countries was highest (9.2 percentage points) when national coverage levels were 26%–30% and lowest (−0.9 percentage points) when national coverage levels were 96%–100%. Regional differences existed as both WHO South-East Asia Region and WHO African Region countries experienced mean negative DTP3 coverage growth at lower coverage levels (81%–85%) than other regions. The regions that have achieved 95% DTP3 coverage (Americas, Western Pacific, and European) took 25–29 years to reach that level from a level of 50% DTP3 coverage. POL3 coverage change trends were similar to described DTP3 coverage change trends.

Conclusions—Mean national coverage growth patterns across all regions are nonlinear as coverage levels increase. Saturation points of mean 0 percentage-point growth in annual coverage varies by region and require further investigation. The achievement of >90% routine coverage is

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observed to take decades, which has implications for disease eradication and elimination initiatives.

Keywords

vaccination; coverage; Polio; DTP3; routine

The Expanded Program on Immunization (EPI) began in 1974 with the goal of ensuring that all children benefit from life-saving vaccines [1]. Vaccination coverage is a key indicator of vaccination program performance, and coverage for the third dose of diphtheria-tetanus-pertussis–containing vaccine (DTP3) is often used as the main indicator for performance of routine vaccination services. Strong routine vaccination services, as measured by high DTP3 vaccination coverage, are critical for successful implementation of key global public health goals. For instance, strong routine vaccination is one of the 4 core strategies for reaching and sustaining polio eradication in the 2010–2012 strategic plan of the Global Polio Eradication Initiative (GPEI) [2, 3]. By 2009, global DTP3 coverage reached 83%, indicating the commitment by many countries to reduce mortality and morbidity from vaccine-preventable diseases (VPD).

In 2000, the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) began a process of annually estimating global, regional, and national routine vaccination coverage across multiple vaccines, including DTP vaccine, polio vaccine (POL), and measles-containing vaccine (MCV). These estimates, which are updated annually, are based on officially reported data from government administrative sources, coverage surveys, and other published and unpublished work [4]. WHO and UNICEF also undertook a retrospective review of these sources to estimate vaccination coverage for 1980–1999. These estimates are used for a wide variety of reasons, including global pay-for-performance incentives, tracking the attainment of key child survival goals, and immunization program objectives and estimates of general changes in infant and child mortality [5–8]. Although these estimates are generally considered the most reliable source of coverage, concerns have been raised about the accuracy of the administrative sources used in the estimates, compared with coverage survey sources [9].

These vaccination coverage estimates provide an opportunity to assess the historical performance of national and regional vaccination services. Generally, analyses of program performance are limited to a brief synopsis of changes in coverage since the previous year [10]. However, benefits exist in an in-depth analysis of the historical performance of vaccination programs worldwide, including how vaccination coverage has varied over time, how varying levels of coverage affect annual changes in coverage, and how coverage has varied between different geographical regions. Such analysis would be informative for the further development of polio, measles, and other vaccine-preventable disease elimination and eradication goals, routine vaccination performance goals, and the application of routine vaccination strategies based on the existing level of performance of a country's vaccination program. Specifically, the 2013–2018 Polio Eradication and Endgame Strategic Plan includes the strengthening of immunization systems as one of 4 objectives to boost immunity and help wide-scale introduction of inactivated polio vaccine (IPV) [10]. The

main indicator of this objective is achievement of a ≥10% annual increase in DTP3 coverage in 80% of high-risk districts of key polio-focus countries between 2014 and 2018 [11].

We studied 1980–2009 vaccination coverage data and assessed (1) the annual mean rate of change in vaccination coverage for countries in each geographic region, (2) the number of years needed to reach various coverage levels by each region, and (3) variability in the annual rate of change in vaccination coverage levels, based on the existing level of vaccination coverage.

METHODS

Data Sources

National DTP3 coverage levels jointly estimated by the WHO and UNICEF were used to calculate the annual rate of change in annual coverage from 1980 to 2009 [12]. The WHO and UNICEF jointly define DTP3 coverage as the number of children who receive DTP3 by 12 months of age, divided by the estimated number of children surviving to their first birthday [4]. Regional and global coverage estimates are calculated using population-weighted national coverage from all countries in a given region or globally; national population data were sourced from WHO/UNICEF immunization reports [13].

For geographical categorization of countries, we used WHO's classification of WHO member states: African Region, Eastern Mediterranean Region, European Region, Region of the Americas, South-East Asia Region, and Western Pacific Region [14].

Analysis of Global and Regional Annual Rate of Change in Coverage

We examined global, regional, and country absolute annual rates of change in DTP3 coverage, the third dose of POL (POL3), and the first dose of measles-containing vaccine (MCV1). We calculated the annual rate of change in coverage for each country by subtracting the country's vaccination coverage for the year from its coverage during the preceding year to calculate an absolute rate of annual change. We calculated the mean annual rate of change in a region's coverage by averaging the calculated annual absolute rate of change in coverage across all countries within a given region for a given year. To account for potential irregularities in the annual rate due to occurrence of single-year extremes, we averaged the annual rate of change for each region's countries during 3 periods: 1980–1989, 1990–1999, and 2000–2009.

Analysis of Annual Rate of Change in Coverage by Baseline Vaccination Coverage Level

We examined the absolute annual rate of change in coverage at different baseline coverage levels and compared these rates at high baseline coverage levels with those at low levels. To do so, we first created 5 percentage-point-increment baseline coverage categories, ranging from 1%–5% through 96%–100%. We then calculated the absolute change in coverage for each year by subtracting national vaccination coverage for the year from the national coverage during the preceding year. For example, if DTP3 coverage for a country was 71% in 2007 and 77% in 2008, the absolute annual rate of change would be 6 percentage points ([coverage in year 2008] – [coverage in year 2007]). This absolute annual rate of change

was associated with a baseline coverage level category of 71%–75% because the baseline year (ie, 2007) coverage was 71%. We calculated regional, population-weighted means for the absolute annual rate, using values from the countries in each region, and calculated global, population-weighted averages, using all countries in the WHO/UNICEF joint estimates data set. To further illustrate the speed and level of the annual rate of change in coverage per baseline coverage category, we calculated a cumulative change in coverage. The latter indicator was calculated by cumulatively summing a region's mean absolute annual rate of change in coverage as the baseline coverage level increased. For example, if a region's mean absolute annual rate of change for the 1%–5% baseline coverage category was 5 percentage points and the mean absolute annual rate of change for the 6%–10% baseline coverage category was 4 percentage points, the cumulative change in coverage at the 10% baseline coverage level was 9 percentage points.

Analysis of Number of Years for Regions to Reach Specific Coverage Levels

We examined the number of years it took for each region to reach specific DTP3, POL3, and MCV1 coverage levels (ie, 60%, 70%, 80%, 90%, and 95%) from a coverage level of 50%. The number of years was calculated by determining which year a region's coverage first reached or went above a specific coverage level and subtracting that year from the year when the region initially passed a previous specific coverage level.

RESULTS

Global, Regional, and National Rates of Change in DTP3 Coverage

Globally, coverage increased from 1980 to 2009, but the annual rate of change slowed over time and varied between regions. From 1980 through 2009, global DTP3 coverage increased from 20% to 82%; however, coverage levels varied substantially among WHO regions (Figure 1). While DTP3 coverage in the Region of the Americas, the European Region, and the Western Pacific Region exceeded 90% in 2009, it was 71% in the African Region and 73% in the South-East Asia Region.

During the same period, global DTP3 coverage increased by 2.1 percentage points annually (Table 1). However, coverage slowed over time as the greatest mean annual change in global DTP3 coverage occurred in the 1980s (5.3 percentage points/year) and then slowed dramatically during the 1990s (0.5 percentage points/year) and 2000s (0.9 percentage points/year). The latter 2 decades correspond to periods of higher vaccination coverage levels; for example, during the 2000s, mean global DTP3 coverage was 78%.

When we analyzed POL3 and MCV1 coverage, similar trends as those observed for DTP3 coverage during 1980–2009 were found (Figure 1 and Figure 3). In the analysis of the change in regional coverage during 1980–2009, the mean change in MCV coverage was 0.1 percentage point higher than the mean change in DTP3 across regions. During the same period, the mean annual change in global POL3 coverage was equal to the corresponding change for DTP3 (Table 1).

Certain countries lagged behind others in coverage levels and in both direction and speed of the annual change in coverage. At the national level, by 2009, 122 of 193 countries (63%)

had ≥90% DTP3 coverage, and 186 countries (96%) had a positive mean annual change in DTP3 coverage during 1980–2009. A minority of countries (14%) experienced both <90% DTP3 coverage in 2009 and either a negative or 0 percentage point mean annual change in DTP3 coverage during 1999–2009 (Figure 2).

DTP3 Annual Rate of Coverage Change, by Baseline Level of DTP3 Coverage

The direction and speed of the annual rate of change in coverage in a country or region differed depending on the level of its baseline vaccination coverage. Generally, the mean annual rate of change was greatest when coverage was low; conversely, the mean annual rate of change slowed at higher coverage levels. At baseline DTP3 coverage levels of ≤5%, the mean annual rate of change in DTP3 coverage the following year across all countries was 2.1 percentage points (Figure 3). Mean annual rate of change in coverage continued to increase as coverage increased from 5% up to 26%–30%. The highest mean annual rate of change in DTP3 coverage was 9.2 percentage points; this occurred when DTP3 coverage was 26%–30%. At higher DTP3 coverage levels, the mean annual increase in DTP3 coverage slowed to between 1 and 6 percentage points at coverage levels of 41%–80% and was <1 percentage point when coverage was 81%–90%. At coverage levels of >90%, the mean annual rate of change in coverage was negative.

We found a similar pattern in the mean annual rate of change in DTP3 coverage at different coverage levels across WHO regions (Figure 4). In most regions, the annual rate of change in DTP3 coverage started low (<5 percentage points/year) when baseline coverage was <10%, and the annual rate of change was greatest when coverage was approximately 30%. The rate of change in coverage then generally declined toward 0 percentage points as coverage approached 100%; in some regions, annual rate of change became negative when coverage exceeded 80%.

Although the general trend patterns were similar among the regions, there were some important differences, including the maximum mean annual rate of change in DTP3 coverage achieved and the coverage levels at which the mean annual rate of change became negative. For countries in the Eastern Mediterranean Region, the South-East Asian Region, the African Region, and the Western Pacific Region, the mean annual rate of change in DTP3 coverage was <3 percentage points when DTP3 coverage was 1%–5%. Mean rate of change in DTP3 coverage increased at higher coverage levels, peaked when coverage was 16%–30%, and declined as coverage increased further (Figure 4). At high (>80%) levels of coverage in these regions, mean annual rate of change in coverage was minimal (<1 percentage point) and eventually became negative in all regions. In both the Region of the Americas and the European Region, the annual rate of change in coverage did not become negative until DTP3 coverage exceeded 95%, whereas in the African Region and the South-East Asia regions, this occurred at DTP3 coverage levels as low as 81%–85%. The mean annual rate of change in coverage at any coverage level was generally lower in the African Region than in other regions. Both MCV1 and POL3 annual rates of change in coverage, stratified by coverage level, followed similar patterns to those described previously for DTP3 (Figure 3).

Years to Reach Coverage Levels at the Regional Level

The number of years that elapsed until vaccination coverage increased from a level of 50% to higher levels varied by region (Table 2). For example, in the Region of the Americas, it took 8 years for regional DTP3 coverage to increase from 50% to 70%, an additional 3 years to increase from 70% to 80%, and 18 more years to reach 95%. The European Region followed a similar pattern as the Region of the Americas, whereas the Western Pacific Region's pattern differed in requiring a short, 3-year period to increase from 70% to 90% but 20 years to reach 95%. Of the 3 regions that have achieved 95% DTP3 coverage (the Region of the Americas, the European Region, and the Western Pacific Region) and the 2 regions that have achieved 95% POL3 coverage, >20 years were needed to increase coverage from 50% to 95%. No region has yet achieved 95% MCV1 coverage.

DISCUSSION

Although the duration needed to increase vaccination coverage among countries in each region varies substantially, the general nonlinear pattern of mean annual rate of change in coverage is similar. Temporally, the highest mean annual rate of change in coverage for MCV, DTP, and POL were measured during the 1980s. From a perspective of coverage levels, the highest mean annual rate of change in coverage occurred when national coverage levels were approximately 25%–30%. For coverage levels between 30% and 80%, mean annual rate of change in coverage generally decreased toward 0 percentage points and became negative as coverage levels reached 90%–95%. The results indicate difficulty in maintaining positive annual growth in vaccination coverage at levels above 90%. This threshold point of 0 or negative rates of change in coverage differed between regions' countries. Only 3 regions reached >95% DTP3 coverage, 2 regions reached >95% POL3 coverage, and no regions reached >95% MCV1 coverage. Regions that have reached 95% coverage required an average of 25.2 years to increase coverage from 50% to >95%.

Our analysis' observed nonlinear growth curve for vaccination coverage is similar to rates of change described for other public health interventions [15]. The nonlinear pattern can be roughly described as an s-shaped trajectory in which little growth occurs at the lowest levels of coverage, followed by rapid growth as coverage begins to increase, and then an eventual leveling off of coverage as coverage stabilizes. In 1981, Shuval et al proposed the threshold saturation theory to describe the factors that help explain the shape of this type of growth curve within the context of water and sanitation interventions [15]. The theory states when health status related to the intervention is poor, it is indicative of few, if any, investments in the public health intervention. As investments increase, at some point a threshold is passed and intervention coverage growth rapidly occurs and, consequently, health status rapidly improves. However, health status and intervention coverage eventually stop growing as they reach a saturation point, at which time additional investments both internal and external to the health intervention may be required to further improve health status. In relation to our analysis, a key finding is how this saturation point for vaccination program coverage differs by region and may be indicative of the differing levels of investment across regions. These investment differences take the form of differences in availability of human resources for health, number of health facilities, and related infrastructure and ability to absorb external

investments in health [16–19].Future regional comparisons should focus on identifying the factors underlying these differences in saturation points between regions.

The observed growth curve in vaccination coverage may also indicate a need to evolve program objectives and performance indicators as coverage increases. For instance, when vaccination coverage is low, general access to vaccination services is a challenge, so investments should focus on establishing vaccine supply chains and ensuring adequate numbers of vaccinators and service delivery points. Key performance indicators during this period may be national vaccination coverage across antigens. When the rate of change in vaccination coverage begins to slow, efforts should be made to identify subnational (ie, region and district) areas where coverage is low, because their performance is masked by high national coverage yet also causes national coverage growth to slow [20]. Program improvement strategies can also shift toward subnational approaches, such as the Reaching Every District strategy [21]. As vaccination coverage improves, inclusion of other performance indicators, such as timeliness of vaccination, may also be needed to ensure that a complete picture of program performance is available [20].

Strong performance in the African Region is critical to lowering VPD mortality and reaching disease eradication goals. Therefore, our analyses may be useful in establishing a projection of future African Region performance. One way to do this is to use another region's performance as a basis. The current state of the African Region bears similarities to that of the Region of the Americas in the past, and consequently, the historical performance of the Region of the Americas may serve as a best-case example of how quickly immunization goals could be achieved in the African Region. Both regions contain many countries (>40), and when the EPI began, many countries in the Region of the Americas were low income, similar to the current state of many countries in the African Region. In 2009, the African Region's DTP3 coverage was 71%. When DTP3 coverage in the Region of the Americas was 70%, in the 1980s, it took 11 years to achieve the GIVS immunization coverage goal of 90%. Similarly, it took the European Region 16 years to achieve this goal. A second projection method is to use the African Region's current DTP3 coverage growth trends (1.8 percentage points/year during the last decade). On the basis of this method, it will take 11 years for the African Region to reach 90% coverage. These methods provide a range of 11 to 16 years for the region to reach 90% DTP3 coverage; however, the investments needed to sustain positive growth will likely need to match or exceed investments seen in the other regions to do so, particularly if the rest of these African countries’ socioeconomic indicators do not improve at rates similar to those observed in these other regions.

This analysis is subject to certain limitations. First, it relies on a mix of administrative data, survey data, and interpretation of these data by the WHO and UNICEF. Although the WHO/UNICEF estimates are generally considered the best vaccination estimates for a country, administrative estimates have been shown to be substantially higher than those obtained by surveys [9]. Our analysis is ecological in nature, but the consistency of trends within and across regions suggests that these patterns exist irrespective of other confounding factors.

VPD elimination and eradication initiatives, including the GPEI, emphasize low routine coverage levels as a key barrier to the success of disease eradication and elimination and VPD mortality reductions [22, 23]. These initiatives do emphasize investments in routine vaccination alongside other strategies to reach disease elimination and eradication goals. The longevity of these strategies and investments to increase immunization coverage should fit in with realistic expectations of what can be achieved within a certain time line. Consideration should be given to the results presented here and to the GPEI indicator of a 10% annual increase in 80% of the high-risk districts in key GPEI countries from 2014 to 2018 [11]. Realistic time lines based on what other countries have already achieved may also serve to further motivate key stakeholders to achieve these same goals. Fortunately, investment for immunization programs has increased substantially since the early years of the EPI in the 1980s [24, 25]. For example, since 2000, multiple new global immunization initiatives, including the GAVI Alliance, the Measles and Rubella Initiative, and the Global Vaccine Action Plan 2010–2020, have brought substantial resources to support and strengthen immunization services and health systems and have committed countries to provide further investments through mechanisms, such as cofinancing [26, 27]. However, backers of these initiatives should understand that the historical trends in routine immunization coverage indicate that annual rates of change in coverage are neither fast nor reliably positive. Therefore, lasting investments in strategies with long-term goals and objectives are needed to achieve the societal benefits of strengthening routine immunization programs worldwide, including the eradication of polio and the elimination and control of other vaccine-preventable diseases.

Acknowledgments

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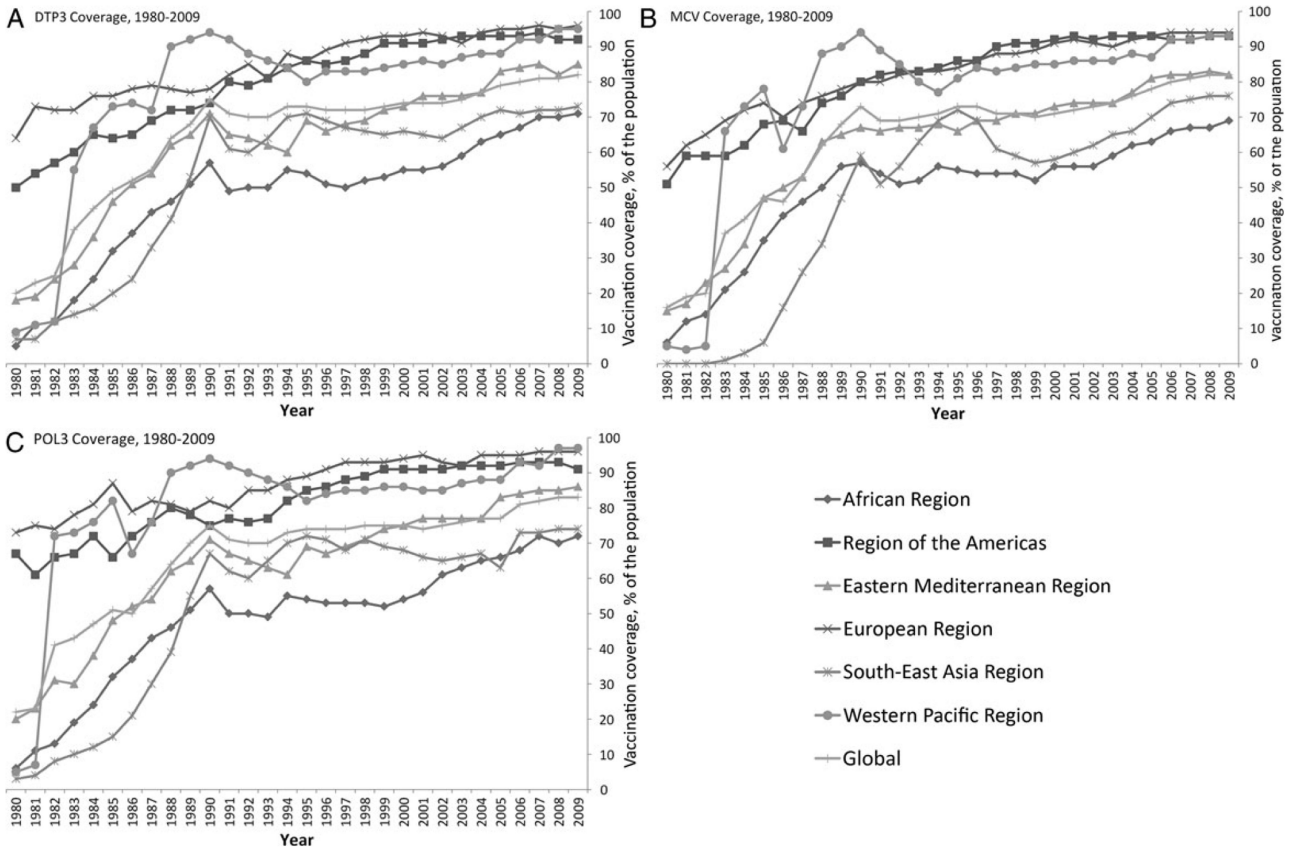

Figure 1.

Global and regional vaccination coverage from 1980 to 2009, based on World Health Organization (WHO)/United Nations Children's Fund coverage estimates [12]. Region definitions are based on WHO categorization [14]. Abbreviations: DTP3, third dose of diphtheria-tetanus-pertussis–containing vaccine; MCV1, first dose of measles-containing vaccine; POL3, third dose of polio vaccine.

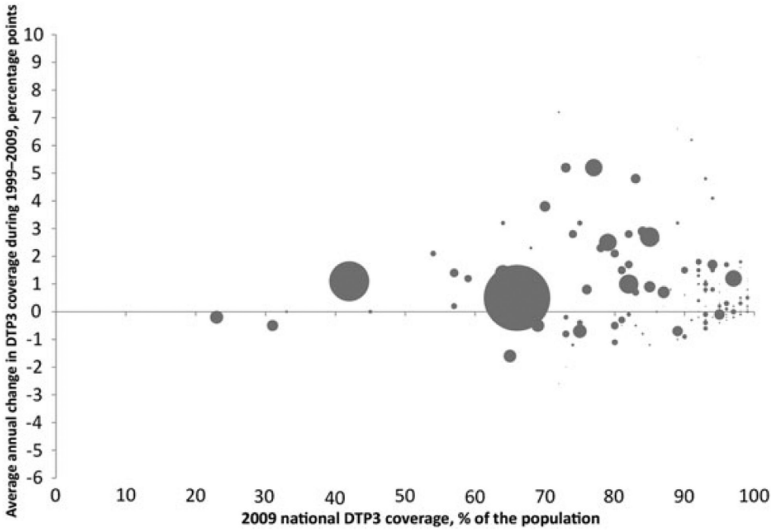

Figure 2.

National coverage with a third dose of diphtheria-tetanus-pertussis–containing vaccine (DTP3) during 2009 and absolute annual rate of change in national DTP3 coverage during 1999–2009. Each dot represents 1 country; the size of the dot is defined by the number of unvaccinated children in the country as of 2009, based on World Health Organization (WHO)/United Nations Children's Fund DTP3 coverage estimates and United Nations population estimates [12, 13]. GIVS, Global Immunization Vision and Strategy Framework for 2006 to 2015 (used as a global framework of goals and objectives for vaccination programs worldwide, including the GIVS 2015 national coverage goals of 90%).

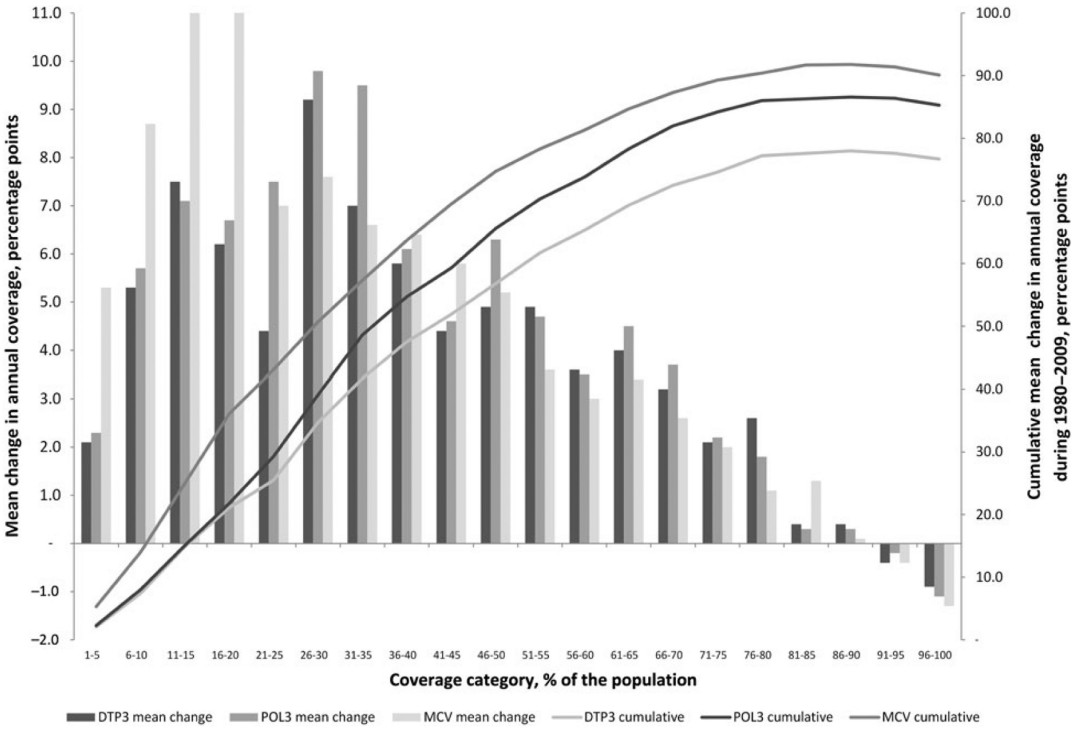

Figure 3.

Mean and cumulative absolute annual rates of change in global vaccination coverage, by coverage category, 1980–2009. Data are based on World Health Organization/United Nations Children's Fund coverage estimates [12]. DTP3, third dose of diphtheria-tetanus-pertussis–containing vaccine; MCV, measles-containing vaccine; POL3, third dose of polio vaccine.

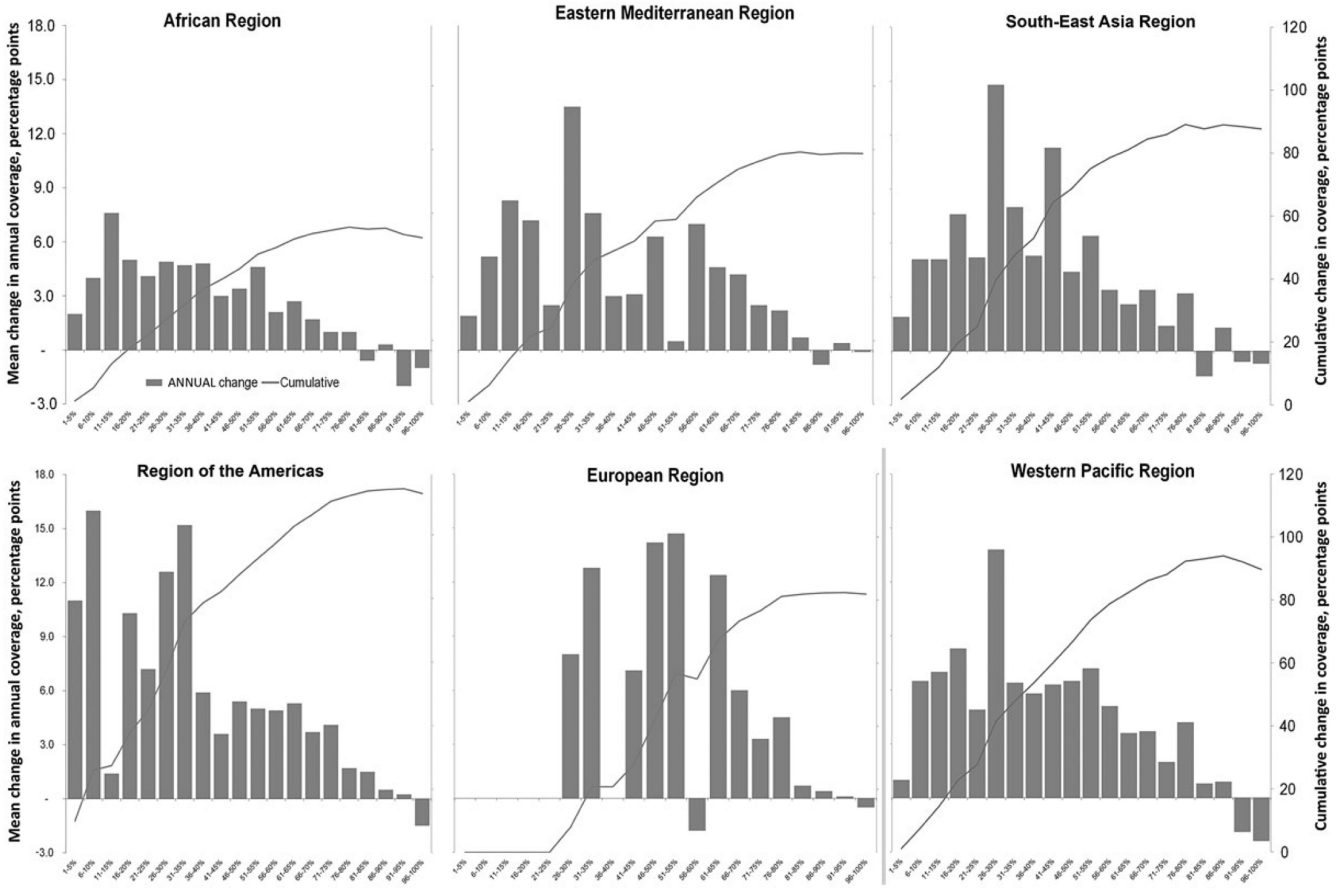

Figure 4.

Mean and cumulative absolute annual rates of change in regional coverage by the third dose of diphtheria-tetanus-pertussis–containing vaccine (DTP3) per coverage category, 1980–2009. Data are based on World Health Organization (WHO)/United Nations Children's Fund coverage estimates [12]. Regions and countries are defined according to WHO standards [14].

Table 1

Absolute Annual Rate of Change in Vaccination Coverage Overall and by Decade During 1980–2009, by World Health Organization (WHO) Region

	1980–1989, %			1990–1999, %			2000–2009, %			1980–2009, %		
Region	**MCV**	**POL3**	**DTP3**	**MCV**	**POL3**	**DTP3**	**MCV**	**POL3**	**DTP3**	**MCV**	**POL3**	**DTP3**
African Region	5.6	5.1	5.1	–0.4	0.1	0.2	1.7	2.0	1.8	2.3	2.4	2.4
Region of the Americas	2.8	1.2	2.4	1.5	1.3	1.9	0.2	0.0	0.1	1.4	0.8	1.4
Eastern Mediterranean Region	5.6	5.0	5.2	0.6	0.9	0.7	1.1	1.2	1.3	2.3	2.3	2.3
European Region	2.4	0.7	1.4	1.1	1.4	1.6	0.5	0.3	0.3	1.3	0.8	1.1
South-East Asia Region	5.2	5.8	5.1	1.0	1.4	1.2	1.9	0.5	0.8	2.6	2.4	2.3
Western Pacific Region	9.4	9.7	9.2	–0.5	–0.6	–0.8	0.8	1.1	1.1	3.0	3.2	3.0
Global	5.8	5.3	5.3	0.2	0.5	0.5	1.2	0.8	0.9	2.2	2.1	2.1

Data are from the WHO/United Nations Children's Fund [12].

Abbreviations: DTP3, third dose of diphtheria-tetanus-pertussis–containing vaccine; MCV, measles-containing vaccine; POL3, third dose of polio vaccine.

Table 2

Times From 50% to 60%–95% Vaccination Coverage During 1980–2009, by World Health Organization (WHO) Region, 1980–2009

	Time, y, by Final Coverage Level				
Region, Vaccine	**60%**	**70%**	**80%**	**90%**	**95%**
African Region					
DTP3	15	18	NR	NR	NR
MCV	16	NR	NR	NR	NR
POL3	13	18	NR	NR	NR
Region of the Americas					
DTP3	3	8	11	19	29
MCV	4	8	10	17	NR
POL3	NA	4	8	19	NR
Eastern Mediterranean Region					
DTP3	1	3	18	NR	NR
MCV	2	12	19	NR	NR
POL3	2	4	19	NR	NR
European Region					
DTP3	NA	1	11	17	25
MCV	NA	3	9	19	NR
POL3	NA	NA	4	16	21
South-East Asia Region					
DTP3	NA	1	NR	NR	NR
MCV	NA	3	5	NR	NR
POL3	1	5	NR	NR	NR
Western Pacific Region					
DTP3	1	2	5	5	25
MCV	NA	3	9	10	NR
POL3	NA	NA	3	6	26

Data are based on WHO/United Nations Children's Fund coverage estimates [12].

Abbreviations: DTP3, third dose of diphtheria-tetanus-pertussis–containing vaccine; MCV, measles-containing vaccine; NA, not applicable (starting coverage was already above the given level); NR, not reached (the given level has not yet been reached); POL3, third dose of polio vaccine.