The effect of mass immunisation campaigns and new oral poliovirus vaccines on the incidence of poliomyelitis in Pakistan and Afghanistan, 2001–11: a retrospective analysis

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Summary

Background **Pakistan and Afghanistan are two of the three remaining countries yet to interrupt wild-type poliovirus transmission. The increasing incidence of poliomyelitis in these countries during 2010–11 led the Executive Board of WHO in January, 2012, to declare polio eradication a "programmatic emergency for global public health". We aimed to establish why incidence is rising in these countries despite programme innovations including the introduction of new vaccines.**

Methods **We did a matched case-control analysis based on a database of 46 977 children aged 0–14 years with onset of acute flaccid paralysis between Jan 1, 2001, and Dec 31, 2011. The vaccination history of children with poliomyelitis was compared with that of children with acute flaccid paralysis due to other causes to estimate the clinical effectiveness of oral poliovirus vaccines (OPVs) in Afghanistan and Pakistan by conditional logistic regression. We estimated vaccine coverage and serotype-specific vaccine-induced population immunity in children aged 0–2 years and assessed their association with the incidence of poliomyelitis over time in seven regions of Afghanistan and Pakistan.**

Findings **Between Jan 1, 2001, and Dec 31, 2011, there were 883 cases of serotype 1 poliomyelitis (710 in Pakistan and 173 in Afghanistan) and 272 cases of poliomyelitis serotype 3 (216 in Pakistan and 56 in Afghanistan). The estimated clinical effectiveness of a dose of trivalent OPV against serotype 1 poliomyelitis was 12·5% (95% CI 5·6–18·8) compared with 34·5% (16·1–48·9) for monovalent OPV (p=0·007) and 23·4% (10·4–34·6) for bivalent OPV (p=0·067). Bivalent OPV was non-inferior compared with monovalent OPV (p=0·21). Vaccination coverage decreased during 2006–11 in the Federally Administered Tribal Areas (FATA), Balochistan, and Khyber Pakhtunkhwa in Pakistan and in southern Afghanistan. Although partially mitigated by the use of more effective vaccines, these decreases in coverage resulted in lower vaccine-induced population immunity to poliovirus serotype 1 in FATA and Balochistan and associated increases in the incidence of poliomyelitis.**

Interpretation **The effectiveness of bivalent OPV is comparable with monovalent OPV and can therefore be used in eradicating serotype 1 poliomyelitis whilst minimising the risks of serotype 3 outbreaks. However, decreases in vaccination coverage in parts of Pakistan and southern Afghanistan have severely limited the effect of this vaccine.**

Funding **Poliovirus Research subcommittee of WHO, Royal Society, and Medical Research Council.**

Introduction

The sustained effort of the Global Polio Eradication Initiative (GPEI) to vaccinate children in Afghanistan and Pakistan reduced cases of serotype 1 and 3 poliomyelitis between 2005 and 2007 in both countries.[1] However, since 2008, the annual incidence of poliomyelitis in Afghanistan and Pakistan has increased, and in 2011, Pakistan reported the highest incidence of poliomyelitis in a decade.[2] Over 60% of all cases in endemic countries and 34% of cases worldwide were recorded in Pakistan,[2] which risks being the last country to interrupt transmission, and so is jeopardising global polio eradication. In July, 2011, cases of poliomyelitis identified in children in the western region of China (Xinjiang autonomous region) were genetically linked to cases in Pakistan, showing the risk to other countries of poliomyelitis in Pakistan.[3]

Since the turn of the century there have been several developments in the GPEI strategy. Until 2005, GPEI relied on the trivalent form of the oral poliovirus vaccine (OPV), which contains all three serotypes. Use of trivalent OPV results in reduced effectiveness against individual serotypes, in particular serotypes 1 and 3, because of interference between Sabin vaccine strains.[4] To address this problem, serotype 1 and 3 monovalent OPVs were produced and licensed in 2005 (wild-type poliovirus serotype 2 was eliminated in 1999). These vaccines are more immunogenic and more effective than the trivalent vaccine.[5–7] In late 2009 and early 2010, a serotype 1 and 3 bivalent OPV was licensed and pre-qualified by WHO and introduced into Afghanistan and Pakistan after its immunogenicity was shown to be non-inferior compared with monovalent OPV for each serotype in a study among neonates in India.[8]

Since the introduction of these improved vaccines to Pakistan and Afghanistan,[9] one would have expected a reduction in cases. However, polio eradication in Pakistan has been affected by weak service delivery[10] and was identified by the GPEI Independent Monitoring

Lancet 2012; 380: 491–98

Published Online
July 4, 2012
http://dx.doi.org/10.1016/S0140-6736(12)60648-5

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Board in 2010 as a country that was not on track for elimination of poliomyelitis.[2,11] The eradication of poliomyelitis in parts of Pakistan and Afghanistan has been complicated by armed conflict, security concerns (eg, areas being inaccessible to vaccination teams because of security concerns, and the movement of families to escape potential conflict), cultural barriers, and natural disasters that have limited accessibility of vaccination teams to target populations. Because of the deterioration of the programme in Pakistan and Afghanistan in 2011, and ongoing transmission of polioviruses in Nigeria, on Jan 21, 2012, the WHO Executive Board declared polio eradication a "programmatic emergency for global public health".[12]

Because poliovirus remains endemic in Pakistan and Afghanistan, identifying where the programme is failing to immunise children is imperative, so that appropriate improvements to the vaccination programme can be made. Although independent monitoring of immunisation campaigns can provide an estimate of coverage,[10] these data do not easily translate to estimates of serotype-specific immunity. Furthermore, recent lot quality assurance sampling of vaccination coverage during campaigns suggested that independent monitoring might significantly overestimate coverage.[13]

Recording a child's vaccination history during the investigation of acute flaccid paralysis provides an opportunity to assess vaccination coverage and effectiveness in Pakistan and Afghanistan. We used vaccination history data from children with acute flaccid paralysis to estimate the clinical effectiveness and population immunity induced by OPVs. We assessed programme performance over time in different regions and examined the association between estimated serotype-specific population immunity and the incidence of poliomyelitis.

See Online for appendix

	Number of cases of poliomyelitis	Number of cases matched to a control (%)	Mean age (SD; months)		Mean number of OPV doses (SD)	
			Cases	Controls	Cases	Controls
Pakistan						
Balochistan	128	59 (46%)	19·0 (12·1)	18·5 (12·4)	2·8 (3·9)	3·9 (4·2)
FATA	140	67 (48%)	14·7 (8·9)	16·3 (8·8)	2·8 (4·8)	5·0 (5·8)
KP	140	77 (55%)	17·9 (9·2)	18·0 (9·2)	4·3 (5·6)	6·9 (5·4)
Punjab+	124	83 (67%)	16·0 (12·5)	15·8 (12·4)	7·2 (5·2)	7·9 (6·0)
Sindh	178	117 (66%)	28·0 (26·2)	28·2 (26·3)	6·9 (4·5)	8·2 (4·6)
All areas	710	403 (57%)	20·1 (17·5)	20·3 (17·5)	5·2 (5·1)	6·7 (5·4)
Afghanistan						
Southern	144	113 (78%)	20·1 (10·5)	20·4 (10·4)	3·8 (5·6)	8·2 (6·5)
Other areas	29	19 (66%)	30·0 (13·7)	29·9 (13·2)	8·8 (7·0)	15·4 (5·0)
All areas	173	132 (76%)	21·5 (11·4)	21·7 (11·2)	4·6 (6·1)	9·2 (6·8)
Overall						
All areas	883	535 (61%)	20·5 (16·2)	20·7 (16·2)	5·1 (5·4)	7·4 (5·9)

FATA=Federally Administered Tribal Areas. KP=Khyber Pakhtunkhwa.

Table: **Characteristics of children with poliomyelitis serotype 1 and matched controls by region**

The results are discussed to highlight improvements that must be made to ensure elimination of poliomyelitis in these endemic countries.

Methods

Data collection

Children are vaccinated using the OPV through either routine immunisation as part of the WHO Expanded Programme on Immunisation or via supplementary immunisation activities, where vaccination teams aim to vaccinate all children aged 0–4 years within a few days through fixed booths and mobile vaccination teams. Initial case investigation includes an interview with the child's caregiver to record demographic information (age, date of birth, sex, district of residence, and details of illness) and vaccination history, including the number of OPV doses received through routine and supplementary immunisation activities. Two stool samples are collected at least 24 h apart within 14 days of the onset of paralysis and are sent under appropriate conditions to the WHO reference laboratory in Islamabad, Pakistan, where they are tested for the presence of wild-type and vaccine-related poliovirus.[14]

We analysed data from 46 977 children in Pakistan and Afghanistan who had an onset of acute flaccid paralysis between Jan 1, 2001, and Dec 31, 2011. Although acute flaccid paralysis surveillance began in Pakistan in 1995 and in Afghanistan in 1997, a virological case definition based on isolation of wild-type poliovirus from stool samples was not adopted until January, 2000, in Pakistan and January, 2001, in Afghanistan.[15,16] Furthermore, indicators of surveillance performance in both countries before 2001, were poor and did not meet international standards (appendix).[15] We therefore excluded children with acute flaccid paralysis reported before January, 2001.

Children with acute flaccid paralysis and wild-type poliovirus detected in at least one stool sample were defined as poliomyelitis cases. Children with acute flaccid paralysis and two adequate stool samples in which neither wild-type nor vaccine-related poliovirus were isolated were defined as non-polio acute flaccid paralysis. Children without sufficient information about age, date of birth, district of residence, or OPV vaccine history, and children without two adequately collected stool samples and with residual paralysis compatible with poliomyelitis (compatible cases), were excluded from the analysis (appendix). We also excluded children with vaccine-derived poliovirus isolated from their stool. Serotype 2 circulating vaccine-derived poliovirus was isolated from six children in Afghanistan between June, 2010, and January 2011; no other circulating vaccine-derived poliovirus was reported from Afghanistan or Pakistan.[17]

For each acute flaccid paralysis case, the numbers of OPV doses received through routine and supplementary immunisation activities, as reported by the caregiver, were separately recorded. All OPV doses received through routine services were trivalent. Vaccinations

received through supplementary immunisation activities were either with trivalent, bivalent, or monovalent OPVs, but the type of vaccine received was not reported by the caregiver. We therefore estimated the number of doses of each OPV type received by a child by multiplying the total number of OPV doses received through supplementary immunisation activities reported by the caregiver by the proportion of supplementary immunisation activities that used OPVs of each type, as calculated from the supplementary immunisation activity schedule.[18] Inconsistencies between the reported number of OPV doses and the supplementary immunisation activity schedule can occur if not all children less than 5 years old in a district were immunised during a supplementary immunisation activity, if additional OPV doses were received outside of the district of residence, or if there is caregiver recall error.

Institutional ethics approval was not sought because this is a retrospective study and the databases are anonymised and free of personally identifiable information.

Statistical analysis

Summary statistics were reported separately for each country and region. Afghanistan and Pakistan were divided into seven regions defined by the GPEI according to patterns of poliovirus epidemiology. Pakistan was separated into Balochistan province; Khyber Pakhtunkhwa (KP) province; the Federally Administered Tribal Areas (FATA); a grouping of Punjab province, Gilgit-Baltistan, Azad Jammu Kashmir, and Islamabad Capital Territory (grouped as Punjab+); and Sindh province. Afghanistan was grouped into the southern provinces of Hilmand, Kandahar, Nimroz, Uruzgan, and Zabul, and the rest of Afghanistan as the remaining region. Incidence rates by region were calculated using the population sizes from the most recent census data from the Afghanistan Information Management Services and the Population Census Organisation, Pakistan. A smoothing cubic spline with 90 degrees of freedom was fitted to the weekly incidence of poliomyelitis and the non-polio acute flaccid paralysis rate.

We used a conditional logistic regression model to estimate the odds of paralysis by poliovirus serotypes 1 and 3 as a function of the number of doses of each vaccine received before the onset of paralysis.[19] The log odds of paralysis was given by:

$$\ln(odds) = \beta_m x_m + \beta_b x_b + \beta_t x_t + \varepsilon$$

where $1-e^{\beta_m}$, $1-e^{\beta_b}$, and $1-e^{\beta_t}$ are the per-dose protective effectiveness of the monovalent (v_m), bivalent (v_b), and trivalent (v_t) OPVs against either serotype 1 or 3 and x_m, x_b,

For the **Afghanistan Information Management Services** see http://www.aims.org.af

For the **Population Census Organization, Pakistan** see http://www.census.gov.pk/Statistics.htm

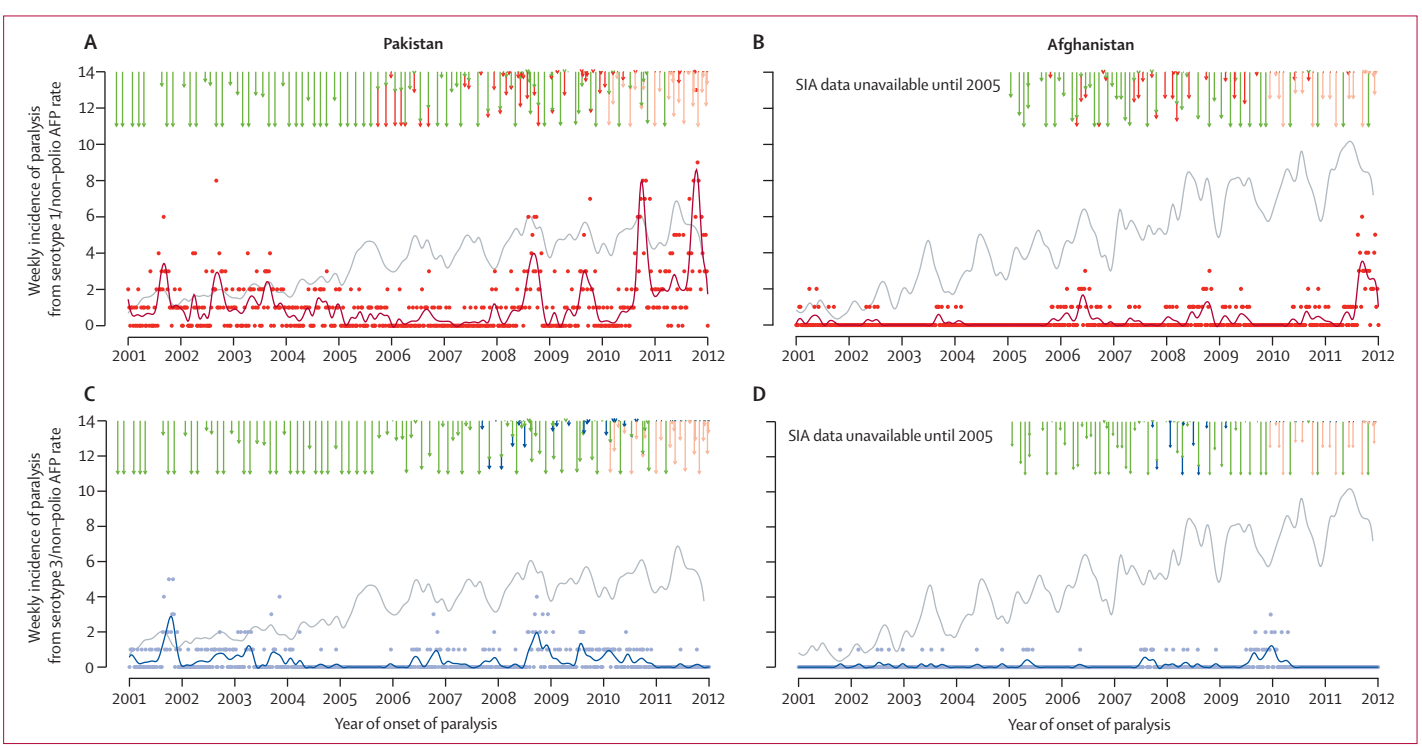
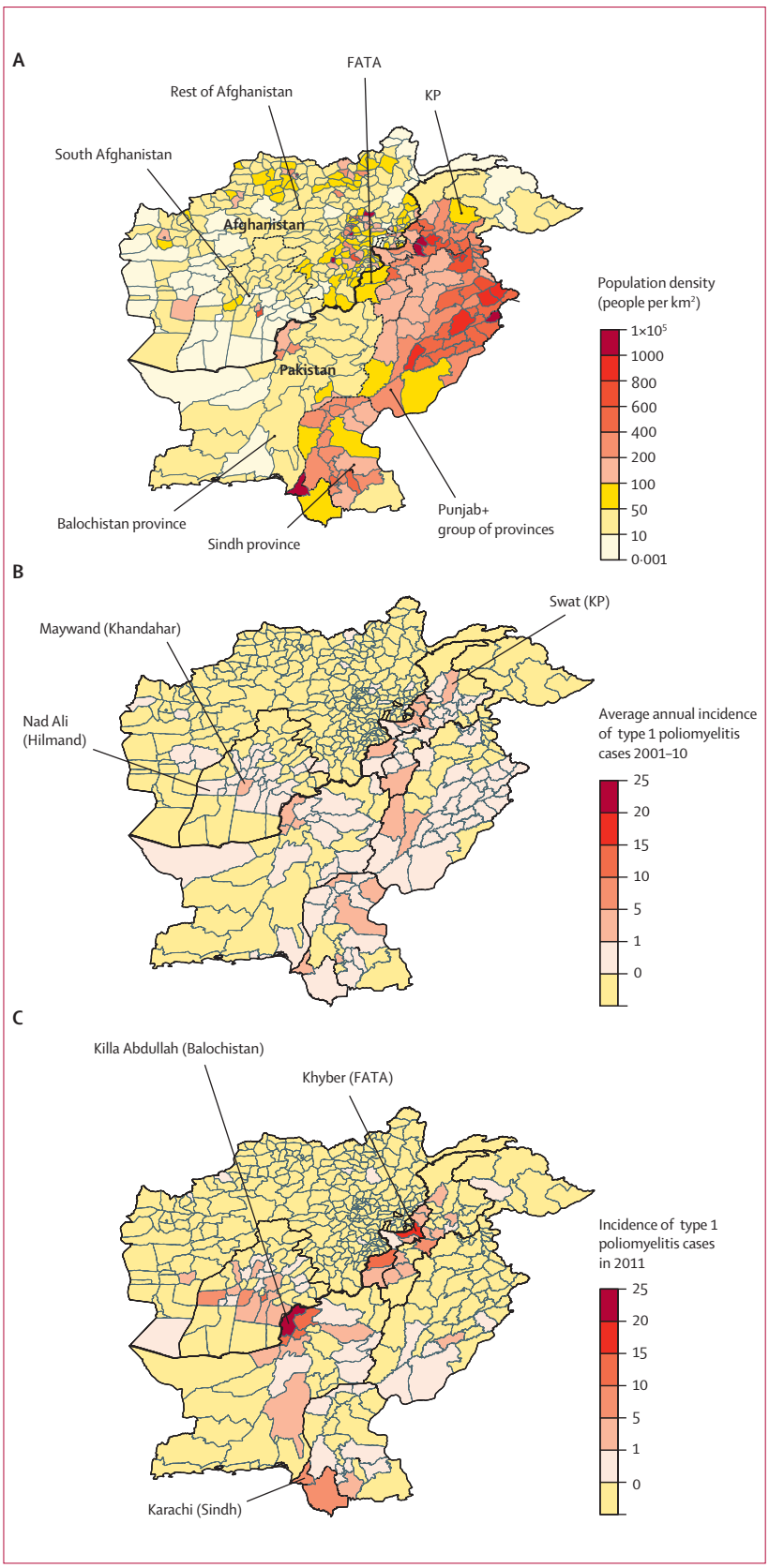


Figure 1: **Weekly incidence of poliomyelitis associated with serotype 1 or 3 wild-type poliovirus and rate of reporting acute flaccid paralysis associated with other causes**
The number of children with poliomyelitis is shown by week of onset of paralysis (coloured dots), with a cubic spline overlaid (coloured line), for serotype 1 in (A) Pakistan and (B) Afghanistan, and for serotype 3 in (C) Pakistan and (D) Afghanistan. The grey lines are a cubic spline of the non-polio acute flaccid paralysis rate, given as an annual number of cases per 100 000 children aged less than 15 years. The arrows at the top of the panels show when SIAs were done, with the length of the arrows proportional to the number of districts included in the campaign and the colours showing the vaccine used (trivalent OPV in green, serotype 1 monovalent OPV in red, serotype 3 monovalent OPV in blue, and bivalent OPV in orange). Only SIAs containing the relevant serotype of vaccine are shown in each panel. OPV=oral poliovirus vaccine. AFP=acute flaccid paralysis. SIA=supplementary immunisation activity.



and, x_t are the number of monovalent, bivalent, and trivalent OPV doses received. The amount of exposure to wild virus, ε, for each matched pair is unknown, but was eliminated from the analysis by maximising the conditional likelihood.[20] Cases of poliomyelitis were matched 1:1 with randomly chosen control children with non-polio acute flaccid paralysis by the methods described previously (eligible control children were randomly selected for each case without replacement, taking the cases in a random sequence; appendix). Cases and control children were matched by age and the date of onset of paralysis (within 3 months) and by district for Pakistan and province for Afghanistan (provinces in Afghanistan are similar in population size to districts in Pakistan).

To calculate vaccine-induced population immunity, children with non-polio acute flaccid paralysis (control children) were assumed to represent a random sample of children in the population of the corresponding age. The probability of a child being directly protected by vaccination against serotype 1 poliomyelitis was calculated from the estimated number of monovalent, bivalent, and trivalent OPV doses received and the estimated effectiveness of these vaccines as:

$$1-(1-\nu_m)^{x_m}(1-\nu_b)^{x_b}(1-\nu_t)^{x_t}$$

Vaccine-induced population immunity among children aged 0–2 years was estimated from the average of this quantity calculated for each single year age group in the acute flaccid paralysis database, weighted to represent the underlying age distribution of the population.

We report vaccine coverage on the basis of the proportion of children aged 0–2 years with non-polio acute flaccid paralysis who were reported to have received more than three doses of OPV. Uncertainty in vaccine coverage was accounted for by taking 10 000 bootstrap samples (with replacement) from the non-polio acute flaccid paralysis cases and recording the percentage of children who received four or more doses for each sample.[21] We report the 2·5th and 97·5th percentiles for these bootstrap samples. We used a linear model to estimate the slope of temporal trends in annual vaccine coverage for each region from 2006 to 2011, and to report the strength of the decrease in coverage a p value was used, where $p<0·05$ denotes that at least 95% of bootstrapped samples had a decrease in coverage. Linear trends in vaccine-induced population immunity against serotype 1 were assessed in the same way, but uncertainty in vaccine effectiveness was also included in bootstrap

Figure 2: **Geographic distribution of children reported with serotype 1 poliomyelitis in Afghanistan and Pakistan and estimated vaccine-induced immunity against this serotype**
(A) Population density in districts of Afghanistan and Pakistan. (B) Average annual incidence of poliomyelitis caused by serotype 1 wild poliovirus by district for 2001–10. (C) Incidence of poliomyelitis caused by serotype 1 wild poliovirus by district for 2011. FATA=Federally Administered Tribal Areas. KP=Kyhber Pakhtunkhwa.

replicates by randomly sampling from a multivariate log-normal distribution with means and variance-covariance matrix given by the conditional logistic regression used to estimate vaccine effectiveness. Estimated population immunity and annual incidence of poliomyelitis were compared for each district-year separately. The correlation between population immunity and incidence was tested by Spearman's rank correlation coefficient. The coverage of routine immunisation was assessed on the basis of the proportion of children with non-polio acute flaccid paralysis who were reported to have received at least three doses of trivalent OPV through routine services.

Role of the funding source

The funders of the study had no role in the study design, data collection, data analysis, data interpretation, decision to publish, or preparation of the manuscript. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Between Jan 1, 2001, and Dec 31, 2011, there were 883 cases of serotype 1 poliomyelitis, 710 in Pakistan and 173 in Afghanistan (table). There were 272 cases of serotype 3 poliomyelitis, 216 in Pakistan and 56 in Afghanistan. During 2004–07, case numbers were lower (in Pakistan) or remained low (Afghanistan) compared with 2001–03 despite improved surveillance that resulted in an upward trend in the number of reported children with acute flaccid paralysis (the non-poliomyelitis AFP rate remained above three cases per 100 000 children aged 0–14 years from 2004 onwards; figure 1). During 2008–11, the number of children with serotype 1 poliomyelitis increased in Pakistan both in absolute terms and as a proportion of all

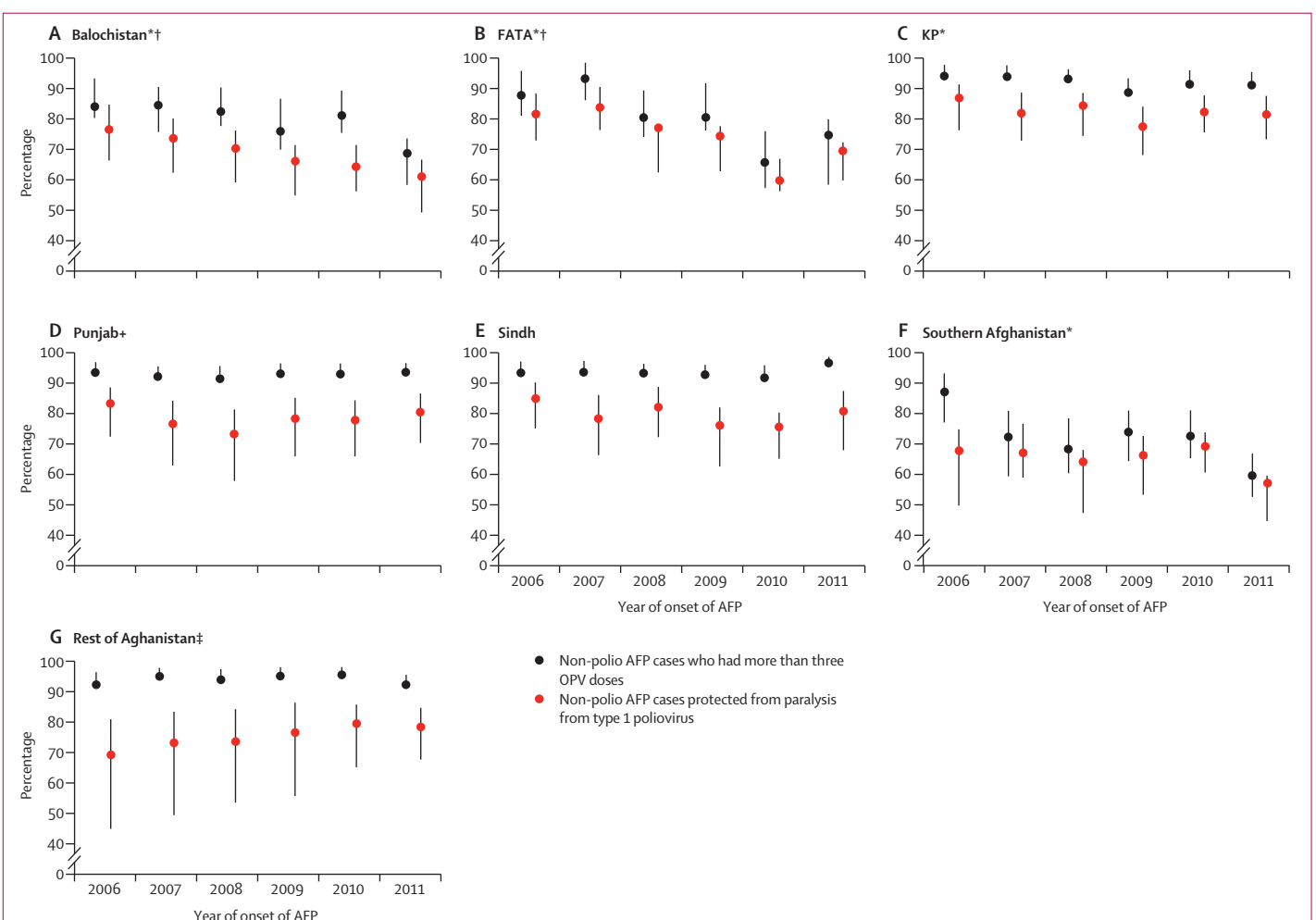


Figure 3: **Estimated vaccination coverage and vaccine-induced population immunity over time by region**

The proportion of children aged 0–2 years who received more than three doses of OPV through routine or supplementary immunisation activities is shown in black and estimated vaccine-induced immunity against serotype 1 in red. Error bars show 95% CIs on the basis of bootstrap resampling. FATA=Federally Administered Tribal Area. KP=Khyber Pakhtunkhwa. OPV=oral poliovirus vaccine. AFP=acute flaccid paralysis. *Significant linear decline in coverage. †Significant linear decline in immunity. ‡Significant linear increase in immunity.

reported acute flaccid paralysis cases. This increase was followed by an increase in Afghanistan in 2011 (figure 1).

The locations of poliomyelitis cases were spatially aggregated; the highest numbers of serotype 1 poliomyelitis cases were reported in Karachi, Swat, and Khyber districts in Pakistan (figure 2). In Afghanistan, Maywand and Shah Wali Kot districts within Kandahar province had the most cases during the study period. In 2011, there were over 20 cases in Killa Abdullah district in Balochistan and between 15 and 20 cases in Quetta and Pishin in Balochistan province and Khyber in FATA (figure 2). In 2011, two cases of poliomyelitis caused by serotype 3 were identified, both in Khyber district in FATA, Pakistan.

Of the 883 serotype 1 poliomyelitis cases, 535 (61%) were matched with suitable controls (table). The estimated clinical effectiveness of a dose of trivalent OPV against serotype 1 poliomyelitis was 12·5% (95% CI 5·6–18·8) compared with 23·4% (10·4–34·6) for bivalent OPV (likelihood ratio test p=0·067) and 34·5% (16·1–48·9) for monovalent OPV (p=0·007). The estimated effectiveness of bivalent OPV was non-inferior compared with monovalent OPV (p=0·21). There was no evidence of significant variation in vaccine effectiveness by country or region within these countries or by number of vaccine doses previously received (likelihood ratio test p=0·22 for the per-dose trivalent model; appendix). There were not enough cases of serotype 3 poliomyelitis between 2001 and 2011 to allow accurate estimation of the effectiveness of each OPV against this serotype.

The estimated coverage with more than three OPV doses among children aged 0–2 years in Afghanistan and Pakistan was moderate to high (above 70%). However, in Balochistan, FATA, KP, and southern Afghanistan there was a significant linear decrease in coverage from 2006, to 2011, (figure 3; appendix). Coverage estimates in Sindh, Punjab+, and the rest of Afghanistan remained stable from 2006 to 2011. In Balochistan and FATA, there was also a decrease during 2006–11 in the percentage of children aged 0–2 years who received three or more OPV doses through routine services (appendix). Routine immunisation coverage remained low in southern Afghanistan.

The percentage of children aged 0–2 years who were protected by direct vaccination against poliomyelitis varied by location and year (figure 3; appendix). Immunity to serotype 1 in FATA and Balochistan decreased, despite the use of more effective vaccines. Coverage estimates for Balochistan, KP, and all of Afghanistan further decreased in 2011 when compared with 2010, although vaccine-induced population immunity against serotype 1 either increased or remained stable, with the exception of southern Afghanistan.

We noted a significant negative correlation (p<0·0001) between the ranked population immunity and annual incidence of serotype 1 poliomyelitis in each district (Pakistan) or province (Afghanistan; Spearman's ranked correlation coefficient –0·11; appendix).

Discussion

This study provides the first estimates of the clinical effectiveness and population immunity induced by OPVs in Pakistan and Afghanistan, including the effectiveness of the bivalent vaccine (panel). Our findings support the results from India,[8] which showed that the immunogenicity of two doses of bivalent OPV given to newborn babies was non-inferior compared with serotype 1 or 3 monovalent OPVs. Our results also compare favourably with the clinical protective effectiveness of the monovalent OPV in India (30%, 95% CI 19–41),[18] which was valuable in improving population immunity and led to the successful interruption of wild-type poliovirus transmission in 2011. Consequently, bivalent OPV will be useful in boosting population immunity against both circulating serotypes during supplementary immunisation activities. Bivalent OPV will be used in six of the eight supplementary immunisation activities planned for 2012 in Pakistan and will be complemented with trivalent vaccine in the remaining two supplementary immunisation activities to maintain immunity to serotype 2.

The estimated effectiveness of trivalent OPV against serotype 1 poliomyelitis in Afghanistan and Pakistan was similar to that reported in India.[7,19] The poor effectiveness of OPV in these settings might be partly explained by the high prevalence of diarrhoeal disease and enteric infections including enteroviruses that might interfere with seroconversion.[4,22] In KP and FATA, the annual average incidence of enteroviruses in non-polio acute flaccid paralysis stool samples was about 30%, which is similar to that reported in Uttar Pradesh and Bihar in India (Grassly NC, unpublished). Although this finding does not implicate enteroviruses specifically, it is consistent with the potential role of enteric pathogens in the compromised effectiveness of OPV.

Since 2006, there has been a decrease in estimated vaccination coverage and population immunity against poliomyelitis in specific regions of Pakistan and Afghanistan, which correlated with an increased incidence of cases. In response to this epidemiological situation, the President of Pakistan launched a National Emergency Action Plan in early 2011.[9] Part of this action plan included a focus on 33 districts with a high incidence of poliomyelitis, largely in KP, FATA, Balochistan, and Sindh.[10] In late 2011, the National Emergency Action Plan was further augmented with tighter oversight and vigorous monitoring to improve quality in vaccination campaigns.[2] However, the analysis presented here suggests that vaccination coverage continued to decrease in 2011, especially in Balochistan. Additionally, coverage continues to be compromised by the ongoing conflict in southern Afghanistan.

Immunisation is not the only intervention with inequitable access in Pakistan and Afghanistan, but poor access to it contributes with other social determinants to poor child health in these areas.[23] Armed conflict and concerns about security are major challenges that can

limit access to children during vaccination campaigns, in addition to disrupting routine health and immunisation services.[24] For example, we noted that access to routine immunisation decreased in Balochistan and FATA in Pakistan, with just 25–33% of children under 3 years old reported to have received three or more doses of OPV through routine services in 2011 (appendix). This finding contrasts with improvements in routine immunisation coverage in areas free from conflict such as northern Afghanistan. However, weak service delivery has also resulted from poor management and scarcity of local accountability;[10,25] even so, polio has been successfully eliminated during times of conflict in many other countries.[24]

The precision of our estimates of vaccine effectiveness might be limited by the accuracy of the caregiver's report of the number of doses of OPV received by a child and difficulties in correctly inferring the type of vaccine received during supplementary immunisation activities. Although vaccination cards were used when recording the number of doses of trivalent OPV received through routine immunisation services, these cards were only available for 25% of children and the number of vaccine doses received through supplementary immunisation activities was not recorded. Errors in the reported numbers of vaccine doses among cases and controls could lead to an underestimate of vaccine effectiveness. Additionally, the inability of the statistical method of matching by location, time, and age to control for differences in exposure to wild-type polioviruses might further contribute to underestimation of vaccine effectiveness.

We attempted to assess the extent of caregiver recall error in several ways, including by examining the correlation between caregiver reports of supplementary immunisation activity doses and administrative records of supplementary immunisation activities, the odds of poliomyelitis as a function of the reported number of doses of vaccine received, and the association between the estimated vaccine-induced population immunity on the basis of caregiver reports of vaccination history and the incidence of poliomyelitis. In each case, results based on caregiver recall were consistent with those expected based on the other data sources, although comparison with the supplementary immunisation activity schedule suggested that at higher dose numbers there was a preference for reporting seven, ten, 12, 15, and 20 doses (appendix). These findings are in agreement with a study in India,[7] where information from detailed interviews with parents of children with poliomyelitis showed some small errors in recall of the number of vaccine doses received by their children but no consistent upwards or downwards bias. Furthermore, vaccination history is taken at a time when both the caregiver and interviewer are unaware of the polio status of the child, thus removing the possibility of differential reporting from cases and controls. The findings of a greater effectiveness of monovalent OPVs and weak evidence of greater effectiveness of bivalent vaccine than trivalent OPV are therefore likely to be robust to recall error of caregivers. We also focused on children aged 0–2 years when estimating vaccination coverage and population immunity to avoid recall errors that might have been more frequent among older children. Children in this age group were also chosen because they are more representative of the at-risk population.

The negative correlation of population immunity with incidence shows protective immunity within the population. However, in some districts there was not the expected reduction in cases despite high estimated population immunity. A limitation of this analysis is that non-polio acute flaccid paralysis cases are assumed to be representative of the entire population. In reality, even within districts there are probably areas not reached by surveillance and vaccination teams, resulting in heterogeneities in population immunity that are not captured in the analysis.

In the past 10 years there have been many developments in the control of poliomyelitis that should enable elimination in Afghanistan and Pakistan. However, an increase in incidence has occurred despite the introduction of more efficacious vaccines because of steep decreases in vaccination coverage. In 2011, 40% of children under 3 years old in Balochistan and FATA in Pakistan and in southern Afghanistan were estimated to be unprotected against serotype 1, the predominant circulating wild poliovirus. If vaccination coverage during the two trivalent and four bivalent OPV campaigns planned in Afghanistan and Pakistan in 2012 could be

Panel: Research in context

Systematic review

We searched PubMed and Web of Science with the search terms "poliomyelitis AND (Pakistan OR Afghanistan)" and "bivalent AND poliovirus", with no date limits set, on March 7, 2012. For over 10 years the incidence and epidemiological status of poliomyelitis in both countries have been reported annually in the *Weekly Epidemiological Record*.[15] Monitoring of vaccine coverage during mass campaigns has been limited, but findings from a lot-quality assurance sampling study in Pakistan suggested that coverage during mass campaigns in 2009 was low.[13] The only immunogenicity study of the present formulation of bivalent OPV that we identified was done in India in 2008, in which the vaccine was non-inferior compared with monovalent vaccines for serotypes 1 and 3.[8] The effectiveness of this bivalent OPV has not been reported previously.

Interpretation

We found the effectiveness of serotypes 1 and 3 bivalent OPV against poliomyelitis caused by serotype 1 wild poliovirus to be non-inferior compared with monovalent OPV. However, despite the use of these more effective vaccines during recent vaccination campaigns, estimated population immunity among children in key regions of Afghanistan and Pakistan decreased between 2006 and 2011 as a result of substantial drops in vaccination coverage. This decrease in population immunity resulted in an increased incidence of serotype 1 poliomyelitis during 2010–11. Vaccination coverage must be considerably improved in 2012 through higher quality campaigns and routine programmes if global eradication of poliomyelitis is to be achieved.

increased to at least 80%, and if persistently missed children could be reached by the programme, the proportion of unprotected children would decrease to less than 10% and eradication would become feasible. To achieve this ambitious goal, major improvements in vaccination delivery will be needed in the face of armed conflict and concerns about security.

Contributors

KMO, RBA, and NCG designed the study. ED, OuI, AQ, NA, TPM, and RT coordinated surveillance of acute flaccid paralysis. All authors contributed to the data analysis and interpretation, writing of the report, and approved it before submission.

Conflicts of interest

We declare that we have no conflicts of interest.

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