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Descriptive Finding

To what extent were life expectancy gains in South Africa attributable to declines in HIV/AIDS mortality from 2006 to 2017? A life table analysis of age-specific mortality

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Abstract

BACKGROUND
In South Africa, life expectancy increased considerably after the government introduced its antiretroviral therapy (ART) program in 2004. The impact of the national ART program on life expectancy may be underestimated if child mortality is not accounted for in formal evaluations.

OBJECTIVE
We measured the extent to which life expectancy gains from 2006 to 2017 were attributable to declines in HIV/AIDS mortality, accounting for all age groups, including infants and children.

METHODS
To calculate life expectancies, we constructed period life tables using age-specific mortality rates estimated by Thembisa, a South Africa–based HIV epidemic model that integrates pediatric HIV data sources. We modeled counterfactual scenarios, a worst-case and best-case, to discern life expectancy gains related to HIV mortality versus other causes of mortality. We reported outcomes as life expectancy gains and life-years saved per person at varying ages.

RESULTS
In South Africa, life expectancy at birth was 65.1 years in 2017, compared to 54.0 years in 2006. Of these 11.1 life-years gained, we found that 8.9 life-years were attributable to HIV mortality reductions. In people under 49 years old, most gains were attributable to HIV reduction. Gains from HIV reduction and other causes became equivalent at about

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age 49. In people over 60, most gains were attributable to causes other than HIV/AIDS reduction.

CONTRIBUTION

This study demonstrated that most life expectancy gains were attributable to declines in HIV mortality following the national ART rollout in South Africa. This analysis tracked life expectancies across age groups, including children, and described their characteristics.

1. Background

Mortality and life expectancy in South Africa improved substantially following the launch of a public sector, universal antiretroviral therapy (ART) program in 2004 (Dorrington et al. 2020; Pillay-van Wyk et al. 2016; Bor et al. 2013). In 2019, of the total population of 59 million, approximately 7.8 million were people living with HIV/AIDS (PLWHA) (UNAIDS 2020). Of PLWHA, approximately 7.5 million were adults (15 years and over) and 310,000 were children (0–14 years) (UNAIDS 2020). Of these individuals, about 73% of adults and 47% of children were treated with ART (UNAIDS 2020).

Following a 2002 court order, the South African government began distributing ART to mothers for the prevention of mother-to-child HIV transmission (PMTCT) (Simelela et al. 2015). In 2004, ART access was expanded to all South Africans living with HIV/AIDS. In 2008, the era of HIV/AIDS denialism in South Africa came to an end with the incoming presidential administration (Simelela et al. 2015). From 2010 to 2019, new HIV infections fell by 53% and HIV mortality fell by 61% (UNAIDS 2020). By 2019, an estimated 92% of PLWHA knew of their status, 70% received treatment, and 64% had suppressed viral loads (defined as having less than 200 viral copies per milliliter of blood, indicating reduced transmissibility) (UNAIDS 2020; Marinda et al. 2020). The ART program cost approximately 19,604 million rand, or US$1.46 billion, in fiscal year 2016–2017 (Guthrie et al. 2018).

Prior studies suggest that recent improvements in average life expectancy and HIV-related mortality were due in large part to the universal ART program (Johnson et al. 2017; Reniers et al. 2017; Johnson et al. 2016; Bor et al. 2013; Herbst et al. 2009). These strides corresponded with gains in adult-specific life expectancy. For instance, based on data collected in an adult cohort in KwaZulu-Natal, South Africa (Tanser et al. 2013, 2008), life expectancy increased by 11.3 years from 2003 to 2014 (Reniers et al. 2017). This trend mapped onto the ART launch in 2004 and extended to the entire country. Nationwide, ART provisions reduced HIV deaths by approximately 1.7 million and saved

6.2 million life-years in adults from 2000 to 2014 (Johnson et al. 2017). As mortality declined throughout the country, life expectancy also improved for the first time since 1995.

Few evaluations have measured HIV/AIDS-related increases in life expectancy from birth or childhood in South Africa, possibly due to limited cohort studies or data collection efforts. Most studies have reported results for adults only, with few incorporating children in their calculations of life expectancy improvements. Yet improvements in HIV mortality in children were dramatic, with mortality rates decreasing from 16% in 2006 to 5% in 2017 (Johnson et al. 2020). While the number of children living with HIV is much lower than that for adults, children are less likely to be diagnosed or treated (Johnson et al. 2020; UNAIDS 2020) even though early treatment could potentially save even more lives and life-years as they grow into adulthood. Our study attempted to fill this literature gap.

This study aimed to measure the extent to which life expectancy gains in South Africa were attributable to HIV mortality reductions from 2006 to 2017. We reported outcomes as life expectancy gains and life-years saved per person by age and sex. We used a newly updated, South Africa–based statistical model called Thembisa, which incorporates recent national child health data into its parameters and calibration process (Johnson and Dorrington 2019). Our findings could demonstrate the achievable life expectancy gains among a population with high HIV prevalence following ART expansion.

2. Data and methods

2.1 Measure and data source

We calculated life expectancy at varying ages and by sex from 2006 to 2017, using age- and sex-specific mortality estimates from Thembisa version 4.2. Thembisa is a mathematical model of the HIV epidemic in South Africa designed to answer policy questions about the impact of ART and other HIV programs on the population (detailed elsewhere; Johnson and Dorrington 2019). Thembisa currently serves as the main source of health statistics for UNAIDS. The Thembisa model has been parameterized with multiple HIV data sources, including HIV mortality rates from the International Epidemiology Databases to Evaluate AIDS – Southern Africa (IeDEA-SA), non-HIV mortality rates from the national vital registration system, and HIV prevalence rates from national household surveys (www.thembisa.org). Previous applications of Thembisa included estimating progress toward pediatric HIV diagnosis and ART coverage targets (Johnson et al. 2020), effects of introducing pre-exposure prophylaxis to pregnant and

breastfeeding women (Davey et al. 2019), and excess HIV infant mortality (Slogrove, Johnson, and Powis 2019). The previous Thembisa version, 4.1, was revised to include pediatric HIV diagnostic estimates; the current Thembisa, 4.2, also incorporates up-to-date children's death records.

2.2 Data analysis

We constructed period life tables using all-cause mortality rates and HIV mortality rates (${}_nm_x$) in South Africa from 2006 to 2017. We used single-year age groups from age 0 to 89 years; the last group was 90 years and older. We estimated ${}_na_x$, the average number of person-years lived in the interval by those dying in the interval, by applying techniques proposed by Coale, Demeny, and Keyfitz (Preston, Heuveline, and Guillot 2000). Using ${}_nm_x$ and ${}_na_x$, we then estimated actual life expectancy at varying ages and by sex. We used Python version 3.7.3 (Python Software Foundation, Delaware, United States).

We applied demographic counterfactual modeling to 'decompose' life expectancy gains into gains attributable to HIV compared to those attributable to non-HIV mortality. First we modeled hypothetical life expectancy for a worst-case counterfactual in the absence of improvements from ART scale-up and other HIV intervention efforts. (This study could not tease out individual effects of each HIV strategy.) The worst-case scenario assumed HIV mortality had not improved since 2006, allowing us to measure indirectly the effect of declining HIV mortality on life expectancy. To construct the worst-case scenario, we created life tables and applied the same HIV mortality rate in 2006 to each subsequent year (2007 to 2017). We assumed stagnant HIV-related conditions from 2007 through 2017, despite ART rollout taking full effect in South Africa after 2006 (Simelela et al. 2015). (Non-HIV-related conditions could vary each year as expected.) With the application of the HIV mortality of 2006 to future years, our results could provide conservative lower bounds of life expectancy gains. Next we subtracted the worst-case life expectancy estimate in 2006 from the estimate in 2017; this result yielded life expectancy gains attributable to non-HIV mortality reductions. Then we took the difference between the non-HIV life expectancy gains and actual life expectancy gains from 2006 to 2017; this result yielded life expectancy gains attributable to HIV mortality reductions.

We modeled a best-case counterfactual to project any additional life expectancy gains that could be realized had it not been for HIV deaths. To construct the best-case scenario, we created life tables and subtracted HIV mortality rates from all-cause mortality rates for each year from 2006 to 2017. Then we took the difference between best-case life expectancy and actual life expectancy in 2017; this result yielded the additional life expectancy gains had HIV deaths been eliminated. To calculate the upper

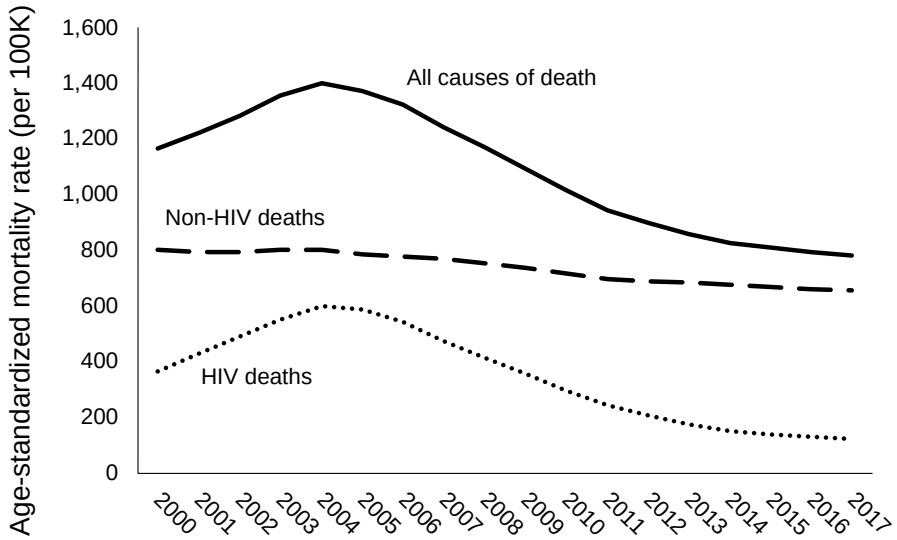
bounds, we did not specify any single intervention responsible for the complete elimination of HIV deaths but rather imagined an ideal what-if scenario in which the combined effectiveness of ART and other HIV strategies could eradicate all HIV deaths. That is, we assumed zero casualties from the HIV epidemic. On a population level, some of these 'saved' patients could still die from other causes. Since our study did not account for possible saved patients, the analysis could overestimate results. With additional data, such as on ART adherence or retention in care, we can produce more accurate estimates in the future.

3. Results

3.1 Mortality trends

After 2006, the all-cause mortality rate decreased steadily in South Africa (Figure 1). From 2006 to 2017, all-cause mortality fell by 41%, reaching 781 deaths per 100,000 persons. HIV mortality declined by 77%, reaching 124 deaths per 100,000 persons, while non-HIV mortality declined by 16%, reaching 657 deaths per 100,000 persons. The trend line for all-cause mortality mirrored that of HIV mortality, suggesting that overall trends were mostly influenced by HIV mortality patterns.

Figure 1: Age-standardized mortality per 100,000 persons from all causes of death, non-HIV deaths, and HIV deaths from 2000 to 2017



3.2 Life expectancy gains

Across all age groups, life expectancy improved in the decade after ART expansion. South Africans born in 2017 could expect to live to about 65.1 years, an 11.1-year improvement compared to 2006 (Table 1). For young adults, life expectancy at age 15 improved 8.9 life-years per person, and life expectancy for those at age 25 improved 8.6 life-years per person. Life expectancy at age 40 increased by 4.4 life-years, whereas life expectancy for older groups, starting age 51, yielded less than 2 life-years. More life expectancy gains were observed in the first half of the decade than in the second half (Table 2).

Table 1: Life expectancy (LE) in South Africa from 2006 to 2017 by single-year age groups. Life expectancy gains were broken into mortality reductions from HIV deaths compared those from to non-HIV deaths

Age	LE in 2006	LE in 2011	LE in 2017	Total difference in LE (2006–2017)	LE gains from reductions in HIV deaths (2006–2017)	LE gains from reductions in non-HIV deaths (2006–2017)
0	54.0	61.5	65.1	11.1	8.9	2.2
1	55.7	62.3	65.6	9.9	8.0	1.9
2	55.4	61.7	64.9	9.5	7.7	1.8
3	54.8	60.9	64.1	9.3	7.6	1.7
4	54.0	60.0	63.2	9.2	7.5	1.7
5	53.1	59.1	62.3	9.2	7.4	1.8
6	52.3	58.2	61.3	9.0	7.3	1.7
7	51.4	57.3	60.4	9.0	7.3	1.7
8	50.4	56.3	59.4	9.0	7.3	1.7
9	49.5	55.3	58.4	8.9	7.2	1.7
10	48.6	54.4	57.5	8.9	7.3	1.6
11	47.6	53.4	56.5	8.9	7.2	1.7
12	46.7	52.5	55.6	8.9	7.2	1.7
13	45.7	51.5	54.6	8.9	7.2	1.7
14	44.8	50.6	53.7	8.9	7.2	1.7
15	43.8	49.6	52.7	8.9	7.2	1.7
16	42.9	48.7	51.8	8.9	7.2	1.7
17	42.0	47.8	50.8	8.8	7.2	1.6
18	41.0	46.8	49.9	8.9	7.2	1.7
19	40.1	45.9	49.0	8.9	7.3	1.6
20	39.2	45.0	48.1	8.9	7.3	1.6
21	38.3	44.1	47.2	8.9	7.3	1.6
22	37.5	43.3	46.3	8.8	7.2	1.6
23	36.7	42.4	45.5	8.8	7.3	1.5
24	35.9	41.6	44.6	8.7	7.2	1.5
25	35.2	40.8	43.8	8.6	7.1	1.5
26	34.5	40.0	42.9	8.4	6.9	1.5
27	33.9	39.2	42.1	8.2	6.8	1.4
28	33.3	38.5	41.3	8.0	6.6	1.4
29	32.8	37.7	40.5	7.7	6.3	1.4
30	32.3	37.0	39.7	7.4	6.1	1.3
31	31.8	36.4	38.9	7.1	5.7	1.4
32	31.4	35.7	38.2	6.8	5.5	1.3
33	30.9	35.1	37.4	6.5	5.2	1.3
34	30.5	34.4	36.7	6.2	4.9	1.3
35	30.1	33.8	35.9	5.8	4.6	1.2
36	29.7	33.2	35.2	5.5	4.3	1.2
37	29.2	32.5	34.4	5.2	3.9	1.3
38	28.8	31.9	33.7	4.9	3.7	1.2
39	28.4	31.3	33.0	4.6	3.4	1.2
40	27.9	30.6	32.3	4.4	3.2	1.2
41	27.5	30.0	31.5	4.0	2.9	1.1
42	27.0	29.4	30.8	3.8	2.6	1.2
43	26.5	28.8	30.1	3.6	2.4	1.2
44	26.1	28.1	29.4	3.3	2.2	1.1
45	25.6	27.5	28.7	3.1	2.0	1.1

Table 1: (Continued)

Age	LE in 2006	LE in 2011	LE in 2017	Total difference in LE (2006–2017)	LE gains from reductions in HIV deaths (2006–2017)	LE gains from reductions in non-HIV deaths (2006–2017)
46	25.1	26.9	28.0	2.9	1.8	1.1
47	24.6	26.2	27.3	2.7	1.6	1.1
48	24.1	25.6	26.5	2.4	1.3	1.1
49	23.6	25.0	25.8	2.2	1.1	1.1
50	23.1	24.3	25.2	2.1	1.1	1.0
51	22.6	23.7	24.5	1.9	0.9	1.0
52	22.1	23.1	23.8	1.7	0.8	0.9
53	21.6	22.5	23.1	1.5	0.6	0.9
54	21.0	21.8	22.4	1.4	0.5	0.9
55	20.5	21.2	21.7	1.2	0.4	0.8
56	19.9	20.6	21.1	1.2	0.4	0.8
57	19.4	20.0	20.4	1.0	0.2	0.8
58	18.8	19.4	19.8	1.0	0.2	0.8
59	18.3	18.8	19.1	0.8	0.1	0.7
60	17.7	18.2	18.5	0.8	0.1	0.7
61	17.2	17.6	17.9	0.7	0.1	0.6
62	16.7	17.0	17.2	0.5	0.0	0.5
63	16.1	16.4	16.6	0.5	0.0	0.5
64	15.6	15.9	16.0	0.4	0.0	0.4
65	15.0	15.3	15.5	0.5	0.1	0.4
66	14.4	14.8	14.9	0.5	0.0	0.5
67	13.9	14.2	14.3	0.4	0.0	0.4
68	13.3	13.7	13.7	0.4	0.0	0.4
69	12.8	13.2	13.2	0.4	0.0	0.4
70*	12.2	12.6	12.6	0.4	0.0	0.4
71	11.7	12.1	12.1	0.4	0.0	0.4
72	11.2	11.5	11.6	0.4	0.0	0.4
73	10.7	11.0	11.1	0.4	0.0	0.4
74	10.2	10.5	10.6	0.4	0.0	0.4
75	9.7	10.0	10.1	0.4	0.0	0.4
76	9.2	9.6	9.7	0.5	0.0	0.5
77	8.8	9.1	9.2	0.4	0.0	0.4
78	8.3	8.7	8.7	0.4	0.0	0.4
79	7.9	8.3	8.3	0.4	0.0	0.4
80	7.5	7.8	7.8	0.3	0.0	0.3
81	7.1	7.4	7.4	0.3	0.0	0.3
82	6.8	7.0	7.1	0.3	0.0	0.3
83	6.4	6.6	6.7	0.3	0.0	0.3
84	6.0	6.2	6.3	0.3	0.0	0.3
85	5.7	5.9	6.0	0.3	0.0	0.3
86	5.3	5.6	5.6	0.3	0.0	0.3
87	5.0	5.3	5.3	0.3	0.0	0.3
88	4.6	5.0	5.0	0.4	0.0	0.4
89	4.3	4.7	4.6	0.3	0.0	0.3
90+	4.1	4.4	4.3	0.2	0.0	0.2

* Value under 0 were truncated to 0.0.

Table 2: South African population estimates for (A) actual life expectancy compared to the hypothetical (B) worst-case scenario and (C) best-case scenario at varying ages from 2006 to 2017. Life expectancy gains were broken into two periods, 2006–2011 and 2011–2017

A. Actual life expectancy

Age	LE in 2006	LE in 2011	LE in 2017	Total difference in LE (2006–2017)	Difference in LE (2006–2011)	Difference in LE (2011–2017)
0	54.0	61.5	65.1	11.1	7.5	3.6
1	55.7	62.3	65.6	9.9	6.6	3.3
5	53.1	59.1	62.3	9.2	6.0	3.2
15	43.8	49.6	52.7	8.9	5.8	3.1
25	35.2	40.8	43.8	8.6	5.6	3.0
40	27.9	30.6	32.3	4.4	2.7	1.7
65	15.0	15.3	15.5	0.5	0.3	0.2
80	7.5	7.8	7.8	0.3	0.3	0.0

B. Hypothetical life expectancy under the worst-case scenario, assuming HIV mortality had not changed from 2006 to 2017

Age	LE in 2006	LE in 2011	LE in 2017	Total difference in LE (2006–2017)	Difference in LE (2006–2011)	Difference in LE (2011–2017)
0	54.0	55.4	56.2	2.2	1.4	0.8
1	55.7	56.9	57.6	1.9	1.2	0.7
5	53.1	54.3	54.9	1.8	1.2	0.6
15	43.8	45.0	45.5	1.7	1.2	0.5
25	35.2	36.2	36.7	1.5	1.0	0.5
40	27.9	28.7	29.1	1.2	0.8	0.4
65	15.0	15.3	15.4	0.4	0.3	0.1
80	7.5	7.8	7.8	0.3	0.3	0.0

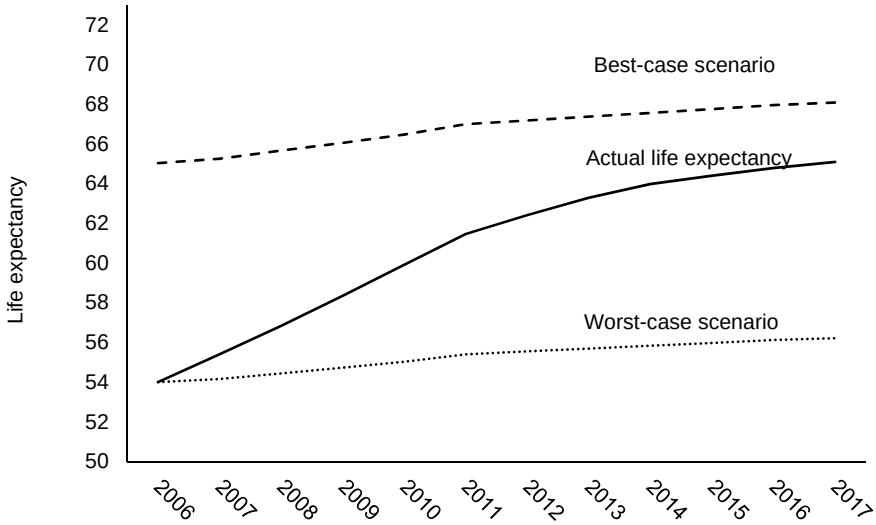
C. Hypothetical life expectancy under the best-case scenario, assuming HIV mortality had been eliminated from 2006 to 2017

Age	LE in 2006	LE in 2011	LE in 2017	Total difference in LE (2006–2017)	Difference in LE (2006–2011)	Difference in LE (2011–2017)
0	65.0	67.0	68.1	3.1	2.0	1.1
1	66.1	67.8	68.6	2.5	1.7	0.8
5	62.9	64.5	65.2	2.3	1.6	0.7
15	53.3	54.9	55.6	2.3	1.6	0.7
25	44.5	45.9	46.6	2.1	1.4	0.7
40	32.4	33.3	33.8	1.4	0.9	0.5
65	15.1	15.4	15.6	0.5	0.3	0.2
80	7.5	7.8	7.9	0.4	0.3	0.1

Hypothetical life expectancy at birth for the worst-case scenario (no improvements in HIV mortality rates since 2006) ranged between 54.0 and 56.2 years, while that for the best-case scenario (no one died because of HIV beginning in 2006) ranged between 65.0 and 68.1 years (Table 2; Figure 2). Of the total 11.1 life-years gained, 8.9 life-years were attributed to reductions in HIV mortality while the remaining 2.2 life-years were attributed to reductions in non-HIV mortality. Therefore HIV mortality reductions contributed to at least three-fourths of the life expectancy gains. Johnson and colleagues

reported that non-HIV mortality reductions in adults were modest (Johnson et al. 2017). If HIV deaths had been eliminated according to the best-case scenario, then the South African population would potentially gain an additional 3.0 life-years at birth in 2017 (Table 2C).

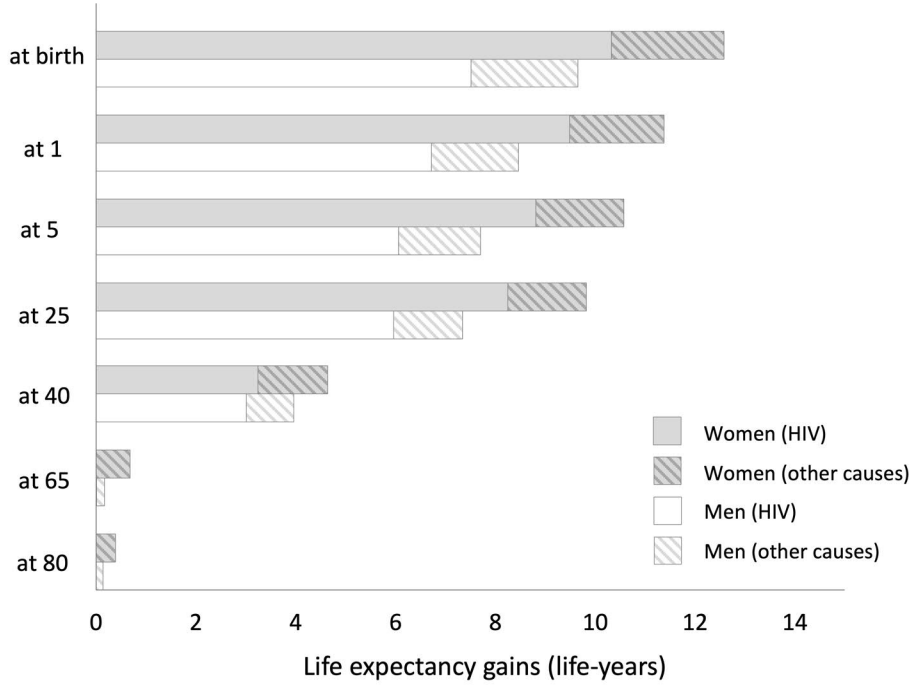
Figure 2: Actual life expectancy at birth in South Africa compared to hypothetical life expectancy under worst-case scenario and best-case scenario from 2006 to 2017



3.3 Subgroup analysis

This study found that women experienced more life expectancy gains than men from both HIV mortality and non-HIV mortality reductions (Figure 3) (Johnson et al. 2017; Reniers et al. 2017). By 2017, life expectancy gains attributable to HIV mortality reductions were approximately 82% for women and 78% for men. Differences in HIV-related life expectancy could also be tracked by age group. The under-50 age group saw the greatest gains in life expectancy from HIV mortality reductions. Life expectancy gains from HIV *and* non-HIV morality reductions became equivalent at about age 49. In people age 60 or older, most life expectancy gains were attributable to non-HIV mortality reductions.

Figure 3: Life expectancy gains for women and men at varying ages from 2006 to 2017



Notes: Results for women were in gray and men were in white. Each bar was divided into two parts. The left bar (solid) represented life expectancy gains from reduced HIV mortality and right bar (striped) represented reduced deaths due to causes other than HIV.

4. Discussion and conclusion

We measured life expectancy gains in South Africa from 2006 to 2017 and the extent to which these gains were attributable to the reduction of HIV mortality compared to other causes of mortality. We reported results by age, including childhood ages; most studies have looked at adults only. The life expectancy at birth reached 65.1 years in 2017, an 11.1-year gain from 2006. Children at ages 1, 5, and 10 could expect an additional 9.9, 9.2, and 8.9 life-years per person, respectively, in 2017 compared to 2006. Young adults at ages 15 and 25 could expect 8.9 and 8.6 more life-years, respectively, while adults at age 40 could expect 4.4 life-years during the same period. Across all ages, most life

expectancy gains occurred in the first half of the decade. Women gained more life-years than men.

Life expectancy gains began declining precipitously when subjects were in their late 20s. We suspected that considerable gains among children had resulted from enhanced HIV prevention and care efforts, including ART and PMTCT, for them and their parents (Johnson et al. 2013, 2020). However, South African adolescents have historically experienced high rates of new HIV infections, as well as the lowest rates of retention in care and viral suppression among all age groups (Mabaso et al. 2018; Haghighat et al. 2021). It takes about ten years (with no ART) or longer (with ART) before young people start dying from HIV/AIDS (Todd et al. 2007). Therefore declining gains in life expectancy at ages after 25 may be due to high infection rates combined with low rates of access to care during adolescence.

While ART expansion had been successful in reducing HIV mortality in South Africa, many more life-years could be saved if expansion had happened sooner and more quickly (Johnson et al. 2017). Most AIDS-related deaths occur in individuals who are not on medication (Johnson et al. 2017). Life expectancy of PLWHA on medication can approach nearly 80% of HIV-negative life expectancy (Johnson et al. 2013). In general, the earlier people start ART, the more likely their life expectancy would increase (May and Ingle 2011). Not only does high coverage of ART promote life expectancy in PLWHA, but it also helps reduce the risk of HIV infection (Tanser et al. 2013). For instance, the successful implementation of PMTCT had led to substantial declines in child mortality rates, likely because it provides ART access to pregnant and breastfeeding mothers, whose reduced viral loads would decrease the risk of transmission to infants (Johnson et al. 2020). (By contrast, this program did not lead to large gains in ART coverage among adolescents.)

This study had limitations. We could not demonstrate a causal relationship between the ART expansion and life expectancy trends. Our analysis was based on imperfect mortality data, as is the case for most countries (Bradshaw et al. 2016; Statistics South Africa 2020). Death registration among some age groups, including those from 5 to 14 years, is reported to be less complete than that for adults (Johnson et al. 2020). Further, deaths from HIV may have been misattributed to co-occurring conditions, such as tuberculosis and pneumonia (Bradshaw et al. 2016). This study used the Thembisa demographic model (Johnson and Dorrington 2019), but an inherent limitation of any model is the embedded assumptions and judgments, which may bias results. Since reductions in HIV mortality rates were likely due to a combination of HIV prevention and HIV treatment programs, this analysis could not delineate the exact contributions of each program.

The South African government announced a life expectancy goal of 70 years by 2030 (South African Government 2013). Although improvements in life expectancy

began to slow in 2014, the potential for further life expectancy gains might be found, for example, through expanding ART coverage to those still in need and by reducing contributing factors, such as poverty, infant and maternal mortality, and tuberculosis (Burton 2015; Bacaër et al. 2008). Additional resources could be invested in strengthening the quality of national vital statistics and demographic surveillance systems. South Africa's national ART scale-up is a noteworthy example of how a government's investment in public health could lead to dramatic improvements in life expectancy.

5. Acknowledgments

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