The incidence of acute rheumatic fever and rheumatic heart disease in Melbourne, Australia from 1937 to 2013

An original article

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Conflicts of interest

The authors have stated explicitly that there are no conflicts of interest in connection with this article. No funding was required for this study. The complete study design, analysis and interpretation was conducted independently from any funding body.

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Brief points

What is already known

- The burden of acute rheumatic fever (ARF) and rheumatic heart disease (RHD) declined in Europe and the United States during the twentieth century.

What this paper adds

- A sharp decline in ARF/RHD admissions to the Royal Children's Hospital Melbourne (RCH) occurred following a peak in 1946, and from 1993, more new hospitalisations at RCH were for patients with RHD than ARF.
- The decline of ARF/RHD in the second half of the 20th century in Melbourne, Victoria, Australia, is consistent with that observed in Europe and the United States.

ABSTRACT

Aim

Acute rheumatic fever (ARF) most commonly presents in children aged five to 14 years old. Lifelong rheumatic heart disease (RHD) can result. This study investigated time trends in ARF and RHD using inpatient data from the Royal Children's Hospital, Melbourne (RCH).

Methods

A retrospective cohort study covering the period 1937-2013 was conducted using records from RCH, a quaternary paediatric hospital in Melbourne, Victoria, Australia. Patient data were identified using RCH classification of diseases coding for ARF or RHD for years <1952. For the period 1952-1987, this system was used in addition to identifying International Classification of Disease (ICD) discharge codes that corresponded to ARF or RHD. From 1988-2013, only ICD codes were used to identify patient data. Descriptive epidemiological analyses were performed, including incidence rate calculations using historical census population denominator data. Analyses focussed on children in the peak age group.

Results

Among children aged five to 14 years, a total of 4,337 RCH admissions with ARF/RHD occurred for 3,015 patients. A sharp decline in first ARF/RHD hospitalisations at RCH occurred from 1959, following a peak mean annual incidence rate during 1944-1947 of 40.1/100,000 children (95%CI: 36.6-43.9; $p<0.05$). Over 1996-2013, the mean annual incidence rate was1.6/100,000 (95%CI: 1.3-1.8) and reached 2.3/100,000 (95%CI: 1.3-3.7) in 2005.

Conclusion

The burden of ARF and RHD treated at RCH declined following the 1940s, mirroring changes seen in North America and Europe. Despite this, inpatient treatment for these conditions continued to be provided right up until the end of the study period.

Keywords: Acute rheumatic fever; rheumatic heart disease; history; child health; epidemiology; Australia.

INTRODUCTION

Acute rheumatic fever (ARF) is a preventable immune-mediated condition triggered in response to group A *Streptococcus* (GAS) infection.(1) A strong causal association with GAS pharyngitis is well established. GAS skin infections may also be causative.(2-4) The incidence of ARF peaks in children aged five to 14 years.(1) Even one bout of ARF can cause irreversible damage to cardiac valves, termed rheumatic heart disease (RHD). Periodic intramuscular injections of benzathine penicillin G over at least 10-years are usually recommended to prevent cardiac damage once ARF has occurred.(5) RHD is a serious chronic health condition, responsible for over 300,000 deaths worldwide each year.(1)

Prior to the 1960s, the worldwide burden of ARF and RHD was high among many populations. Specialised hospital wards were established to care for very unwell paediatric patients in many high-income countries.(6, 7) The incidence of ARF declined dramatically in high-income countries from the 1960s, however an important burden of disease persists in low/middle-income countries and among certain (often indigenous-minority) groups. Indigenous Australians, and New Zealand Māori and Pacific Island peoples have the highest reported rates of ARF in the world.(1) Precise reasons why ARF rates declined so considerably in high-income settings over the previous century remain unclear. ARF has frequently been associated with features of socioeconomic deprivation.(7) Predisposing genetic risk markers have inconsistently been identified in some at-risk groups. ARF is nowadays considered a disease of social injustice.(8)

In Australia, ARF/RHD patient registers are widely used in control programmes. The first computerised patient register was established in the Northern Territory in 1997 with other registers subsequently implemented.(9) ARF is legally notifiable to public health authorities

in most Australian jurisdictions (which utilise register–based control programmes) with the exceptions of Victoria, Australian Capital Territory and Tasmania.(10) Currently around 6,000 patients with ARF/RHD are listed on jurisdictional patient registers, over 90% of whom are Indigenous Australians.(9) By contrast, just over 3% of the total Australian population identify as having Indigenous ethnicity.(11) Register data are incomplete, however, due to limited case finding ability and limited information sharing between registers.(9) ARF/RHD hospitalisation records are fragmented and affected by miscoding and misdiagnosis. Furthermore, hospital admission data is not routinely made available for analysis. Thus no effective national surveillance system for ARF/RHD exists. Consequently it is difficult to implement effective public health interventions to prevent and control ARF, or to evaluate the successes of such activities on a national level, or in states where registers do not operate.(12)

The disease burden in Victoria remains largely unknown. The most recent published estimates demonstrated an incidence of around 3 ARF/RHD hospital admissions per 100,000 people aged <65 years old during 2009-2010. A total of 200 deaths were attributed to RHD in Victoria between 2005-2007.(13) Given the availability of records through the Royal Children's Hospital, Melbourne, (RCH) and its status as the major quaternary paediatric hospital in Victoria, our aim was to investigate time trends in the occurrence of ARF and RHD from the 1930s on using inpatient data from RCH.

METHODS

Setting

Australia is a high-income country located in the south Pacific. Victoria is the most densely populated Australian state and the second most populous. At the time of the 2011 census, 5.35 million people lived in Victoria; almost one-quarter of the national population. At that time, 0.7% of the state population identified as having Indigenous Australian or Torres Strait Islander ethnicity.(14) Melbourne is the state capital.

The RCH was established in Melbourne, Victoria in 1870, and remains the major specialist paediatric hospital for the state. It contains 340 beds. Over 2012-2013, 36,058 admissions took place.(15) The Cardiac Surgery Unit was established there in 1976. This is the largest paediatric cardiac centre in Australia. It provides comprehensive cardiac surgical services for patients from Victoria, Tasmania, South Australia, Western Australia and the Northern Territory, in addition to accepting some overseas referrals.(16) Information about what proportion of Victorian paediatric ARF/RHD cases are treated at RCH is not publicly available, however RHDAustralia (a national agency developed to support efforts to control RHD) recommends that known Victorian paediatric patients are referred there.(17)

Data sources

Preliminary discussions with members of the Health Information Services team at RCH identified 1937 as the earliest year for which reliable discharge diagnostic codes were available. All admission records had been entered by hospital staff onto an electronic database. For the period 1937-1951, ARF/RHD admissions were identified using RCH internal classification of diseases coding (ARF: 100-104; RHD: 400-416). For the period 1987 to 2013 inclusive, ARF/RHD admissions were identified by International Classification

of Disease (ICD) discharge codes corresponding to ARF (ICD-9: 390-392; ICD-10: I00-I02) and RHD (ICD-9: 393-398; ICD-10: I05-I09). During the period 1952-1986, admissions were identified where relevant codes were found using either system (Supplementary Table 1).

Patient anonymity was protected using the RCH unique patient identifier number. Demographic data (i.e. age in years at discharge, gender), admission dates, and discharge dates were obtained where available. Other demographic data, such as birthdate, patient ethnicity (ie. Indigenous Australian; Yes/No), and residential postcode were inconsistently available for years prior to 1970 but were identified for 97% of patients admitted after 1969.

We defined 'first hospitalisation' as a patient's first admission to RCH with ARF/RHD. Patients could only have one first RCH hospitalisation, regardless of which condition they were admitted with. Subsequent admissions were distinguished using the unique patient identifier. An 'episode' of ARF was defined as lasting up to 90 days from the hospital admission date. Thus, repeat admissions occurring within 90 days of each other were classified as a single episode. The period of 90 days was selected in accordance with previous research.(18) As RHD does not occur in episodes, each hospitalisation with RHD was counted consecutively.

We classified ARF episodes as occurring with or without carditis. When identifying the disease type, if RHD diagnostic codes appeared, then the episode was classified as RHD. If no RHD diagnostic codes appeared, and an ARF with carditis diagnostic code appeared, then the event was classified as ARF with carditis. If no RHD codes, and no ARF with carditis codes appeared, then the episode was classified as ARF without carditis.

Statistical analysis

We performed simple descriptive analyses, in which first hospitalisations were distinguished, and annual numbers reported. Incidence rates were calculated using age group specific historical Victorian population estimates (based on census data), available for each year of the study. These population denominator data were publicly available online through the Australian Bureau of Statistics.(19) We plotted the annual incidence of first hospitalisations, initial ARF and recurrent ARF episodes, and initial and subsequent RHD hospitalisations, from 1937-2013. Other reported summary statistics included patient numbers and proportions according to patient gender; age group; disease type; and season of admission. The Chi-squared test was applied to investigate whether reported proportions were significantly different. The t-test was used to assess differences in incidence rates. Differences were considered statistically significant if $p<0.05$. ~~Analyses were generally~~Some analyses were restricted to the age group at highest risk of ARF; five to 14 year old children.(1)

Ethics approval

Ethics approval was provided by the RCH Ethics Committee (Application ID: 170346), a Human Research Ethics Committee certified by the National Health and Medical Research Council of Australia.

RESULTS

Total hospitalisations with ARF and RHD

A total of 4,955 ARF/RHD admissions to RCH were identified during 1937-2013, which corresponded to 3,484 patients. A total of 3,626 ARF episodes were identified, which corresponded to 2,868 patients (median episodes per patient: 1; interquartile range; IQR: 1-1; mean: 1.3; range: 1-6 ARF episodes). A total of 1,074 RHD hospitalisations occurred for 759 patients over the study period (median: 1; IQR: 1-2; mean: 1.6; range: 1-13 RHD hospitalisations). Most patients, 78.2%, were hospitalised with ARF only, 4.1% had hospitalisations with ARF and RHD, and 17.7% were hospitalised with RHD only.

Most first hospitalisations were for males, 53.3% (p<0.05), and 86.6% (N=3,015) were for children aged five to 14 years. The median age at first hospitalisation was 9 years (IQR: 6-11 years; when the first hospitalisation was ARF the median age was 9 years, IQR: 6-11 years; and when RHD was 9 years, IQR: 5-12 years). There was very little seasonal variation, ~~with~~ although there were slightly more first hospitalisations in ~~winter~~ autumn and fewest in spring (26.2~~1~~% versus 23.8%, p<0.05, with 26.1% of first hospitalisations in winter and 24.0% in summer). The majority of first hospitalisations were for ARF (81.5%); most of these (78.4%) occurred with carditis (Table 1).

The median age of children with a recurrent ARF hospitalisation was 10 years (IQR: 8-12 years) and for children with repeated hospitalisation for RHD, the median age was was 11 years (IQR: 9-13 years). Of the 674 patients hospitalised after 1969 for whom ethnicity and postcode data were available, 12.6% were Indigenous Australians and 11.9% had a postcode outside of Victoria.

ARF and RHD hospitalisations among children aged five to 14 years

A total of 3,015 children were first hospitalised with ARF/RHD at RCH when aged five to 14 years. The incidence of first hospitalisation was high between 1937 and 1959 (23.0 per 100,000, 95%CI: 22.0-24.1), with a distinct peak between 1944 and 1947 (40.1, 95%CI: 36.6-43.9). Between about 1960 and the mid-1980s incidence decreased more than 95% (1986-1995 incidence: ~~2.9~~0.3, 95%CI: ~~1.8~~0.2-0.4~~4.5~~), before increasing modestly after 1995 (1996-2013: 1.6, 95%CI: 1.3-1.8), with the highest burden during this period in 2005 (n=15 first hospitalisations in 2005, incidence 2.3 per 100,000 95%CI: 1.3-3.7, Figure 1).

After 1969, a total of 65 Indigenous Australian children aged five to 14 years had a first hospitalisation (93.8% with RHD and the remainder with ARF). All were hospitalised during 1994-2013. Fifty Indigenous Australian children were hospitalised during 2000-2013, accounting for 49% of all first ARF/RHD hospitalisations in this period. Postcode data was available for 632 children with first hospitalisations in the 5-14 year-old age group, and 103 (16.3%) had postcodes outside Victoria. Between 2000-2013, 73 of 149 (49.0%) first hospitalisations were children with postcodes outside Victoria. Sixty-two (95.4%) of the 65 Indigenous Australian children had postcodes outside Victoria, including 47 children first hospitalised during 2000-2013.

From 1937-1995 the majority (2,552 of the 2,833, 90.1%) first hospitalisations for children aged five to 14 years were with ARF. Conversely, from 1996-2013, the majority were for RHD (152 of 182,83.5%, first hospitalisations). The annual incidence of first hospitalisation with ARF remained less than 1.0 per 100,000 from 1980. Meanwhile, the incidence of first RHD hospitalisation remained remarkably steady over the whole study period, ranging

between 0.0-2.6 per 100,000 (excluding the first year of analysis – 1937; as it was impossible to tell which hospitalisations occurring that year were first or repeated; Figure 1).

The majority (78.4%) of the total 2,582 first hospitalisations for ARF in the peak age group involved carditis. From 1937-1959, 90.9% involved carditis - including 100% from 1944-1947. Between 1960 and the mid-1980s, the proportion with carditis had declined to 48.5%, was 25.0% between 1986-1995, then rose to 80.0% from 1996-2013. (Supplementary Figure 1).

The incidence of first hospitalisation among children aged five to nine years was generally very similar to the incidence for children aged 10 to 14 years throughout the study period; 7.3 per 100,000 children (95%CI: 6.9-7.6) and 6.7 (95%CI:6.3-7.0) respectively (Supplementary Figure 2).

Among children aged five to 14 years, the mean annual incidence of first ARF episode peaked during 1945-1947 at 42.3 per 100,000 (95%CI: 38.1-46.8). A total of 735 recurrent ARF episodes were treated at RCH. The majority, 93.9% (n=690) of recurrent episodes occurred during 1938-1961, and especially during 1946-1948 (36.4%; 268 recurrent episodes, mean annual incidence 34.0 per 100,000, 95%CI: 30.3-38.0). From 1952, this rate declined to remain <5.0 per 100,000, and <1.0 per 100,000 from 1960. The annual incidence of repeated RHD hospitalisations ranged between 0.0-2.8 per 100,000 children over the study period (Supplementary Figure 3).

DISCUSSION

Our study is a novel exploration of the changing incidence of ARF/RHD in Victoria over a 76 year period. A striking reduction in ARF/RHD was observed at RCH over the course of the latter half of the 20th century. The decline in the disease burden most clearly began following 1956. From 1993 onwards, the majority of new presentations to RCH were with RHD, rather than ARF, including >80% RHD in the last 14 years of the study period. From 2000-2013, around half the burden of ARF/RHD treated at RCH appears to have been referrals from outside Victoria. Despite this, local patients continued to present for treatment. Reasons why admissions for ARF declined but RHD admissions increased are not clear. The decline in ARF may result from improvements in socioeconomic conditions and better access to antibiotics to treat GAS infections, thus reducing the ARF risk for the general population.(7) RCH's status as a major cardiology and cardiac surgery provider likely meant that very unwell children from outside Victoria were referred for treatment, particularly after the new millennium. The persisting burden of ARF/RHD among Indigenous Australian children is important and inequitable.

A sharp peak in the annual incidence of first hospitalisation with ARF/RHD at RCH was observed following World War II. We showed an increase in mean annual incidence rates between 1944 and 1947, reaching 40.1 per 100,000 children in the peak age group, with a series of fluctuations and a gradual decline following 1956 towards unprecedented low rates during the 1980s and onwards. Considerable year-to-year variation affected this rate, most likely due to relatively low case numbers. While fluctuations in the period after the War may have been stochastic, the explanation for the sharp increase during the mid-late 1940s is unclear. One explanation concerns possible increases in household crowding following the Great Depression, perhaps increasing transmission of GAS infections.(1) Another possibility

is that new GAS strains may have been introduced into the population by returning servicemen, however no data are available to test this hypothesis. An analogous, but far more pronounced, phenomenon was hypothesised following the end of World War I, wherein returning soldiers transmitted H1N1 influenza to populations in their home countries, producing the 'Spanish flu' pandemic.(20) Lastly, there is the possibility that data collection techniques during this period were different to those used prior to 1942 and after 1950. We cannot be certain of the contribution of any of these hypotheses. The incidence of recurrent ARF episodes also peaked in the late 1940s and declined dramatically from the 1950s on – perhaps reflecting the effectiveness of secondary prophylaxis. While RHD is usually up to twice as common in females than males, gender disparities in ARF are less common. Australian register data indicates that 56% of ARF cases are female.(21) We observed slightly more male patients, however (Table 1). Similar findings have been noted in some overseas populations.(22)

The changes in incidence we detected over the study period largely mirror those observed for European and North American populations overseas.(6, 7) An increase in ARF during the 1940s was documented in Denmark, but by 1962 the incidence had fallen to 12 per 100,000 population.(23) In the United States, ARF was so common that there were long waiting lists for specialised hospitals in 1946, and from 1960 to 1964 the incidence of ARF was 26 per 100,000 children aged 5 to 19 years.(24) By the early 1980s, the incidence in the US had fallen further, although outbreaks of ARF were documented in isolated areas.(25)
A 200~~5~~8 review estimated low annual ARF incidences of less than 10 per 100,000 for North America and Western Europe.(1) In our setting, and in Europe and the United States, the general decline in incidence from the late 1940s to the 1980s broadly correlates with

improvements in standards of living, a declining average household size and increased availability of antibiotics to treat GAS infections.(7)

This study implies a persisting burden of ARF/RHD. While our highest estimated annual incidence rate during the last decade of the study period was nearly six-times lower than the reported 2013 national incidence (of 13 per 100,000 children aged five to 14 years-old(21)), all patients and their families require intensive, culturally-appropriate counselling, education and health promotion, and clinical management including administration of secondary antibiotic prophylaxis, usually with intramuscular benzathine penicillin every 21-28 days. These considerations, with regular clinical surveillance of patients, comprise best practice standards of care for reducing morbidity and mortality.(5) Until an effective vaccine against GAS becomes available, ARF/RHD prevention strategies and careful case management will remain the only approaches for reducing the burden of disease.

Recognition and management of ARF/RHD in a non-endemic setting such as Victoria is difficult and presently occurs without the public health resources allocated to endemic settings. Integrated case management might be strengthened by a requirement for public health notification of ARF and establishment of a statewide ARF/RHD control program. Contracting one of the established registers to provide a case management service in Victoria may also help improve patient outcomes.

There are a number of limitations to this study. First, we relied on data from a single paediatric hospital. Although RCH is likely to admit most patients with ARF/RHD in Victoria, patients may be treated elsewhere, and so we likely underestimated incidence rates. Second, this study was retrospective, data on admissions prior to 1937 was not uniformly

available, and the analyses relied on hospital discharge coding. This was further complicated by two systems of coding (RCH internal coding and ICD coding), use of which overlapped from the 1950s until the late-1980s. Further, ascertaining the burden of RHD using ICD-10 coding is problematic. RHD codes used by this system include valvular heart disease of unspecified origin,(12) which may have resulted in an overestimation of the RHD burden. Finally, there was a lack of detailed data to investigate ethnic or socioeconomic status, and no information on whether patients had travelled to Victoria for treatment. It is unlikely that no Indigenous children were treated prior to 1994. Possibly, attempts to obtain accurate Indigenous ethnicity data did not begin until 1994 and previously all children had simply been coded as 'Not Indigenous'. A detailed investigation of case presentations during recent years would be helpful for planning services currently needed in Victoria.

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REFERENCES

1. Carapetis JR, Steer AC, Mulholland EK, Weber M. The global burden of group A streptococcal diseases. *Lancet Infect Dis.* 2005;5(11):685-94.

2. Williamson DA, Smeesters PR, Steer AC, Morgan J, Davies M, Carter P, et al. Comparative M-protein analysis of Streptococcus pyogenes from pharyngitis and skin infections in New Zealand: Implications for vaccine development. *BMC Infect Dis.* 2016;16(1):561.

3. Parks T, Smeesters PR, Steer AC. Streptococcal skin infection and rheumatic heart disease. *Curr Opin Infect Dis*. 2012;25(2):145-53.

4. McDonald M, Currie BJ, Carapetis JR. Acute rheumatic fever: a chink in the chain that links the heart to the throat? *Lancet Infect Dis*. 2004;4(4):240-5.

5. RHDAustralia (ARF/RHD Writing Group), National Heart Foundation of Australia and the Cardiac Society of Australia and New Zealand. The Australian guideline for prevention, diagnosis and management of acute rheumatic fever and rheumatic heart disease (2nd edition). 2012.

6. Gordis L. The virtual disappearance of rheumatic fever in the United States: lessons in the rise and fall of disease. T. Duckett Jones Memorial Lecture. *Circulation*. 1985;72(6):1155-62.

7. Steer AC. Historical aspects of rheumatic fever. *J Paediatr Child Health*. 2015;51(1):21-7.

8. Steer AC, Carapetis JR. Acute rheumatic fever and rheumatic heart disease in indigenous populations. *Pediatr Clin North Am*. 2009;56(6):1401-19.

9. Australian Medical Association. AMA Report Card on Indigenous Health 2016. Canberra, Australia: AMA; 2016.

10. RHDAustralia. Rheumatic Heart Disease Control Programs 2018 [cited 2018; 29 Mar]. Available from: https://www.rhdaustralia.org.au/programs.

11. Biddle N, Markham F. The Conversation. Census 2016: what's changed for Indigenous Australians? 2016 [updated 2016; 28 Jun]. Available from: http://theconversation.com/census-2016-whats-changed-for-indigenous-australians-79836.

12. Katzenellenbogen JM, Nedkoff L, Cannon J, Kruger D, Pretty F, Carapetis JR, et al. Low positive predictive value of International Classification of Diseases, 10th Revision codes in relation to rheumatic heart disease: a challenge for global surveillance. *Intern Med J*. 2019;49(3):400-3.

13. Australian Institute of Health and Welfare. Rheumatic heart disease and acute rheumatic fever in Australia: 1996–2012. Canberra, Australia: AIHW; 2013.

14. Australian Bureau of Statistics. 3101.0 - Australian Demographic Statistics, Jun 2018 Canberra, Australia; 2019 [updated 2019; 20 Mar]. Available from: http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3101.0Jun%202018?OpenDocument.

15. Australian Insitiute of Health and Welfare. Royal Children's Hospital [Parkville]. Canberra, Australia; 2019. Available from: https://www.myhospitals.gov.au/hospital/210A01191/royal-childrens-hospital-parkville/emergency-department.

16. The Royal Children's Hospital Melbourne. The Cardiac Surgery Unit. Melbourne, Australia; 2018. Available from: https://www.rch.org.au/cardiac_surg/.

17. RHDAustralia. Victoria. Darwin, Australia; 2018. Available from: https://www.rhdaustralia.org.au/victoria.

18. de Dassel JL, de Klerk N, Carapetis JR, Ralph AP. How Many Doses Make a Difference? An Analysis of Secondary Prevention of Rheumatic Fever and Rheumatic Heart Disease. *J Am Heart Assoc*. 2018;7(24):e010223.

19. Australian Bureau of Statistics. 3105.0.65.001 - Australian Historical Population Statistics, 2014. Canberra, Australia; 2014 [updated 2014; 18 Sep]. Available from: http://www.abs.gov.au/AUSSTATS/abs@.nsf/DetailsPage/3105.0.65.0012014?OpenDocument.

20. Oxford JS, Lambkin R, Sefton A, Daniels R, Elliot A, Brown R, et al. A hypothesis: the conjunction of soldiers, gas, pigs, ducks, geese and horses in northern France during the Great War provided the conditions for the emergence of the "Spanish" influenza pandemic of 1918-1919. *Vaccine*. 2005;23(7):940-5.

21. Australian Institute of Health and Welfare. Acute Rheumatic Fever and Rheumatic Heart Disease in Australia. Canberra, Australia; 2019 [updated 2019; 14 Jun]. Available from: https://www.aihw.gov.au/reports/indigenous-australians/acute-rheumatic-fever-rheumatic-heart-disease/data.

22. Oliver J, Pierse N, Williamson DA, Baker MG. Estimating the likely true changes in rheumatic fever incidence using two data sources. *Epidemiol Infect*. 2017;146(2):265-75.

23. Vendsborg P, Hansen LF, Olesen KH. Decreasing incidence of a history of acute rheumatic fever in chronic rheumatic heart disease. *Cardiologia*. 1968;53(6):332-40.

24. Kaplan EL, Markowitz M. The fall and rise of rheumatic fever in the United States: a commentary. *Int J Cardiol.* 1988;21(1):3-10.

25. Hosier DM, Craenen JM, Teske DW, Wheller JJ. Resurgence of acute rheumatic fever. *Am J Dis Child*. 1987;141(7):730-3.