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Review Article

Heterogeneity of the COVID-19 epidemic: what can we learn from it?

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Abstract: Objectives: The goal of this article is to evaluate and explain the heterogeneity of the Coronavirus disease 2019 (COVID-19) epidemic in Australia, to offer advice for stopping the current outbreak and preparing for a suitable response to epidemics in the future. Methods: We conducted a review to analyze the epidemic and explain its variable manifestation across states in Australia. Most COVID-19 cases and deaths were in the states of Victoria and New South Wales due to differences in the governance of the epidemic and public health responses (quarantine and contact tracing) among states. Results: Countries could learn from Australia's overall successful response not only through good governance, effective community participation, adequate public health, adequate health system capacity and multisectoral actions but also from the heterogeneity of the epidemic among states. Conclusions: A successful response to epidemics in countries with a decentralized administration requires multilevel governance with alignment and harmonization of the response.

Keywords: SARS-CoV-2, COVID-19, governance, epidemic, health responses

Introduction

The pandemic of coronavirus infectious disease, caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), has spread rapidly around the world [1, 2]. Controlling the spread of the epidemic remains the focus of public health authorities worldwide [3, 4]. As of July 13, the global epidemiological situation is variable across regions: the Americas (165,258,879 cumulative cases and 2,769,531 deaths) and Europe (232,128,863 cumulative cases and 2,031,96 deaths) were most affected, followed by Southeast Asia (58,792,794 cumulative cases and 790,625 deaths), the Eastern Mediterranean (22,168,063 cumulative cases and 343,796 deaths), Africa (9,152,899 cumulative cases and 173,746 deaths), and the Western Pacific (65,491,304 cumulative deaths and 240,280 deaths). The Western Pacific region had the lowest burden of the epidemic. The epidemic was also variable across countries around the world.

Australia is one of the countries with a successful response to COVID-19, with 8,643,705 confirmed cases and 10,518 deaths as of July 13, 2022. COVID-19 cases and deaths per million population are less than those in many developed countries in Europe and America. This success was made possible by the good governance of the epidemic response, adequate public health systems, adequate health systems capacity, community engagement, community trust, and multicultural actions [5]. In addition, Australia's protection of its indigenous populations can be considered as one of the most successful models. Australia successfully protects its indigenous populations by implementing several interventions, including travel restrictions to remote areas, the establishment of COVID-19 clinics, rapid testing and an expansion of workforce capacity. As a result, indigenous Australians are six times less likely to contract COVID-19 than those in Canada or Brazil [6].

Nevertheless, the severity of the epidemic in Australia varies by state, with high and low numbers of cases and deaths per million population compared to the national average. We think that analyzing and explaining the hetero-

geneity of the epidemic in Australia is useful to better control future waves of COVID-19 and even (re)emerging epidemics in the future. Therefore, the purpose of this article is to analyze and explain the heterogeneity of the epidemic in Australia with the aim of providing recommendations toward ending the current epidemic and preparing for an adequate response to epidemics in the future. We hope that the lessons from Australia will also be valuable to other countries.

COVID-19 can cause lasting side effects [7, 8]. This review could help people understand Australia's overall successful response due to the abovementioned approaches and learn about the heterogeneity of the epidemic among states in Australia. Successful responses to epidemics require multilevel governance with the alignment and harmonization of the response. We hope our review will help people around the world in the corresponding response planning.

Methods

To conduct a qualitative study, we employed a qualitative method to explain the epidemics in the different states. Epidemiologic data were extracted from Australian government reports, and the data were analyzed by comparing the confirmed cases, deaths, and testing rates as well as the deaths, hospitalization rate, death rate, and the number of people tested per million population.

We conducted a scoping review to identify the factors that may explain the heterogeneity of the epidemic in Australia. We used the following response measures in our review and synthesis: governance, public health capacity, community engagement, health system, multiple sectoral actions, and vulnerability, which have helped Australia and the world in the corresponding response planning. We searched the literature for the period from January 2020 to July 2022. The main databases used for this report review were PubMed, Scholar, Embase and Medline. Grey literature was also included in our search, especially government reports. In the selected documents, we also conducted a manual search for citations. We excluded duplicates in the search data by using EndNote X 9.0 software.

The search string was based on the keywords "[weaknesses and strengths of coronavirus OR COVID-19 OR SARS-CoV-2 strategy]" [All Fields] AND '[Victoria OR New South Wales OR Queensland OR Australian Capital Territory OR Northern Territory OR South Australia OR Western Australia OR Tasmania]' [Title/Abstract].

Eligibility criteria

Inclusion criteria were defined as follows: (1) weaknesses and strengths of the response to COVID-19 in Victoria (VIC); (2) weaknesses and strengths of the response to COVID-19 in New South Wales (NSW); (3) weaknesses and strengths of the response to COVID-19 in Queensland (QLD); (4) weaknesses and strengths of the response to COVID-19 in the Australian Capital Territory (ACT); (5) weaknesses and strengths of the response to COVID-19 in the Northern Territory (NT); (6) weaknesses and strengths of the response to COVID-19 in South Australia (SA); (7) weaknesses and strengths of the response to COVID-19 in Western Australia (WA); and (8) weaknesses and strengths of the response to COVID-19 in Tasmania (TAS). The review includes all papers based on qualitative, quantitative, and mixed studies. The review was limited to papers published in English.

Article selection and data extraction

The relevance of the identified studies was evaluated with a two-stage screening process. The first stage was based on the title and abstract. Ten articles were excluded according to irrelevant titles and abstracts. For the second filter, we reviewed the full text such as the publication date, the nationality of the author, the title, the main content of the study, and the main findings. Studies in languages other than English or applied fields unrelated to COVID-19 were excluded. A total of 28 records were included. A summary of the papers' names, states, study types, and findings was recorded.

Results

The COVID-19 epidemiologic data for Australia and its states are displayed in **Table 1** below. As of July 13, 2022, 8,643,705 confirmed cases and 10,518 deaths were reported. Specifically, 174,861 cases in ACT, 179,661 cases

Table 1. COVID-19 cases in Australia

State	Total cases	Total deaths	Hospitalization rate	Case fatality rate	Total tests	Total tests per 100,000
ACT	174,861	84	0.00%	0.7%	1,291,777	199,433
NSW	179,661	3,785	0.04%	0.7%	33,152,654	342,720
NT	83,192	53	5.41%	0.00%	809,244	269,088
QLD	1,360,713	1,368	0.63%	0.3%	7,998,424	127,236
SA	641,312	599	2.4%	0.4%	5,207,910	205,409
TAS	208,813	105	0.001%	5.5%	723,950	98,170
VIC	2,234,742	4,131	1.65%	1.2%	21,587,698	285,554
WA	980,739	433	0.03%	0.8%	4,213,437	86,378
Australia	8,643,705	10,518	0.03%	1%	74,985,094	344,688

ACT: Australian Capital Territory; NSW: NSW New South Wales; NT: Northern Territory; QLD: Queensland; SA: South Australia; TAS: Tasmania; VIC: Victoria; WA: Western Australia.

in NSW, 83,192 cases in NT, 1,360,713 cases in QLD, 641,312 cases in SA, 208,813 cases in TAS, 2,234,742 cases in VIC, and 980,739 cases in WA were reported. Moreover, 84 deaths in ACT, 3,785 deaths in NSW, 53 deaths in NT, 1,368 deaths in QLD, 599 deaths in SA, 105 deaths in TAS, 4,131 deaths in VIC, and 433 deaths in WA were reported. Victoria was the most affected state: the number of cases and deaths per million population in Victoria are almost three times the national number. NSW was the second most affected state with half of the cases per million population and a quarter of the deaths per million population of the national average. The Northern Territory was the least affected area in the country.

Governance

The Australian federal system has three levels of government: the federal government as well as state and local governments for six states and two territories - the Australian Capital Territory and the Northern Territory. With regard to the responsibilities for the epidemic, the federal government manages quarantine and international border movement and intervenes through fiscal power for conditional appropriations, while states and territories take primary responsibilities for public health, hospitals, schools, and law and order. This epidemic requires the active participation of the federal and state government regions to respond. Therefore, close cooperation among governments is needed because the pandemic impacts exceed the scope of federal and state/territory responsibilities [9, 10].

However, the management of aged care facilities has emerged as a major weak point of cooperation between the two governments [11]. Aged-care institutions in Australia are privately owned and managed by the federal government only on the issues related to funds and regulation. State governments are responsible for public health, public order and hospital management. When a 'disaster event' such as COVID-19 occurs, the decision to transfer or treat residents in nursing homes and who should take responsibility are questioned [12]. In the second wave of the epidemic, more than 1,300 cases of COVID-19 occurred in Victoria's aged-care facilities and 655 elderly individuals died, accounting for 72% of total deaths [5].

Another governance issue arose in term of cooperation and taking responsibility for the passengers of the "Ruby Princess" cruise ship, who disembarked without adequate coronavirus testing or quarantine measures in Sydney, New South Wales. Specifically, 663 COVID-19 cases and 28 deaths were linked to passengers of the "Ruby Princess" [13], triggering a dispute between the federal government and the state governments [14]. Similarly, the Queensland government has been accused of insufficient governance in border restrictions [15]. In July 2020, the police allowed two women who tested positive to enter Queensland without verifying their false border declaration forms, which was criticized by the public [16]. Compared to the three states mentioned above, WA, SA, TAS, ACT, and NT have performed well in the COVID-19 epidemic by taking context-specific actions instead of the "one size

fits all" approach [17] and have succeeded in controlling the epidemic by enacting health legislation and safeguarding the rights of people with disabilities, thus preventing the second wave of the epidemic from getting out of control [18].

Public health response

The public health response is based on four elements: domestic and international border control, surveillance work and testing capabilities, contact tracing and quarantine. The overall testing rate in each state was high, with Victoria having a higher rate than other states at 51,363 tests per 100,000 persons [19]. However, the severe outbreaks in Victoria were linked with to the shortcomings in hotel quarantine, which eventually required more stringent lockdown measures to be taken by the state government [19], and the second wave of the epidemic was traced back to the staff of the two quarantine hotels. In addition, the genome sequencing briefing confirmed that many cases in northern Melbourne were related to confirmed cases in quarantine hotels [20, 21]. The resulting outbreak was responsible for 768 deaths and 18,418 cases [22], reflecting the inadequate contact tracing of 3763 cases of local transmission [23]. A parliamentary investigation found that the Victorian government was stubbornly reluctant to accept the new digital contact tracing system with a manual data entry process at the beginning, which is unsuitable for tracking contacts. A digital system was later introduced in the subsequent reform of the surveillance system, and a decentralized contact tracing center was established with more contact tracing personnel [24].

The second wave of deadly outbreaks in Victoria spread to New South Wales with the first case of community transmission occurring in a hotel in Sydney, and the State Department of Health actively carried out tracing work [25]. The virus spread at a low level in New South Wales, and surveillance work has been progressing well. Control measures and large-scale testing have been very successful in reducing the current number of infected cases, with a testing rate of 40,540 per 100,000 people [26]. Compared with Victoria and New South Wales, the testing rate in Queensland was lower with 25,306 tests per 100,000 [27]. However, fewer cases have been reported, and most can still be traced back to another confirmed case or high-risk activities, such as international travel. Electronic records were used to contact and track the potentially infected people through QR codes, electronic forms and online reservation systems. The government's strategy of active contact tracing and strict containment measures seemed to be working. The Queensland Department of Health has increased its testing capabilities by increasing manpower and working hours to manage the demand for respiratory clinics across the state, especially in the southeast of the state. Moreover, the COVID-19 wastewater surveillance programme was launched to monitor the infection trend in communities that supplied wastewater to the sewer system and overall public health actions [16]. The number of confirmed cases in other states was much lower than those in Victoria, New South Wales, and Queensland, with most of the cases infected overseas [17] and very few cases of community transmission. Nevertheless, all states still have adopted strict contact tracing and quarantine measures to control the epidemic. Digital apps such as the Check In App are also used to track attendees and provide information [18].

Community engagement

According to the COVID-19 prevention guidelines for the general population, people need to maintain a social distance of 1-1.5 m in public and wash hands regularly with hand sanitizer or soap [28-30]. Moreover, the mandatory order of wearing masks in public places reduced the risk of transmission from asymptomatic or mildly symptomatic people [31]. A survey shows that the compliance rate for wearing masks in Victoria is high with almost 99% of people wearing masks in public and 75% of residents wearing masks in public [32]. However, other social restrictions are not well observed in Victoria. From March 23 to August 26, the Victorian Police issued almost 20,000 fines for COVID-19 breaches [33], among which 1,669 fines were for not maintaining social distancing, 2,145 were for violations of the Melbourne curfew, 5761 were for "noncompliance with instructions" and 20 were for failure to self-isolate, which far exceeded the 1,440 fines that were issued in New South Wales [34]. In other states,

strict social distancing has been maintained, and states have made efforts to encourage residents to wash hands regularly. State governments have released a COVID Safe tracking mobile app and are encouraging all Australians to download it and associate it with relaxation of social distancing and shutdown measures [32].

Vulnerability

The first confirmed case in Australia was reported in Victoria on January 25, 2020, from a man who traveled internationally from Wuhan to Australia [35]. The first case of the second wave of the outbreak was also an international passenger in the quarantine hotel. Victoria has a large and busy airport for both domestic and overseas passengers. Compared to other states, Victoria has easier access to cases acquired overseas because the risk of contracting infectious diseases increases while traveling. As of January, 2020, a total of 1,044 cases had been acquired overseas [36]. Moreover, Victoria is a multicultural state with large immigrant communities (28.4% of the total population). Many of Melbourne's hot spots are in immigrant communities, including Darebin, Moreland, Brimbank, Hume, Cardinia and Casey, where the proportion of people speaking languages other than English are 40%, 41.2%, 62%, 46%, 13%, and 38.2%, respectively. During the second wave, the delivery of public health orders was not sufficient for culturally and linguistically diverse communities, with over 6,000 cases in these communities.

Studies have proven that the possibility of COVID-19 spreading among people increases with an increase in population density [37, 38]. The population densities of Victoria and New South Wales are higher than those of other states (26.11 persons per km^2 and 9.52 persons per km^2, respectively) [39]. Therefore, population density might have facilitated community transmission of the virus in Victoria and New South Wales more than other states [40]. The reported case fatality rates were highest in Victoria and Tasmania, with 4.00% and 5.56%, respectively, and the number of deaths per million population was highest in Victoria. These numbers may be due to the larger proportion of elderly individuals in the population in these states. The percentages of residents above 65 years are 13.2% and 14% in Victoria and Tasmania, respectively, whereas this proportion is approximately 12% in other states [41].

Compared to previous outbreaks of COVID-19 caused by the original strain or other variants, the outbreak of the Delta variant has had an additional impact. The greater transmission capacity of the Delta variant makes it more difficult to use public health measures to contain outbreaks and increases the risk of further outbreaks of COVID-19. Millions of Australians are under lockdown as the highly contagious Delta strain of the virus continues to spread. The lockdown areas include Western Australia, Queensland, New South Wales, and Victoria. To make matters worse, Australia had been slower than most other countries in immunizing its population, leaving some at-risk groups in urgent need of protection. As of June 6, 2020, only approximately 3 percent of the population had been fully vaccinated [42].

Health system

The capacity of the intensive care units (ICUs) is relatively balanced, approximately 2.8 ICUs beds per 100,000 people, ranging from 2 to 5 hospital beds per 100,000 population in each Australian state. Moreover, the medical and health workforce has increased in all states to manage the peak of the epidemic [43]. Victoria has expanded the capacity of its health system, including increasing the number of beds in ICUs to more than 7,000 and installing more than 1,000 ventilators. However, the health system in Victoria was under extreme pressure at the peak of the second wave, with more than 700 confirmed cases per day. Furthermore, the capacity of ICUs has doubled and more ventilators have been added in New South Wales and Queensland [44]. In other states, hospitals, aged-care facilities, and specialized COVID-19 clinics have recruited more doctors, nursing staff, and other health professionals to respond to the growing demands on the health system [45, 46].

Multisectoral actions

The multisectoral actions in each state are similar to a series of far-reaching economic initiatives in partnership with private sectors, which further revitalizes states' economies as they move beyond the threats of COVID-19.

Table 2. Summary of success and challenges in each state

Section	Successes	Challenges
	WA, SA TAS ACT, and NT have taken context-specific actions instead of "one size fits all" approach	Management of aged-care facilities has emerged as a major weakness of cooperation between the two governments; Insufficient governance in border restrictions of Queensland Government; "Ruby Princess" cruise ship disembarking without adequate coronavirus testing or quarantine measures in NSW
Public health response	Higher testing rate in VIC and NSW; good tracking work in NSW; electronic records and wastewater surveillance programme used in QLD, increased the testing capabilities in QLD; strict contact tracing and quarantine measures in other states	Shortcomings in hotel quarantine in VIC
Community engagement	High compliance rate for wearing masks in VIC	Low compliance rate for social restriction in VIC; low compliance rate in self-isolate in NSW
Vulnerability	/	More easily have overseas cases because of frequent international traveling; insufficient delivery of public health orders in immigrant community in VIC; higher percentage of elderly population in VIC and TAS; higher population density in VIC and NSW
Health system	Increased health system capabilities in each state	Under extreme pressure in VIC, NSW and QLD
Multisectoral actions	Far-reaching economic initiatives in each state	/

Each state has a plan for the next phase to ensure domestic employment while continuing to protect health [47]. For example, rent remission and land tax exemption have been adopted to reduce the burden on commercial tenants and landlords. Grants ranging from $3,000 to $10,000 were distributed to individuals and small businesses. In addition, the states have implemented the Jobkeeper and Jobseeker programs to guarantee the basic living expenses of businesses and people [48]. School closure is an important measure taken in many countries, and Australia closed its campuses and implemented online school and university teaching at the peak of the epidemic. From March 27, 2020, to April 22, 2020, more than 90% of schools worldwide suspended classes or adopted online teaching including schools in Australia [49].

Discussion

The COVID-19 epidemic is variable across different states in Australia, and the burden was highest in Victoria. Effective and timely measures that contribute to the control of the epidemic (governance, public health response, health system, community engagement, vulnerability, governance and public health actions) were less adequate in New South Wales and Victoria compared to other states, whereas health system capacity, community engagement and population vulnerability were similar across states (**Table 2**).

Inadequate governance was demonstrated in aged-care facilities. The COVID-19 outbreak in aged-care facilities has highlighted that the federal government and state governments lack appropriate actions to copy with cases in nursing homes, which has resulted in 655 deaths among elderly people [50]. In contrast, no deaths were reported in nursing homes in Hong Kong, Singapore, or South Korea, which have well-trained infection control doctors and adequate personal protective equipment [51]. Therefore, in addition to the improved governance of age-care facilities, regular and targeted training is needed for the nursing staff to incorporate infection prevention principles into daily practice in Australia. At the same time, the combination of strengthening infection control procedures and maintaining an adequate supply of personal protective equipment remains essential to prevent an epidemic [52].

New Zealand has a parliamentary system similar to that of Australia, although it does not suffer from the tension of federal and state policies at odds over some COVID-19 responses, such as internal border closures and the declaration of outbreak 'hot spots' [53]. New Zealand's unitary governance system (unlike Australia's multilevel governance) concentrates authority in the central government, which reduces conflicts among levels of government and facilitates greater coordination and cooperation [51]. China has provided a successful example in responding to the epidemic, demonstrating a strong cooperation between provincial governments and the central government in implementing measures such as strict blockades through community supervision [44].

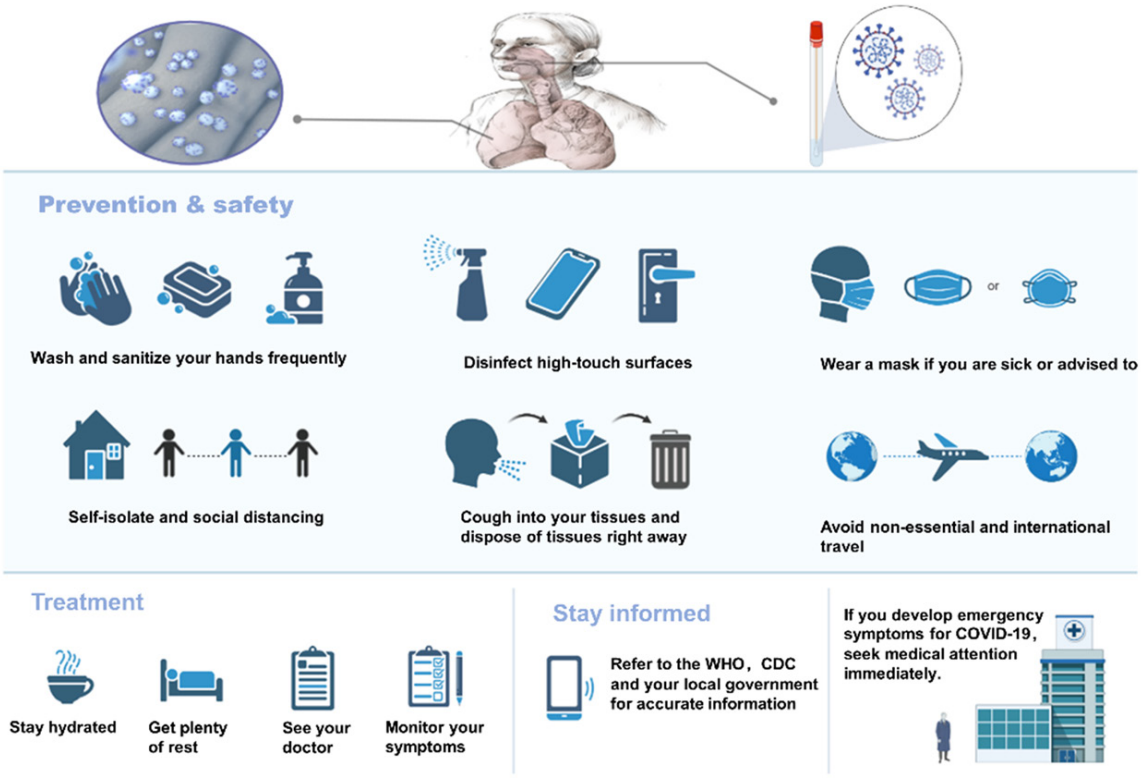

Figure 1. The preventive strategies of the COVID-19 pandemic are illustrated.

Quarantine and contact tracing are effective methods to cope with COVID-19 [54, 55], by which Japan, South Korea, and Singapore have effectively controlled the epidemic in districts where many tests, strict isolation measures and digital contact tracing technology have been applied [56]. Taiwan and Hong Kong's responses to the epidemic have been considered among the most successful models worldwide. They have achieved positive results in controlling the epidemic, mainly due to early recognition and a timely response, the isolation of suspicious cases, and adequate personal protective equipment [57]. Tailored health communication is vital for effective epidemic prevention and control [58]. Detailed and timely information about the expected behaviors, testing and contact tracing should be provided in a suitable format [59]. Importantly, heterogeneity exists at the epidemic level in Australia. Most reports have focused on Victoria, New South Wales and Queensland because these three states have had more confirmed cases and deaths than any other state.

Several recent articles have conducted qualitative and quantitative studies of COVID-19 models through state-of-the-art fractal fractional operators and other mathematical models. One study proposed that increased vaccination campaigns have meaningfully reduced the number of confirmed cases and deaths [60]. Similarly, two other studies used a fractional model to clarify that COVID-19 cases would be reduced rapidly if the community keeps social distancing well, practices regular cleaning of hands, and wears masks [61, 62]. Two articles adapted the SEIQR system and the SEIQ epidemic model to accurately explain the spread of COVID-19 [63, 64]. Furthermore, this group used nonlocal fractional operators to study the dynamics of SARS-CoV-2 to understand the transmission dynamics of SARS-CoV-2 in their study [65]. This study is subject to limitations: (1) All published reports and papers may not be included in the search scope of the database; (2) This study only collected data from literature published until July 2022, but the epidemic changes rapidly; (3) The quality of this study has not been assessed.

In summary, Australia can control its epidemic with comprehensive strategies built on good governance, adequate public health systems, adequate health systems capacity, community engagement, community trust, and multicultural actions (**Figure 1**). Despite the successful management of the epidemic in this country,

Victoria and New South Wales fared worse than other states because of differences in governance, quarantine, contact tracing, and health communication. Countries could learn from Australia to control their epidemics. The success of an epidemic response depends on governance at both the federal and state levels. Thus, understanding local epidemics in terms of populations at risk is equally important so that appropriate and proactive measures can be undertaken.

Disclosure of conflict of interest

None.

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