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Chikungunya virus-associated encephalitis: a cohort study on La Réunion island, 2005-2009

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Abstract

Objectives: To estimate the cumulative incidence rate (CIR) of Chikungunya virus (CHIKV)-associated Central Nervous System (CNS) disease during the La Réunion outbreak, and assess the disease burden and patient outcome after three years.

Methods: CHIKV-associated CNS disease was characterized retrospectively in a cohort of patients with positive CHIKV RT-PCR or anti-CHIKV IgM antibodies in the cerebrospinal fluid and fulfilling International Encephalitis Consortium criteria for encephalitis or encephalopathy. Neurological *sequelae* were assessed after three years.

Results: Between September 2005 and June 2006, 57 patients were diagnosed with CHIKV-associated CNS disease, including 24 with CHIKV-associated encephalitis, the latter corresponding to a CIR of 8.6 per 100,000 persons. Patients with encephalitis were observed at both extremes of age categories. CIR per 100,000 persons were 187 and 37 in patients below 1 year and over 65 years, respectively, both far superior to those of cumulated causes of encephalitis in the USA in these age categories. The case fatality rate of CHIKV-associated encephalitis was 16.6% and the proportion of children discharged with persistent disabilities estimated between 30% and 45%. Beyond the neonatal period, the clinical presentation and outcomes were less severe in infants than in adults.

Conclusions: In the context of a large outbreak, CHIKV is a significant cause of CNS disease. As with other etiologies, CHIKV-associated encephalitis case distribution by age follows a U-shaped parabolic curve.

Keywords: Chikungunya virus; case fatality rate; cohort studies; disease burden; encephalitis; encephalopathy; incidence studies; neurological sequelae; prognosis; viral infections.

Introduction

Chikungunya virus (CHIKV) is a re-emerging alphavirus.[1] Alphaviruses are divided into "arthritogenic" viruses (Old World) and "encephalitogenic" viruses (New World) including equine encephalitis viruses.[2]

Until its reemergence in the Indian Ocean in 2004 and the worldwide spread that followed, beyond the burden of arthritis, known for lasting weeks to years,[3] Chikungunya was considered as a non-fatal disease with spontaneous resolution, not causing lifelong disabilities, even though rare cases of central nervous system (CNS) disease had been reported.[4,5]

The major outbreaks that have occurred since 2005 in the Indian Ocean islands were attributable to a new "Indian Ocean lineage" (IOL) that evolved form the East Central South African (ECSA) lineage and selected the mutation E1-A226V, which favors transmission by *Aedes Albopictus*.[6,7] Recently, Asian lineage CHIKV emerged in the Caribbean and expended to the Americas, and recent clinical and experimental data indicate differences in the pathogenicity between both Asian and lineages .[8-10]

The 2005-2006 epidemic on La Réunion Island, affected 300,000 persons and enabled the observation of severe forms of the disease.[11] These included rare severe or fatal cases with CNS involvement, both in adults and neonates.[12-16]

Here, we report the results of an ambispective cohort study aimed at characterizing clinical and biological features of CHIKV-associated encephalitis, disease burden and three-year neurologic outcome of patients with this condition.

Methods

We conducted this study in the Groupe Hospitalier Sud Réunion, the largest hospital of the four general hospitals on the island, which covers a population of 277,602 inhabitants.[17]

Retrospective cohort study

We considered all patients hospitalized between the 1st of September 2005 and the 30th of June 2006 with CHIKV infection and neurological symptoms that led to perform a lumbar puncture (LP) eligible to the study. Patients with positive cerebrospinal fluid (CSF) for CHIKV RNA or anti-CHIKV IgM antibodies were further studied.

Anti-CHIKV IgM assay in the CSF was performed by ELISA using the ETIMAX 3000 ® (Diasorin, Italy). A one-step TaqMan real-time quantitative RT-PCR was performed from CSF samples using the Light Cycler 2.0 system® (Roche Diagnostics).

Ethical requirement

Each patient provided oral consent for the use of clinical, biological and imaging data, in accordance with the recommendations of the local Committee for Clinical Research.[13]

Case definition

We used positive CSF findings (CHIKV RNA or IgM) to provide the more specific case definition. Additionally, we used IEC (International Encephalitis Consortium) criteria to classify our patients according to an up-to-date definition of encephalitis.[18] These combine the major criterion "altered mental status" (defined as decreased or altered level of consciousness, lethargy or personality change lasting ≥ 24 hours with no alternative cause identified), with a set of minor criteria: (*i*) fever (≥ 38 °C) within the 72 hours before or after presentation, (*ii*) general or partial seizures not fully attributable to an epilepsy, (*iii*) new onset of focal neurologic signs, (*iv*) CSF white blood cells (WBC) count ≥ 5/mm^3, (*v*) brain parenchyma on neuroimaging suggestive of encephalitis either new from prior studies or appears acute in

onset, (*vi*) electroencephalography consistent with encephalitis and not attributable to another cause.

Exclusion criteria were the main causes of encephalopathy and of non-infectious encephalitis, listed as follows: positive HIV status, pyogenic meningitis, thrombophlebitis, brain abscess, empyema, cerebral malaria, acute disseminated encephalomyelitis, voltage-gate potassium channels, N-methyl-D-aspartate receptor antibodies, systemic vasculitis, multiple sclerosis, or paraneoplastic-related encephalitis, prion disease, encephalopathy of primary tumor, hematological, toxic or metabolic origin.[19]

Thus, we defined probable CHIKV-associated encephalitis in presence of the major criterion and at least three minor criteria, possible CHIKV-associated encephalitis in presence of the major criterion and two minor criteria,[18] and "non-encephalitic CHIKV-associated CNS disease" (NECACD) in the presence major criterion alone or with one minor criterion, or in the presence of two minor criteria other than fever.

Prospective follow-up study

We followed-up each patient with CHIKV CNS disease to search for neurological *sequelae* over a three-year period using the framework of the extended Glasgow Outcome Scale (adult and pediatric versions). [20] For children, trained psychometrists assured neuropsychological evaluation using the revised neurodevelopmental scale of Brunet-Lézine, a standardized psychometric test routinely used in francophone countries. For adults, neurologists performed clinical and electro-encephalogram (EEG) examinations. CT or MRI scans were performed on clinical indication.

Statistical analysis

We compared characteristics of CHIKV-associated encephalitis and non-encephalitic CHIKV associated CNS disease globally and between adults and children using chi-2 or Fisher exact test for proportions, as appropriate. Distributions were compared using Mann-Whitney or

Kruskal-Wallis tests. We tested correlations between CSF and serum viral loads in children, or between CSF and serum IgM levels in adults, were tested using Spearman's correlation coefficients.

We provided cumulative incidence rates (CIR) for CHIKV-associated encephalitis (probable, possible or both), overall and by age groups, applying weights for sub-population structure using data from the 2006 census. We then compared these estimates to US standards.[21]

We assessed the range of neurological *sequelae* in applying the same actual rate or null for the missing observations, this assumption being likely conservative, given the very low probability of lost-to-follow-up due to death or *sequelae* in the insular population of the study.

We used Stata (v10.0®, StataCorp. 2008, Texas, USA) for comparisons. Statistical significance was set at P=0.05.

Results

Retrospective cohort study

Characteristics of acutely infected CHIKV patients with neurological symptoms

Among the 129 CHIKV-infected patients with CNS disease, biological analysis of the CSF was positive for 55 CHIKV RNA or 30 anti-CHIKV IgM, in 78 patients and negative in 51 patients (Figure 1).

We excluded nine patients because they exhibited additional conditions, which invalidated CHIKV as a unique cause for the neurological symptoms. Briefly, these consisted in encephalopathy of primary metabolic origin (n=3), alcohol-related encephalopathy (n=3), posterior reversible encephalopathy syndrome in systemic lupus erythematosus (n=1), *Streptococcus pneumoniae* meningitis (n=1), and neurocysticercosis (n=1). The 69 remaining patients showed at least one IEC encephalitis criteria but 12 of them were excluded because incomplete charts did not allow definite classification. Thus, a total of 57 patients diagnosed with CHIKV-associated CNS disease were enrolled in the study. Among them, 24 (42.1%) patients with altered mental status matched IEC encephalitis definition, whereas 33 (57.9%) others did not and were designated as NECACD in further analysis.

We identified six confirmed cases of CHIKV-associated encephalitis (*i.e.*, altered mental status plus at least three minor criteria), while 18 patients were classified as possible cases (*i.e.*, two minor criteria). Both groups shared the same clinical and biological profiles, which confirmed the appropriateness of the IEC classification that allow these groups to be pooled for case registration (data not shown).

As expected, CHIKV encephalitic cases were more likely to exhibit severe CNS disease, than cases of NECACD, which consisted almost exclusively in mild to moderate behavioral changes (Table 1). Two indicators of CSF inflammation, WBC count and protein level, were higher in patients with encephalitis than encephalopathy, but viral loads or IgM titers in serum

or in CSF were not significantly different between these groups of patients (Table 2). Importantly, encephalitic cases required more intensive care support than NECACD cases (Table 3).

The cohort contained 21 adults (mean age, 63.9 years; SD, 15.6 years; range, 33-88 years) and 36 infants (mean age, 1.6 month; SD, 1.15 month; range, 4 days - 5.4 months).

Five infants were in the early neonatal period (< 7 days) and four in the late neonatal period (7 to 28 days), corresponding to cases of mother-to-child and post-natal mosquito-borne transmission, respectively.

Infants were more likely to experience a recent onset of fever prior to hospitalization, behavioral changes, skin rash, or survival and adults were more likely to experience decreased consciousness, coma, focal neurologic signs, seizures, or a fatal issue (Table e-1). Protein, glucose and chloride CSF levels were higher in adults than infants (Table e-2). CHIKV loads in the CSF or serum were higher in infants than adults, whereas it was the opposite for IgM. These results are in line with the fact that adults were observed later than infants in the course of the CHIKV-associated CNS disease. CHIKV loads in the CSF and serum for infants and between IgM levels in the CSF and serum from adults positively correlated (data not shown). In infants, CHIKV loads in serum negatively correlated with age, while in adults IgM levels in serum positively correlated with age (data not shown).

Except for one neonate exhibiting cerebral edema MRI features, no early (< 7 days) diffusion-weighted (DWI) MRI scan was available for CHIKV-associated encephalitic cases, although DWI is increasingly recognized as the most sensitive technique for timely diagnosis of acute brain parenchyma inflammation.[22] Subsequently, no radiological image evocative of acute stage of CHIKV-associated encephalitis was observed among the 22 other patients submitted to brain CT scans, late MRI scans, or both.

Cumulative incidence rates of CHIKV-associated encephalitis

The overall CIR estimate of CHIKV-associated encephalitis was 8.6 per 100,000 persons (95% CI: 6.9–10.4). Importantly, the age distribution pattern of CHIKV-associated CNS disease (Figure 2a) or CHIKV-associated encephalitis incidence (Figure 2b) exhibited an U-shaped parabolic pattern with a very clear trend to the highest incidence towards the youngest age than the oldest.

Prospective cohort study

Six adult patients died (mean, 67.5 years; SD, 15.7 years; range, 41-83 years) during hospitalization (case fatality rate [CFR]: 10.5%). Detailed cause-specific mortality was as follows: cardiac failure (n=2), septic shock (n=2), respiratory failure (n=1), sudden death (n=1). Death certificates mentioned Chikungunya as the primary cause for degradation in each case. As a consequence, 51 patients were eligible to the follow-up study.

Eight adults were discharged with neurological *sequelae* and are presented in Table e3. One deceased three months after discharge (case n°6). He was a 72-year old male individual free from past medical history presenting altered mental status, classified as NECACD. He deteriorated gradually towards dementia and deceased in a clinical picture of metabolic encephalopathy due to dehydration and hypernatremia. EEG revealed a global slowdown without spike. Sub-acute stage CT scans showed extensive demyelination and cerebral subcortical atrophy. Four adult survivors were lost in follow-up and the ten others were assessed clinically at three-year. Of these, we diagnosed three patients with neurological *sequelae* (epilepsy, post-infectious dementia, cognitive disorder, respectively) and four with an absence of detectable *sequelae*.

Nineteen infants were lost-to-follow up, and 17 evaluated at an average of 38 months of age. One developed severe cerebral palsy and blindness. He was a full-term normal-for-gestational age boy free of obstetrical history presenting with hemorrhagic fever on day 4 of life (case n°2, Table e3). Sub-acute and late stage MRI findings evidenced progressive

decrease of cerebral and cerebellar hemorrhages and replacement of brain edema features by subsequent demyelination of the white matter, whose evolution contrasted with monophasic or multiphasic patterns of acute disseminated encephalomyelitis (ADEM). Four infants exhibited poor neurodevelopmental performances (Brunet-Lézine development quotients [DQ] ≤ 85), irrespective of prenatal alcohol exposure, the other eight had age-related appropriate skills (mean DQ: 98, SD: 9, range: 86-120). Of these five children, two were infected vertically and three in the post-neonatal period (day 17, day 35 and day 73, respectively) (Table e3). The medical history of the lost-to-follow-up infants was uneventful, except for one who developed Langherhans histiocytosis.

Given the high attrition in the follow-up and the risk for information bias, the burden of neurological *sequelae* resulting from CHIKV-associated CNS disease could not be precisely calculated and was estimated to be in the range of 17.6% (9/51) to 43.1% (22/51). Nevertheless, lost-to-follow-up children corresponded to the milder forms of CNS disease so that our estimates are likely conservative owing to the fact that the incidence of *sequelae* often correlates with the intensity of the acute stage of infection in a previously healthy population. For CHIKV-associated encephalitis, the CFR was 16.6% (4/24) and the three-year burden of neurological *sequelae* in the range of 30% (6/20) to 45% (9/20). Importantly, we observed an age difference in 3-year outcome of CHIKV-associated encephalitis, poor prognosis (*i.e.*, death or *sequelae*) being predominant in adults (52.6% *vs* 18.2%, *P*=0.020).

Discussion

To our knowledge, this study reports unique findings on CHIKV-associated CNS disease (encephalitis and encephalopathy) using both CSF examination findings and IEC criteria for encephalitis. Importantly, our data reveal that during the 2005-2006 CHIKV outbreak in La Réunion island, the incidence of CHIKV-associated encephalitis contributed to a twofold increase of the regional overall incidence (14.6 *versus* 6.0 cases per 100,000 persons per year at baseline) of all encephalitis. Remarkably, this burden far exceeds the annual rate of encephalitis calculated for mainland France in 2000-2002 about encephalitis of infectious or specified etiology,[23] as well as the rate reported in the USA between 1998 and 2010 for all encephalitis.[21] Of note, the CIR of CHIKV-associated encephalitis in La Réunion island was also superior to those observed with West Nile virus (WNV) and other neuroinvasive arboviral infections in the USA between 1999 and 2007,[24] or to the global incidence observed with Japanese encephalitis.[25]

Though no similar study has been previously reported to our knowledge, our findings are consistent with earlier report of CNS conditions complicating CHIKV infection, ranging from mild neurocognitive or behavioral disorders to severe neurological syndromes including acute stage encephalopathy/encephalitis, post-infective ADEM (*e.g*, encephalomyeloradiculitis) and post-infective Guillain-Barré syndrome (*e.g*, polyradiculoneuritis).[14-17] They are also in agreement with earlier observational studies, even though the criteria used to define encephalitis differ from those we used.[5,26-28] CHIKV-associated CNS disease prognosis seems similar to that of other viral etiologies. It was associated in our setting with more pejorative figures than previously reported in India,[26,27] or even recently in Thailand.[28] This substantial toll is compatible with that of other virus-associated encephalitis.[29-31]

Interestingly, the age distribution of encephalitis incidence was U-shaped with two peaks observed in young infants and elder adults, consistent with the distribution of encephalitis in

general populations,[21,29,30] or with overall neuroinvasive disease of viral origin reported in the USA.[21] The CIR of CHIKV-associated encephalitis in these extreme age groups is 25-fold higher for children under 1 year and 6-fold higher for people over 65 years than those found for encephalitis of specified etiology in the USA.[21] This also contrasts the bimodal age distribution of Herpes Simplex virus encephalitis which peaks between 60 and 64 years,[32] that of WNV, which have a greater effect on the elderly,[24,33] or that of La Crosse virus, which targets rather the young children.[24,34] Higher susceptibility of children to CHIKV-associated encephalitis is also supported by the cerebral edema features observed in a neonate infected by mother-to-child transmission. Accordingly, young mice are more susceptible to CHIKV than adult mice.[35] CHIKV targets the choroid plexuses, meningeal and ependymal envelopes, but does not invade brain parenchyma of adult mice deficient for type-1 interferon and adult monkeys,[35,36] despite the presence of viral RNA or infectious virus in the CSF of animals during the acute phase of infection, whereas CHIKV infects neurons of neonatal/suckling mice.[37] A defective host response may contribute to the higher susceptibility of neonates to CHIKV, as suggested by studies showing that the neonatal immune response is quantitatively and qualitatively distinct from that of adults.[38] Thus, in contrast to New World alphaviruses that cause encephalitis in humans and in animal models as a consequence of viral invasion of the brain parenchyma,[39] CHIKV is not a neurotropic virus in experimentally infected adult animals, although it disseminates and replicates in the meningeal and ependymal envelopes.[35]

In contrast to what observed in adults, CSF and serum of infants contained CHIKV RNA, which is likely explained by their earlier presentation to hospital in our cohort. Moreover, the higher the CHIKV load was in the serum, the higher it was in the CSF, and we made the same observation in the adult with CHIKV-specific IgM (CSF/serum ratios smaller than one). Therefore a passive diffusion of viral RNA or IgM from the serum to the CSF, either by

traumatic LP or as a result of a leakage in the blood-brain barrier, rather than CHIKV replication or IgM production in the CNS, cannot be excluded.

Importantly, although infants appear more susceptible to CHIKV-associated encephalitis, the clinical presentation and three-year outcome of CHIKV-associated encephalitis were more severe in adults than in infants, except for one neonate. As also observed in the CHIMERE cohort study,[40] they consisted exclusively in behavioral changes and neurocognitive impairment in infants, while they affected cortical functioning and led to disabling *sequelae* in adults. These data are in line with French national data and WNV encephalitis in the USA showing milder presentation and better outcomes in children.[20,31,33]

Our study has some limitations. First, we have not searched for CHIKV RNA and IgM systematically in patients presenting neurologic manifestations. Second, LP was not repeated in the absence of clinical deterioration. We may therefore have missed pathological changes in CSF protein level or WBC count, notably in neonates who are prone to pro-hemorrhagic conditions.[14] Third, we have not performed neuroradiologic examination routinely, so that patients with mild neurologic forms were probably underestimated, while in turn, cases of major CNS disease could be unstable to undergo timely MRI scans. Thus, as our study was not population-based, we may have underestimated the real burden and slightly overestimated the CFR and incidence of neurological *sequelae*. Fourth, the data collection was partially retrospective and we may have missed some minor symptoms, such as tremors or other movement disorders indicative of thalamic or basal ganglia involvement.[22] Thereby, we focused on the symptoms whose presence was constantly notified, so that our description of CHIKV-associated CNS disease is likely conservative and limit information bias. Fifth, our study was restricted to a fairly localized area so that we cannot rule out the extent of CHIKV-associated CNS disease in recent years may reflect a stronger neurovirulence of the ECSA sub-lineage. Encephalitis has not yet been described everywhere the ECSA genotype has

circulated. The occurrence of encephalitis may depend of the magnitude of the outbreak, by targeting susceptible hosts to CHIKV-associated CNS disease. The study of host and CHIKV genetic factors underlying CHIKV-associated CNS disease may help better understand the pathogenesis of CHIKV-associated CNS disease. In this regard, we have much to learn from current outbreaks throughout the world due to African and Asian lineages viruses.

We report here that CHIKV-associated CNS disease, including encephalitis as defined by the IEC, may complicate CHIKV infection. Altogether these data contribute to improve the knowledge of CHIKV-associated neuropathology and illustrates the clinical neurotropism of CHIKV and its deleterious consequences, especially in neonates.

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Footnote section

List of abbreviations. ADEM: acute disseminated encephalomyelitis; CHIKV: Chikungunya virus; CFR: case fatality rate; CIR: cumulative incidence rate; CNS: central nervous system; CSF: cerebrospinal fluid; CT: computed tomography; DQ: development quotient; DWI: Diffusion-weighted imaging; EEG: electroencephalogram; ECSA: East Central South African; HIV: human immunodepression virus; IEC: international encephalitis consortium; IgM: immunoglobulin M; LP: lumbar puncture; MRI: magnetic resonance imaging; NECACD: non-encephalitic CHIKV-associated CNS disease; RNA: ribonucleic acid; RT-PCR: reverse transcriptase polymerase chain reaction; SD: standard deviation; WBC: white blood cell; WNV: West Nile virus.

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References

1. Staples JE, Breiman RF, Powers AM. Chikungunya fever: an epidemiological review of re-emerging infectious disease. Clin Infect Dis 2009; 49: 942-948.
2. Weaver SC, Winegar R, Manger ID, Forrester NL. Alphaviruses: population genetics and determinants of emergence. Antiviral Res 2012; 94: 242-257.
3. Brighton SW, Prozesky OW, de La Harpe AL. Chikungunya virus infection. A retrospective study of 107 cases. S Afr Med J 1983; 63: 313-5.
4. Chastel C. [Human infections in Cambodia by the Chikungunya virus or a closely-related agent. Serology]. Bull Soc Path Exot 1963; 56: 892–915.
5. Carey DE, Myers RM, DeRanitz, CM, Jadhav M, Reuben R. The 1964 Chikungunya epidemic at Vellore, South India, including observations on concurrent dengue. Trans R Soc Trop Med Hyg 1969; 63: 434–445.
6. Schuffenecker I, Iteman I, Michault A, et al. Genome microevolution of Chikungunya viruses causing the Indian Ocean outbreak. PLoS Med 2006; 3: e263.
7. Tsetsarkin KA, Vanlandingham DL, Mc Gee CE, Higgs S. A single mutation in chikungunya virus affects vector specificity and epidemic potential. PLoS Pathog 2007; 3: e201.
8. Leparc-Goffart I, Nougairede A, Cassadou S, Prat C, de Lamballerie X. Chikungunya in the Americas. Lancet 2014; 383: 514.
9. Miner JJ, Aw-Yeang YH, Fox JM et al. Chikungunya viral arthritis in the United States: a mimic of seronegative rheumatoïd arthritis. Arthritis Rheumatol 2015; 67: 1214-1220.
10. Teo TH, Her Z, Tan JJ, et al. Carribbean and La Réunion Chikungunya virus isolates differ in the capacity to induce pro-inflammatory Th1 and NK cell responses and acute joint pathology. J Virol. 2015; 89: 7955-69.
11. Gérardin P, Guernier V, Perrau J, et al. Estimating Chikungunya prevalence in La Réunion Island outbreak by serosurveys: two methods for two critical times of the epidemic. BMC Infect Dis 2008; 8: 99.
12. Lemant J, Boisson V, Winer A, et al. Serious acute chikungunya virus infection requiring intensive care during the Réunion Island outbreak in 2005-2006. Crit Care Med 2008; 36: 2536-2541.
13. Gérardin P, Barau G, Michault A, et al. Multidisciplinary prospective study of mother-to-child chikungunya virus infections on the island of La Réunion. PLoS Med 2008; 5: e60.
14. Tournebize P, Charlin C, Lagrange M. [Neurological manifestations in Chikungunya: about 23 cases collected in Réunion Island]. Rev Neurol (Paris) 2009; 165: 48-51.
15. Ganesan K, Diwan A, Shankar SK, et al. Chikungunya encephalomyeloradiculitis: report of 2 cases with neuro-imaging and 1case with autopsy findings. AJNR Am J Neuroradiol 2008; 29: 1636-1637
16. Lebrun G, Khadda K, Reboux AH, Martinet O, Gaüzère BA. Guillain-Barré syndrome after chikungunya infection. Emerg Infect Dis 2009; 15: 495-496.
17. Gérardin P, Fianu A, Malvy D, et al. Perceived morbidity and community burden after a chikungunya outbreak: the TELECHIK survey, a population-based-cohort study. BMC Med 2011; 9: 5.
18. Venkatesan A, Tunkel AR, Bloch KC, et al. Case definitions, diagnostic algorithms, and priorities in encephalitis: consensus statement of the International Encephalitis Consortium. Clin Infect Dis 2013; 57: 1114-1128.
19. Mailles A Stahl JP. Infectious encephalitis in france in 2007: a national prospective study. Clin Infect Dis 2009; 49: 1838-1847.
20. Beers SR, Wisniewski SR, Garcia-Fillion P, et al. Validity of a pediatric version of the Glasgow Outcome Scale-Extended. J Neurotrauma 2012; 29: 1126-1139.
21. Vora NM, Holman RC, Mehal JM, Steiner CA, Blanton J, Sejvar J. Burden of encephalitis-associated hospitalizations in the United States, 1998-2010. Neurology 2014; 82: 443–451.

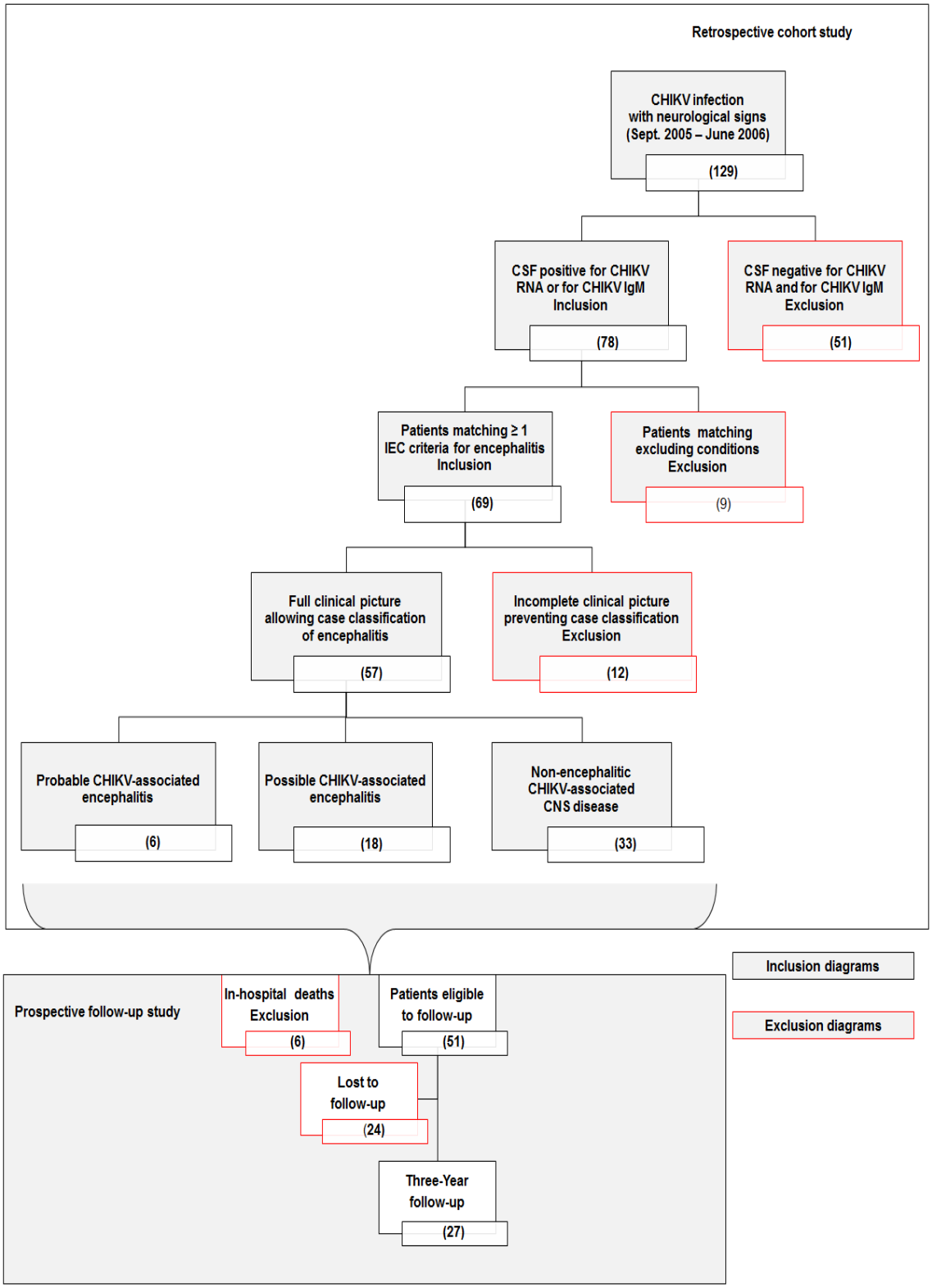
22. Solomon T, Michael BD, Smith PE, et al. Management of suspected viral encephalitis in adults - Association of British Neurologists and British Infection Association National guidelines. J Infect 2012; 64: 347-363.
23. Mailles A, Vaillant V, Stahl JP. Encéphalites infectieuses : données et limites du PMSI pour l'étude épidémiologique, France métropolitaine 2000-2002. Med Mal Infect 2007; 37: 95-102.
24. Reimann CA, Hayes EB, DiGuiseppi C, et al. Epidemiology of neuroinvasive arboviral disease in the United States, 1999-2007. Am J Trop Med Hyg 2008; 76: 974-979.
25. Campbell GL, Hills SL, Fischer M, et al. Estimated global incidence of Japanese encephalitis: a systematic review. Bull World Health Organ 2011; 89: 766-774.
26. Rampal, Sharda M, Meena H. Neurological complications in Chikungunya fever. J Assoc Physicians India 2007; 55: 765-769.
27. Lewthwaite P, Vasanthapuram R, Osborne JC, et al. Chikungunya virus and central nervous system infections in children, India. Emerg Infect Dis 2009; 15: 329–331.
28. Chusri S, Siripaitoon P, Hirunpat S, Silpapojakul K. Short report: cases reports of Neurochikungunya in southern Thailand. Am J Trop Med Hyg 2011; 85: 386-389
29. Glaser CA, Honarmand S, Anderson LJ, et al. Beyond viruses: clinical profiles and etiologies associated with encephalitis. Clin Infect Dis 2006; 43: 1565–1577.
30. Granerod J, Ambrose HE, Davies NWS, Clewley JP, Walsh AL, Morgan D. Causes of encephalitis and differences in their clinical presentations in England: a multicentre, population-based prospective study. Lancet Infect Dis 2010; 10: 835-844.
31. Mailles A, De Broucker T, Costanzo P, et al. Long-term outcome of patients presenting with acute infectious encephalitis of various causes in France. Clin Infect Dis 2012; 54: 1455–1464
32. Steiner I, Kennedy PGE, Pachner AR. The neurotropic herpes viruses: herpes simplex and varicella-zoster. Lancet Neurol 2007; 6: 1015–1028.
33. Sejvar J. The long-term outcomes of human West Nile virus infection. Clin Infect Dis 2007; 44: 1617–1624.
34. Gaensbauer JT, Lindsey NP, Messacar K, Staples JE, Fischer M. Neuroinvasive arboviral disease in the United States: 2003 to 2012. Pediatrics 2014; 134: e642-650.
35. Couderc T, Chrétien F, Schilte C, et al. A mouse model for Chikungunya: young age and inefficient type-I interferon signaling are risk factors for severe disease. PLoS Pathog 2008; 4: e29.
36. Labadie K, Larcher T, Joubert C, et al. Chikungunya disease in nonhuman primates involves long-term viral persistence in macrophages. J Clin Invest 2010; 3: 894-906.
37. Fraisier C, Koraka P, Belghazi M, et al. Kinetic analysis of mouse brain proteome alterations following chikungunya virus infection before and after appearance of clinical symptoms. PLoS One 2014; 9: e91397.
38. Adkins B, Marshall-Clarke S, Leclerc C. Neonatal adaptive immunity comes of age. Nat Rev Immunol. 2004; 4: 553–564.
39. Zacks MA, Paessler S. Encephalitic alphaviruses. Vet Microbiol 2010; 140: 281-286.
40. Gérardin P, Sampériz S, Ramful D, et al. Neurocognitive outcome of children exposed to perinatal mother-to-child chikungunya virus infection: The CHIMERE cohort study on Réunion island. PLoS Neglect Trop Dis 2014; 8: e2996.

Figure legends

Figure 1. Study population of CHIKV-associated CNS disease, Réunion island, 2005-2006.

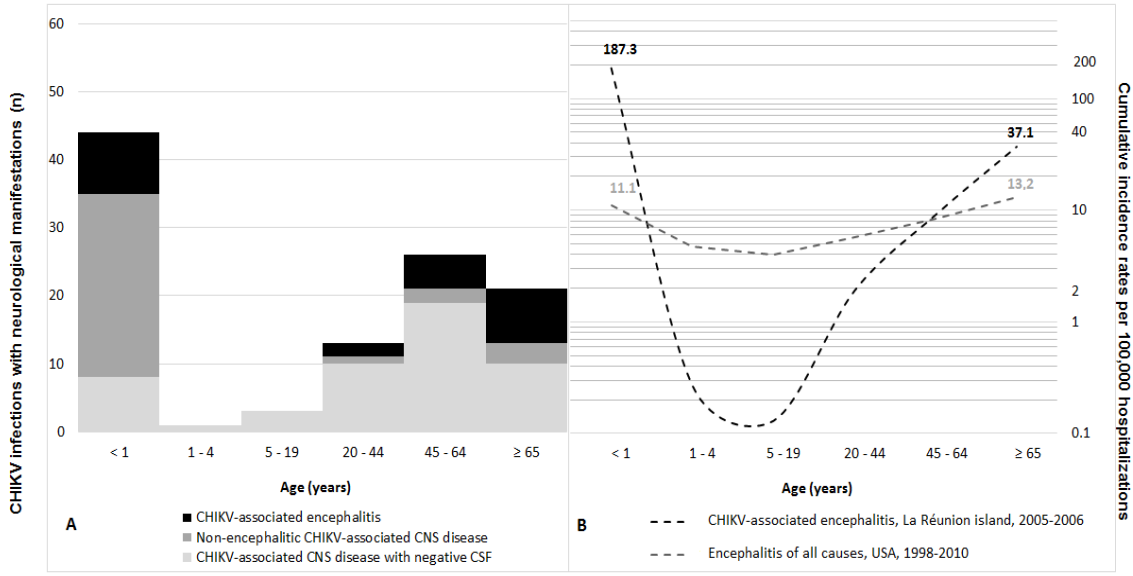
Figure 2. CHIKV-associated CNS disease and encephalitis by age categories, Réunion island, 2005-2006.

Figure 1



The flow chart classifies the cases reports of CHIKV-associated CNS disease at inclusion and at follow-up.

Figure 2



Data are the total case reports of CHIKV-associated encephalitis, non-encephalitic CHIKV CNS disease and CHIKV-associated CNS disease with negative CSF by age categories (Figure 2a) or the age-stratified cumulative incidence rates of CHIKV-associated encephalitis in La Réunion or the age-stratified cumulative incidence rates of all encephalitis in the USA (Figure 2b)

Table 1. Clinical features of CHIKV-associated CNS disease in La Réunion island, 2005-2006

Variables	Encephalitis[♯] N = 24		NECACD[♯♯] N = 33		
	n	(%)	n	(%)	*P* value
Age group (years)					0.003 [¶]
< 1	9	37.5	27	81.8	
1 – 19	0	0	0	0	
20 – 44	2	8.3	1	3.0	
45 – 64	4	16.7	1	3.0	
≥ 65	9	37.5	4	12.1	
Female sex	11	45.8	16	48.5	0.843
History of fever (≥ 38°C)	24	100	33	100	1
Onset of fever ≤ 7 days	12	60.0	18	85.7	0.063
Altered mental status *	24	100	33	100	1
Decreased consciousness [†]	8	33.3	2	6.1	0.012
Coma [‡]	4	16.7	1	3.0	0.151
General or partial seizures	3	12.5	1	3.0	0.300
Focal neurologic signs	5	20.8	0	0	0.010
Other behavioral changes **	15	62.5	32	97.0	0.001
Skin rash	8	33.3	17	51.5	0.190
Intensive care support	10	41.7	3	9.1	0.009
Length of stay > 4 days	14	58.3	13	39.4	0.187
Deaths	4	16.7	3	9.1	0.439

[♯]Probable or possible. [♯♯] Non-encephalitic CHIKV-associated CNS disease. Unless stated, the data were available for 24 encephalitic cases and 33 cases of NECACD. The onset of fever was available for 20 encephalitic cases and 21 cases of NECACD. [†] Glasgow coma score (GCS) < 15. [‡] GCS ≤ 9. * decreased or altered level of consciousness, lethargy, or personality change (disorientation, agitation). ** attention disorders, memory troubles, excessive pain feeling (irritability). [¶] Fisher's exact overall *P* value testing the five age categories.

1

1

Table 2. Biological parameters of CHIKV-associated CNS disease in La Réunion island, 2005-2006.

Variables	Encephalitis[#] N= 24		NECACD[##] N = 33		
	n	**%**	**n**	**%**	***P* value**
CSF white blood cells ≥ 5 / mm^3	17	70.8	4	12.1	< 0.001
CSF proteins ≥ 40 mg / dl	21	91.3	16	50.0	0.001
	mean	**SD**	**mean**	**SD**	***P* value**
CSF white blood cells (/mm^3)	12.8	21.9	1.7	2.7	< 0.001
CSF proteins (mg/dl)	75.3	39.4	47.2	23.7	< 0.001
CSF glucose (mmol/l)	4.2	1.3	3.7	1.0	0.086
CSF chloride (mmol/l)	123.3	4.3	121.1	5.8	0.039
CSF CHIKV load (cp/ml)	578,815	1,787,072	221,914	796,673	0.126
Serum CHIKV load (cp/ml)	1.2×10^8	2.2×10^8	9.0×10^7	1.7×10^8	0.330
CSF anti-CHIKV IgM (ui/l)	101.0	83.0	143.7	168.7	0.885
Serum anti-CHIKV IgM (ui/l)	139.3	115.6	57.3	92.9	0.219
CSF/serum CHIKV loads ratio [†]	0.63	0.14	0.55	0.20	0.055
CSF/serum IgM levels ratio [‡]	0.41	0.33	0.96	0.57	0.069

[#]Probable or possible. [##] Non-encephalitic CHIKV-associated CNS disease. CSF: cerebrospinal fluid. CSF proteins were available for 23 encephalitic cases and 32 cases of NECACD. CHIKV loads were measured in the CSF available for 52 patients (36 infants and 16 adults). CSF of all infants, of whom 9 are encephalitic, and CSF of 4 encephalitis adults are positive. Among the 12 adults with CSF negative, 9 are encephalitic. CHIKV loads were measured in the serum available for 37 patients (32 infants and 5 adults). Among infants, 31 are positive and 9 of them are encephalitic, while the 5 adults are negative. CHIKV IgM are found in the CSF of 21 patients on 52 (2 weakly positive infants with NECACD and 19 highly positive adults, of whom 10 encephalitis) and in serum of 32 patients on 37 (13 weakly positive infants of whom 6 encephalitis; 19 highly positive adults, of whom 10 encephalitis). [†] Data are complete for 9 infants with encephalitis, 22 infants with NECACD. [‡] Data are complete for 12 adults with encephalitis, 4 adults with NECACD.

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Table 3. Outcomes of CHIKV-associated CNS disease in La Réunion island, 2005-2009

Variables	Encephalitis[♯] N = 24		NECACD[♯♯] N = 33		
	N	**(%)**	**n**	**(%)**	***P* value**
Intensive care support	10	41.7	3	9.1	0.009
Length of stay > 4 days	14	58.3	13	39.4	0.187
Extended Glasgow Outcome Scale					0.946 [¶]
1. Dead	3	18.7	4	21.0	
2. Vegetative State	0	0	0	0	
3. Lower Severe Disability (Lower SD)	1	6.3	2	10.5	
4. Upper Severe Disability (Upper SD)	0	0	2	10.5	
5. Lower Moderate Disability (Lower MD)	1	6.3	1	5.3	
6. Upper Moderate Disability (Upper MD)	3	18.7	2	10.5	
7. Lower Good Recovery (Lower GR)	1	6.3	1	5.3	
8. Upper Good Recovery (Upper GR)	7	43.8	7	36.8	
Not assessed.	8		14		

[♯]Probable or possible. [♯♯] Non-encephalitic CHIKV-associated CNS disease. Unless stated, the data were available for 24 encephalitic cases and 33 NECACD cases. The Extended Glasgow Outcome Scale (GOSE) was assessed at discharge for non-survivors and at three years post infection for the survivors. We used both adult and pediatric versions of the GOSE. Percentages are calculated on a total of 35 patients. [¶] Fisher's exact overall *P* value testing seven of the eight outcome categories.