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Meningococcal meningitis and carriage in western Zaire: A hypoendemic zone related to climate?

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SUMMARY

An analysis of bacteria recovered from cerebrospinal fluid over a 16-year period at a rural hospital in western Zaire showed that *Neisseria meningitidis* accounted for only five (2·2%) isolates. A survey of naso-pharyngeal colonisation with *N. meningitidis* in 378 healthy children was undertaken to distinguish whether this low frequency was due to lack of carriage or, by inference, lack of the co-factors necessary to permit invasive disease. *N. meningitidis* was recovered from only three (0·78%) of the children. All isolates were non-typable strains of low pathogenicity.

A review of studies examining the aetiology of bacterial meningitis and the geographical location of epidemics of meningococcal meningitis in and around Zaire reveals a 'hypoendemic zone', the limits of which correlate well with the area in which mean absolute humidity remains above 10 g m^{-3} of air throughout the year. Continuous high absolute humidity appears to reduce the transmission of meningococci.

INTRODUCTION

Marked seasonal variation is a well-recognized feature of meningococcal meningitis. While this is most clearly observed in the 'meningitis belt' (Fig. 1) of sub-Saharan Africa it is also apparent in temperate climates [1, 2]. Changes in incidence are closely associated with climatic factors: in the meningitis belt epidemics usually start in the middle of the dry season when it is hot and dusty and terminate soon after the onset of the rains [3]. In countries such as Togo or Nigeria which straddle the edge of the belt meningococcal meningitis remains infrequent in the southern coastal areas even when a major epidemic is taking place in the north [4, 5].

In 1952 Waddy [6] proposed that absolute humidity, rather than rainfall or temperature, was the critical climatic variable: he observed that epidemics in the meningitis belt of Northern Ghana usually begin to decline 4 weeks after absolute

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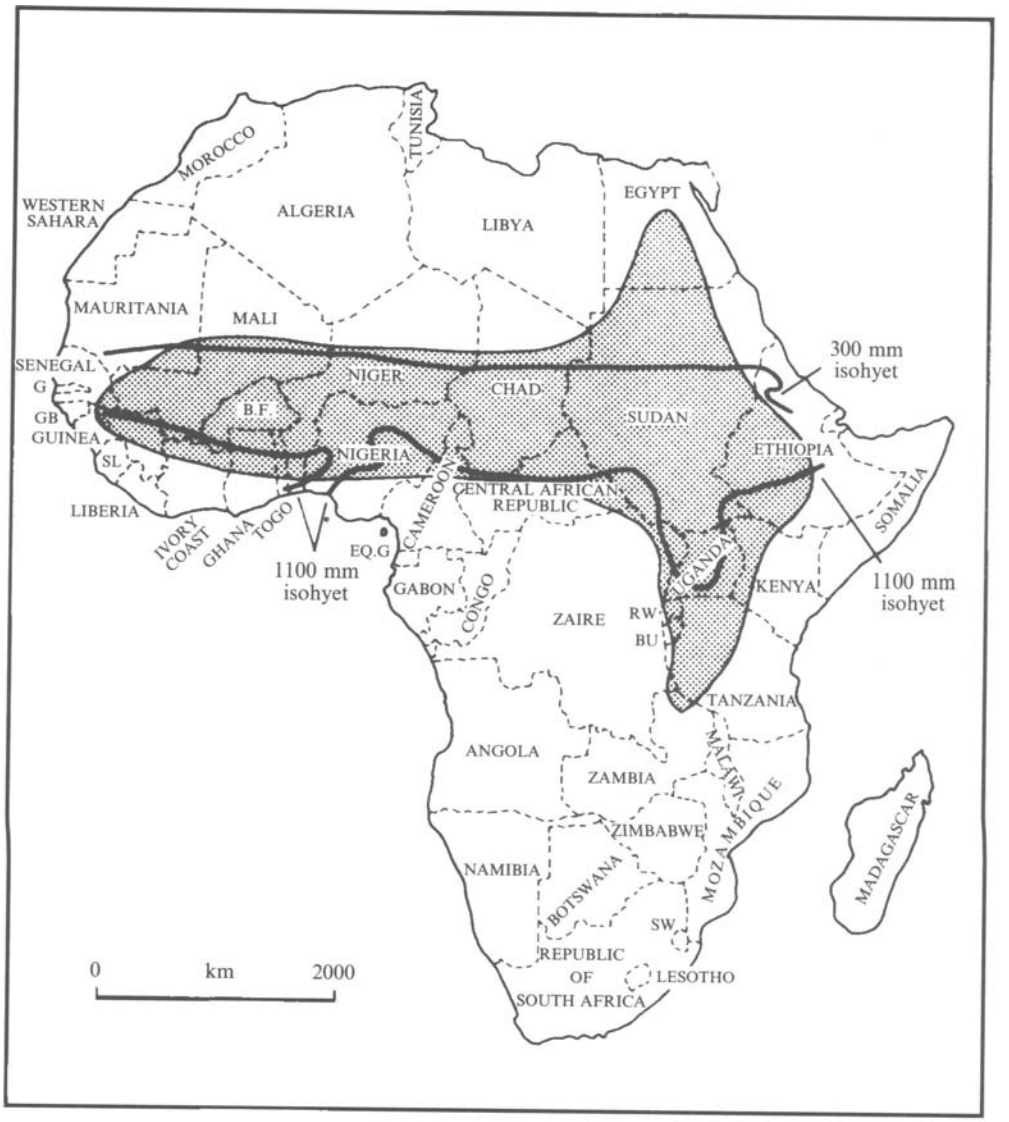

Fig. 1. Map of Africa with the position of the 300 mm and 1100 mm isohyets (limits of the classical meningitis belt) and the extended zone where epidemics may occur from time to time, ⊡.

humidity starts to increase, and that cases are rare once absolute humidity rises above 10 g of water vapour per cubic metre of air (10 g m^{-3}), a finding later partly corroborated by Greenwood and colleagues in Nigeria [7]. In temperate climates meningococcal meningitis peaks in the winter when absolute humidity reaches its nadir.

How climate modulates meningococcal disease remains unclear. Several detailed studies in the meningitis belt have shown that there is little change in the level of meningococcal carriage or the rate of acquisition of nasopharyngeal colonization with season [8, 9], suggesting that climate primarily influences co-factors, such as mucus desiccation or upper respiratory tract infection [7, 10], which might facilitate the progression of colonization to invasive disease. A recent report from

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Malawi, however, has shown an increase in the prevalence of carriage in the dry season prior to the onset of an epidemic (unpublished observation, Dr L. Cuevas), and studies from the Gambia noted a higher rate of meningococcal acquisition among inhabitants of villages affected by meningococcal disease than those unaffected [11]. These findings suggest that transmission *per se*, or the inoculum required to establish colonization, may also be affected by climatic factors. The observation that total airborne bacteria are increased in dry weather also supports this contention [12]. The relative importance of the various mechanisms by which climate and meningococcal disease interact are not clearly established.

Determining the prevalence of carriage in locations where the climatic factors which appear to suppress epidemic disease are present all the year around might elucidate this issue: were carriage still present, far from a major reservoir of known infection, it would suggest that the absence of facilitating co-factors was critical. Conversely, the absence of carriage would suggest that the disruption of transmission was important, either directly by suppressing airborne survival of the organism or by suppressing the duration or intensity of carriage in the nasopharynx.

We have performed such a study in a part of Zaire, which on the basis of a 16-year review of laboratory records presented in this report, has a very low incidence of meningococcal meningitis. These findings are compared with representative reports from elsewhere in Africa to describe a zone in which both endemic and epidemic meningococcal meningitis is rare. The monthly variation in absolute humidity within this zone has been examined to assess whether the concept of a level of absolute humidity which is not permissive of meningococcal disease appears to be valid.

MATERIALS AND METHODS

Study samples

Study to determine the relative frequency of bacteria isolated from cerebrospinal fluid (CSF) at Institut Médical Evangélique (IME).

Data were collected by inspecting the records kept by the bacteriology laboratory at IME from April 1976 to May 1992. This laboratory processes specimens submitted from the wards and outpatients' clinics of IME, a 400-bed general mission hospital situated at Kimpese in western Zaire (Fig. 2).

Kimpese is on the busy main road from Matadi, Zaire's major seaport, to Kinshasa and is therefore exposed to travellers who have contact with sailors frequenting Europe and other parts of Africa. While the hospital serves a predominantly rural community of approximately 150000 people, occasional patients come from as far as Kinshasa for treatment.

All CSFs with greater than 5 WBC/μl collected over this time were cultured on chocolate and MacConkey agar. Plates were incubated at 37 °C for 48 h in candle jars. Isolates were identified to species level by standard biochemical techniques. The clinical indications for sampling CSF and laboratory processing remained constant over the study period.

The point prevalence of meningococcal carriage among children at Kimpese was determined in three separate studies.

(i) The posterior pharyngeal wall was sampled by per-oral swabbing in 134

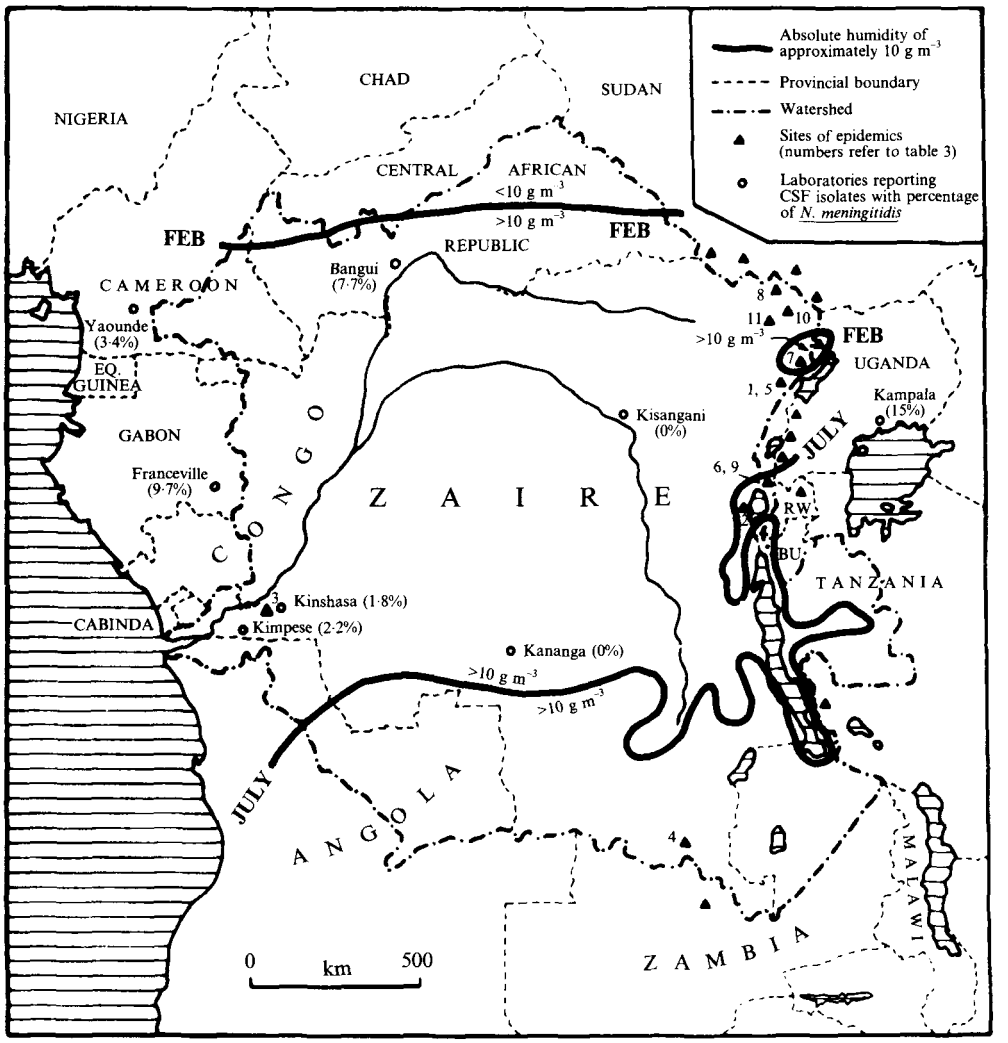

Fig. 2. Distribution of epidemics of meningococcal meningitis and laboratories reporting CSF isolates in the Congo Basin related to 10 g m^{-3} absolute humidity contour for the month in which this reaches furthest into the basin. Reference numbers refer to locations in Table 3.

children aged between 3 and 24 months attending routine weight monitoring and immunization clinics at IME. Most of these children came from the town of Kimpese or surrounding villages and were in good health. This study took place in May 1990 (late wet season).

(ii) Per-nasal swabs sampling the posterior nasopharyngeal space were collected from 131 children aged 10–14 years attending a boarding school in Kimpese on a single day in November 1990 (early wet season).

(iii) A second series of pernasal swabs from 118 previously unsampled children in the same age range attending this school were collected on a single day in May 1991 (late wet season).

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Laboratory processing

In studies (i) and (ii) swabs were plated directly on to selective Kellogg's media (LabM UK) immediately after collection. In study (iii) swabs were inoculated directly on to Gonoline cultivation and transport systems (API Biomérieux, France). This incorporates a CO_2-generating tablet and both selective and non-selective agars. It was employed to reduce any loss of viability on transport and also to confirm adequate nasopharyngeal sampling by checking for a heavy growth of normal flora on the non-selective media. Plates were placed, within 3 h of collection, at 35 °C in candle jars for 48 h and Gonolines were incubated at 35 °C for 48 h.

All colonies growing on selective media were picked off for Gram stain and oxidase testing. Organisms compatible with *Neisseria* species were subcultured to chocolate slopes and brought to the UK for further identification by sugar fermentation, ONPG, DNase testing, and growth on nutrient agar. Organisms compatible with *N. meningitidis* were sent to the Public Health Laboratory Service Meningococcal Reference Laboratory, Manchester, UK, for final identification including grouping and typing.

Climatological data source

Climatological data has been abstracted from Atlases [13–15]. Humidity values in these publications are presented as either monthly or seasonal means calculated from several years of data. It is therefore inevitable that absolute humidity will deviate from the figures presented in this paper for some days in each month. When data are available as vapour pressure or as the mixing ratio for water vapour an accurate estimate of absolute humidity can be calculated. Such accuracy is not possible if relative humidity alone is given. This is because relative humidity is calculated from the quotient of actual vapour pressure over saturated vapour pressure. Since saturated vapour pressure is a function of temperature an accurate estimate can only be made if temperature is known.

In this study absolute humidity in grams per cubic metre of air (g m^{-3}) was calculated from vapour pressure using the equation:

$$\text{Absolute humidity (g m}^{-3}) = \frac{M_w e}{RT} = \frac{2165\,e}{T}$$

where e is the vapour pressure (kPa), R is the gas constant (8·31 J mol^{-1} K^{-1}); M_w is the gram-molecular mass for water vapour and T is the temperature (K). The influence of temperature is small because the annual mean diurnal temperature range is only about 10 K in the Congo Basin.

The mean monthly temperature and vapour pressure data used to derive the contour in Fig. 2 were taken from the mapped data sets published by Bultot, who collected data from stations within the Congo Basin between 1950 and 1959 [13]. Absolute humidity was calculated from the mean monthly vapour pressure maps based on 130 stations in conjunction with the mean monthly temperature maps based on 229 stations. The data are presented as an estimated line joining points which have a calculated monthly mean absolute humidity of 10 g m^{-3}. The isohyets in Fig. 1 were redrawn and simplified from maps of mean annual rainfall

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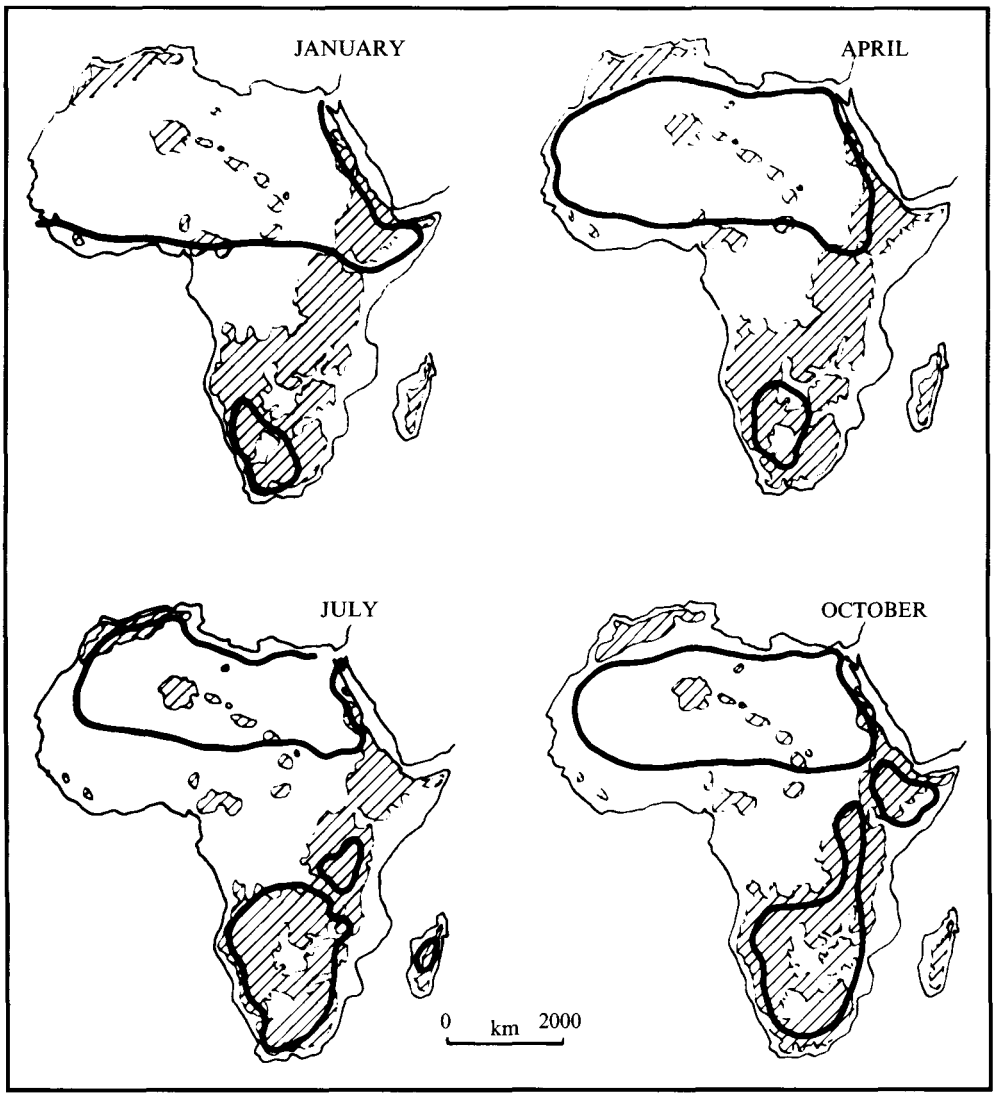

Fig. 3. Map of Africa showing land over 1000 m above sea level related to 10 g m^{-3} absolute humidity contour for selected months. ----, absolute humidity at approximately 10 g m^{-3}; ▨, land over 1000 m.

in Thompson [14] and Jackson [15], which were also the source of the data presented in Figs 3 and 4.

Search methods for African meningitis data

To compare the epidemiology of meningitis at Kimpese with meningitis from other locations in Africa the Medline database was interrogated using the following key words: Meningitis and either, epidemiology, Africa or developing country from 1981 to 1992. Additional references were found in the bibliographies of the references generated by this search, some from journals not in the Medline database. Reports from which the percentages of CSF isolates of the three major

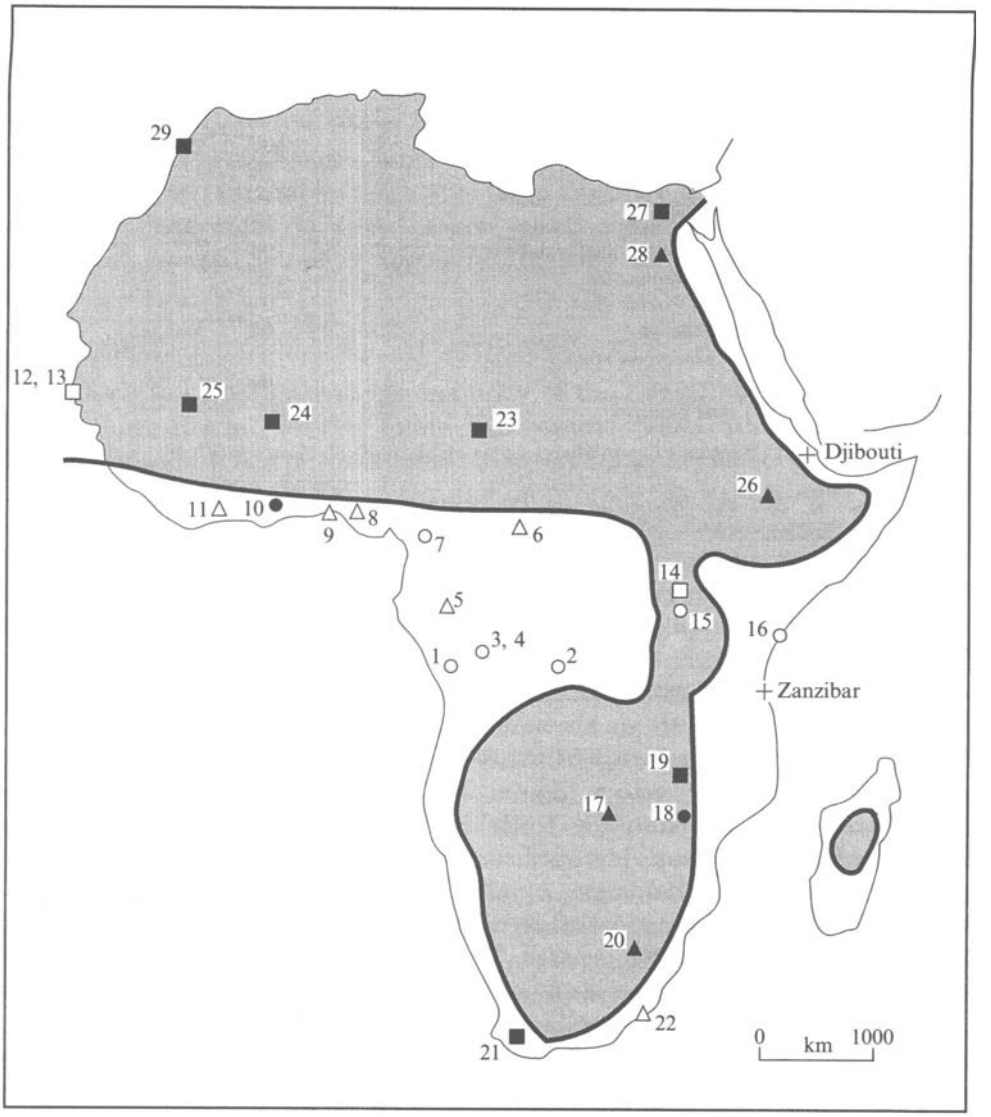

Fig. 4. Map showing the zone in Africa (▨) in which absolute humidity falls below 10 g m^{-3} for at least one month per year (composite of data presented in Fig. 3). With locations of studies quoted in Table 2. *N. meningitidis* as percentage of total CSF isolates: ○, 0–5; △, 6–10; □, 11–15; ●, 16–20; ▲, 21–50; ■, >51. +, Location with very low incidence reported.

meningeal pathogens *N. meningitidis*, *Streptococcus pneumoniae* and *Haemophilus influenzae* could be extracted were tabulated and locations of epidemics recorded. The CSF isolate data sets regularly published by the Antibiotic Study Group of South Africa in the *South African Journal of Medicine* were summated for the 3 years 1984–6 to yield additional data. These data were further supplemented by personal communications from Professor D. G. Montefiore and Professor J. Vandepitte.

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Table 1. *CSF cultures at IME between August 1976 and May 1992*

	No.	%
Streptococcus pneumoniae	78	34·0
Haemophilus influenzae	60	30·5
Neisseria meningitidis	5*	2·2
Cryptococcus neoformans	19	11·3
Salmonella sp.	11	4·8
Other Enterobacteriaceae†	23	10·0
Pseudomonas sp.	4	1·7
Acinetobacter sp.	1	0·4
Candida sp.	1	0·4
Streptococcus sp.	5	2·1
Listeria sp.	1	0·4
Total isolates	229	100

* Two additional CSFs had Gram stains compatible with *N. meningitidis* but not growth on culture.

† Includes: *E. coli* (4), *Klebsiella* sp. (3), *Enterobacter* sp. (3), *Citrobacter* sp. (1), and unidentified coliforms (12).

RESULTS

CSF isolates

The distribution of 229 CSF isolates by organism is shown in Table 1. *S. pneumoniae* and *H. influenzae* account for 65% of all meningitis. Cryptococcus, the next most frequent isolate, has increased in adults since the late 1980s with the advent of AIDS in western Zaire. The relatively large contribution of Enterobacteriaceae is mainly due to the inclusion of neonatal cases. Laboratory records were not sufficiently detailed to establish the age of the patient in many cases, thus precluding an analysis by age.

Only five cases of meningococcal meningitis were proven by culture accounting for 2·2% of the positive CSF isolates. Two further cases were identified in which gram-negative diplococci were seen on Gram stain of the CSF but no growth was detected on culture. These cases were widely separated in time; no data was available on locations to determine whether there was any geographic clustering. Three of the five culture confirmed cases occurred during the dry months from May to October.

Assuming an average catchment population of 150000, the annual incidence of meningococcal meningitis over the period of the study was 0·2 per 100000. While some cases of meningitis within this population would not have reached IME due to a fulminating course, it is likely that most would have been referred, as IME is the only major hospital in the area and had established close relations with local primary care facilities which would not usually have attempted to manage meningitis without referral. The arrival of some cases from outside the usual catchment area would have tended to compensate for any loss of local cases.

Meningococcal carriage

A total of 383 children had samples collected from the upper airway for meningococcal culture, 134 by per-oral swabbing and 249 by pernasal retropharyngeal swabbing. Recovery of meningococci is adequate and broadly similar by both methods [16]. Only three isolates compatible biochemically with *N.*

meningitidis were detected, one in the first study and two in the last. None of the isolates could be serogrouped or serotyped by the reference laboratory and were therefore classified as non-pathogenic *N. meningitidis*. The overall carriage rate of *N. meningitidis* was 0·78% (95% confidence limits 0–1·7%) and in the school sample 0·8% (95% confidence limits 0–1·9%).

Only one of the 118 samples inoculated into Gonoline systems failed to yield any normal nasopharyngeal flora on the non selective media and in two more the growth was scanty. Sampling therefore appeared to be adequate in 99% of children.

Climatic data

The absolute humidity over the majority of the Congo Basin and thus Zaire remains above 10 g m^{-3} all year round. The contour demarcating the edge of this zone and the month in which it applies is shown in Fig. 2. The northern boundary enters the Congo Basin in December and on average reaches its most southerly position in February. While this is still north of the Zaire border, islands of absolute humidity below 10 g m^{-3} are present in the upland areas of western Uganda and neighbouring Zaire. The southern boundary enters Zaire in May and extends furthermost north in July reaching a latitude approximately 6 degrees south. Some areas in the upland regions on the eastern border of Zaire with Rwanda and Burundi have an absolute humidity below 10 g m^{-3} from June to October. In June this area covers parts of Rwanda and Burundi together with the Kivu area of Zaire to the north-west of Lake Tanganyika. By July this area has expended to form a continuous belt of low humidity which reaches its maximum shown in Fig. 2. Thus it can be seen that the southern areas of Zaire are prone to low absolute humidity from May through to September with the zone most prone moving to South-East Zaire and Zambia during September. The upland areas in the east of Zaire are prone to low absolute humidity for many months of the year. These areas receive about 1000 mm $year^{-1}$ of rain compared with 2000 mm $year^{-1}$ in the Congo Basin. This reduced rainfall together with the lower temperature experienced at high altitude account for this reduction in absolute humidity.

The zones in which mean monthly absolute humidity would be expected to fall below 10 g m^{-3} for the whole African continent in selected months are shown in Fig. 3, which also shows the relationship to altitude. These contours are based on relative humidity and temperature maps [14, 15] and while the calculated absolute humidity is inherently less precise than that employed in Fig. 2 the contours are broadly comparable.

Comparison with Fig. 1 shows how the meningitis belt falls within the less than 10 g m^{-3} of air humidity contour in January and April and that humidity has risen above this threshold by July corresponding well with the seasonality of meningitis in this area. A tongue of low humidity can be seen extending up over the high ground around the Rift Valley in eastern African in October which corresponds well to the southern extension of the epidemic zone [17] shown in Fig 1.

A summation of these data to delineate the area in which mean monthly humidity would be expected to drop below 10 g m^{-3} at some time during the year (hatched zone) and that in which it remains above this threshold at all times is shown in Fig. 4. Virtually the whole of the Zaire basin and the West Africa coastal strip is outside this low humidity zone.

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Table 2. *Distribution of major bacterial meningitis pathogens in Africa by geographical area*

Country	Place	Years of study	No. of isolates	Study* pop.	% of isolates of			Fig. 4 location number	Ref.
					N. men.	*S. pn.*	*H. flu.*		
Western Central Africa									
Zaire	Kimpese	1975–92	229	m	2·2	34·1	26·2	1	†
Zaire	Kananga	1956 8	99	m	0	55·6	34·3	2	[18]
Zaire‡	Kinshasa	1958–77	249	c	1·6	33·3	46·2	3	[19]
Zaire‡	Kinshasa	1959–72	474	m	1·8	27·3	23·3	4	[20]
Gabon	Franceville	1983–4	31	m	9·7	38·7	12·9	5	[21]
CAR	Bangui	1987	39	a	7·7	71·8	10·3	6	[22]
Cameroon	Yaounde	1982–3	174	c	3·4	42·5	30·5	7	[23]
Western Coastal Africa									
Nigeria	Ibadan	1976–80	463	c	5·6	34·3	28·3	8	[24]
Nigeria	Lagos	1963–8	342	m	5·6	33·6	24·9	9	[25]
Ghana	Accra	1965	45	m	15·6	66·7	11·1	10	[26]
Ivory Coast	Abidjan	1971–5	833	m	6·4	38·8	13·6	11	[27]
Senegal	Dakar	1970–9	2515	m	14·6	39·1	26·7	12	[28]
Senegal	Dakar	1983–6	222	c	11·3	32·0	42·3	13	[29]
East Africa									
Uganda	Kampala	1947–52	167	m	15·0	61·7	5·4	14	[30]
Uganda	Kampala	1965	97	m	2·0	37	39	15	[31]
Kenya	Kilifi	1990–2	41	c	2·4	40·0	35·0	16	[32]

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Southern Central Africa and Republic of South Africa									
Zambia	Lusaka	1978–81	445	m	35·7	33·7	8·3	17	[33]
Malawi	Blantyre	1972–3	79	m	19·0	30·4	35·4	18	[34]
Malawi	Lilongwe	1986–90	494	m	75·7	18·2	2·6	19	§
RSA	Jo'burg	1980–2	535	m	31·0	21·9	16·4	20	[35]
RSA	Cape Town	1981–4	247	c	56·7	13·8	19·0	21	[36]
RSA	Durban	1986	51	m	9·8	52·9	37·2	22	[37]
Meningitis belt									
Chad	N'Djamena	1968–71	1304	m	89·7	6·0	1·6	23	[28]
Burkina Faso	Ouagadougou	1970–3	1067	m	63·3	6·4	6·4	24	[28]
Mali	Bamaku	1979–91	1537	m	50·1	20·6	29·3	25	[38]
North Africa									
Ethiopia	Addis Ababa	1975–6	120	c	25·0	21·7	41·7	26	[39]
Egypt‖	Cairo	1966–89	3211	m	66·3	17·9	10·0	27	[40]
Egypt	Assiut	1985–7	104	m	47·1	23·1	11·5	28	[41]
Morocco	Casablanca	1960–6	501	m	40·8	19·7	15·6	29	[42]

* Study population: a, adults; c, children; m, mixed.
† Current report.
‡ Some paediatric data common between these two studies.
§ Data collected during epidemic of meningococcal meningitis (unpublished data, Dr L. Ceuvas, Liverpool School of Tropical Medicine).
‖ 1538 isolates of *M. tuberculosis* removed from this analysis to render it more comparable with other data in Table 2.

Analysis of literature search

The literature search identified 64 reports from Africa from which the relative frequency of the three major pathogens could be derived. A representative sample of these studies is shown in Table 2 and Figure 4. While studies based on a relatively large number of isolates were preferred a few smaller studies are included where data is otherwise scarce from within a particular geographic area. Studies were also selected to show both the highest and lowest frequency of *N. meningitidis* from each area and neonatal data removed when sufficient data was given to make this possible.

Studies with a very high frequency of *N. meningitidis* from the classic meningitis belt can be compared with studies showing an equally high frequency from northern Africa and central southern Africa, while studies from western coastal and central Africa in general show a much lower frequency. Several reports attest to outbreaks of meningococcal disease in the east African highlands of Uganda, Kenya and Tanzania which have not spread into more humid coastal areas such as Zanzibar [43, 44] or Djibouti [45].

Comparison of the data extracted from the reports of the Antibiotic Study Group of South Africa showed that meningococci accounted for 37·2% of 500 CSF isolates from Cape Town, 23·7% of 131 isolates from Pretoria, 22·6% of 469 isolates from Johannesburg and 13·7% of 386 isolates from Durban. Among these cities Durban has the highest average absolute humidity.

DISCUSSION

Meningococcal disease is generally regarded as a worldwide problem [46]. The endemic incidence varies from approximately 1–3/100000 in the USA [47] to 10–25/100000 in many developing countries [48]. During epidemics this may increase to over 500/100000. Reports suggesting that particular countries have a very low incidence must be treated with caution as this may simply reflect data collected between epidemics. The endemic level may be very low between epidemics and this interval can be prolonged; the recent epidemic in Malawi began in 1986, nearly 50 years after the previous outbreak [49]. The figure of 0·2 per 100000 in this study would appear, nevertheless, remarkably low.

The studies from Zaire, which are also shown in Fig. 2, reveal a remarkable consistency: the percentage of bacterial meningitis due to meningococcus varies from zero in the report from Kananga [18] to 1·8% in the report from Kinshasa [20] and 2·2% in this report. In support of this, *N. meningitidis* was not isolated between 1948 and 1958 in Kisangani (unpublished observations, Prof. J. Vandepitte). Other less detailed reports attest to the low incidence of meningitis, the absence of epidemics and rarity of meningococcal disease in the western and central regions of Zaire: Lambotte-Legrand reports only 21 cases of meningitis with 15 CSF isolates among a total of 741 paediatric admissions in Kinshasa in 1949 none of which were meningococcal [50].

Platel and Vandergoten conducted a detailed study of children from birth to 5 years of age between 1934 and 1938 in Mayombe in western Zaire. In their cohort of approximately 1000 children meningitis was rare and no deaths due to

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Table 3. *Reported epidemics of meningococcal meningitis in Zaire*

Place	Altitude*	Map ref. no.	Year(s) of onset	Months	Season	Number of cases	Reference
Ituri	1500	1	1918	Not stated	Dry	100†	[52]
Bukavu	1500	2	1919	Not stated	Dry	100†	[52]
Kinshasa	311	3	1921	June–Aug.	Dry	10	[53]
Lubumbashi	1298	4	1925–27	May–Sept.	Dry	278	[52]
Ituri	1500	5	1927	Not stated	Dry	250†	[52]
Rutshuru	2000	6	1935	Aug.–Oct.	Dry	N.S.‡	[54]
Mahagi	2000	7	1937	Dec.–Mar.	Dry	Many	[55]
Faradje	1000	8	1938	Jan.–Mar.	Dry	Many	[55]
Rutshuru	2000	9	1977	July–?	Dry	69	[56]
Laybo	1000	10	1990	Dec.–Mar.	Dry	169	§
Watsa	1000	11	1991	Dec.–Jan.	Dry	105	§

* Altitude in metres above sea level. Figures rounded to nearest 500 m are appropriate.
† Approximate number – precise details not given.
‡ Not stated.
§ Data from Medecins sans Frontières, Paris.

meningitis were recorded (51). The other studies from western central Africa show a relatively low frequency of meningococcal isolation.

Among studies from the meningitis belt *N. meningitidis* typically accounts for 50% or more of all confirmed bacterial meningitis, although this varies depending on whether the study period includes an epidemic. The proportion of *N. meningitidis* isolates in series from locations relatively close to the edge of the belt in coastal west Africa generally vary from 5–15%.

In studies from inland eastern and southern central Africa the percentage of meningococci varies widely as epidemics occur with a much lower frequency than that observed in the classic meningitis belt. The absolute humidity contour shown in Figure 4 corresponds reasonably well with the edge of the zone in which epidemics of meningococcal disease have occurred in east Africa [43, 44].

The far north eastern corner of Zaire is cut off by the 1100 mm isohyet, which is regarded as the southern border of the meningitis belt [1]. Several epidemics of meningitis have been reported in this zone close to the Sudan/Uganda border. These and all the other recorded epidemics in Zaire are detailed in Table 3 and Fig. 2. The northern epidemics all originated outside Zaire and penetrated no further than the districts close to the border. The 1935 epidemic in Rutshuru appears to have been an extension of an epidemic from neighbouring Rwanda. This town however appears to have been the initial focus of the 1977 epidemic which spread extensively into Rwanda without any significant further extension into Zaire [56]. In the Katanga region of southern Zaire an epidemic among copper miners which peaked in 1925 has been reported [52]. The only epidemic of meningococcal meningitis every reported in Kinshasa began in June 1921, consisting of a cluster of 10 cases [53]. All these epidemics, apart from the 1977 outbreak in Rwanda which continued into the wet season, started in the dry season and apparently waned soon after the rains began.

Thus, while epidemics have been reported regularly from several countries bordering Zaire to the north, Central African Republic and Sudan, and less frequently those to the east, viz Uganda, Rwanda, Burundi, Tanzania and

infrequently from Zambia [57], these, with the exception of the small epidemic in Kinshasa, have only spread to upland areas above 1000 metres on the rim of the Zaire basin.

These reports suggest that meningococcal disease is remarkably rare in the Congo basin. One possible explanation for this might be that climatic factors that are known to curtail epidemics in other areas exist throughout the year in the Congo basin, and thus reduce the incidence of meningococcal diseases to a very low level and prevent epidemic spread. The risk of epidemics in the meningitis belt is greatest in the hot, dry, dusty season when absolute humidity is lowest. Although western Zaire has a distinct dry and dusty season from late May to October the skies are usually cloudy and humidity remains high. Absolute humidity, rather than rainfall, would therefore appear to be a more likely critical climatic factor. Figure 2 also shows the limits of the zone in the Congo basin in which mean monthly absolute humidity remains above 10 g m^{-3} throughout the year and the month in which contour reaches furthest into this zone. There is a clear temporal association between known epidemics and minimum humidity.

The pan-African data shown in Figs 3 and 4 appear to corroborate the hypothesis that an absolute humidity of 10 g m^{-3} or greater throughout the year affords some protection from meningococcal disease. The Congo basin and west African coastal strip are clearly in this zone and reports of a low incidence from coastal east Africa also fit. Data from Cape Town appear to represent an exception in that meningococcal disease is not uncommon there particularly in the winter (July map in Fig. 3) despite the high humidity [36]. However, this city is close to the edge of this zone, the borders of which cannot be defined with absolute precision and will inevitably be violated by atypical weather conditions. The data sets compiled from the reports of the South African Antibiotic Resistance Study group which allow a more accurate comparison of the relative frequency of the three major pathogens across the Republic of South Africa corroborate these results.

The low point prevalence of meningococcal nasopharyngeal carriage may reflect sub-optimal timing and selection of the study samples. If carriage and absolute humidity are inversely related a study undertaken in the late dry season might be expected to show a higher rate. The need to co-ordinate these studies with other projects in Zaire dictated collection in the wet season. The switch from younger children in the first study to older children living in a school in the later studies was made in an attempt to maximise the likely carriage rate. The year groups were selected on the basis of likely compliance with per nasal swabbing. Slightly younger children between 5 and 10 years might have shown a higher prevalence of carriage.

The point prevalence of carriage in countries with endemic meningococcal meningitis varies with age. Among children over 5 years and adults it is usually between 5 and 10% [46, 58]. Higher levels are often seen in closed communities such as schools or barracks while levels as low as 0·6% have been reported in younger children [59]. To demonstrate a prevalence of carriage significantly lower than this requires a larger study than that reported here.

Five other published studies from tropical Africa examining meningococcal carriage outside the meningitis belt have been published which are detailed in Table 4. With the exception of the study from Djibouti, all show a carriage rate

Table 4. *Meningococcal carriage in tropical Africa outside the classic meningitis belt*

Place	Proximity to 'Belt'*	Year of study	Study pop.	No. of subjects	(%) No. of isolates	Serogroups isolated (No.)	Reference
Rwanda	250	1976	School children	250	26 (10)	B, W135, Y	[56]
Djibouti	500	1988	Soldiers	100	4 (4)	A(3) NT(†) (1)	[45]
Nigeria							
Nsukka	80	1973/4	Mixed adults and children	1126	112 (10)	A(11) B(66)	[60]
Nigeria		1981	Mixed adults and	303	42 (14)	A, B, C, D, X,	
Nsukka	80		children			> 80% groups B	[61]
Enugu	180						
Cairo	1750	1972/3	School children	1165	306 (18)	A(34) B(28) C(4) D(1) X(2) Y(21) Z(7) NT(†) (209)	[62]
			Mixed adults and children	2740	700 (26)	A(28) B(59) C(28) X(54) Y(7) Z(1) NT(†) (585)	

* Proximity (in kilometres) to nearest border of the classic meningitis belt as defined by the 300 mm and 1100 mm isohyets.
† NT, Not typable.

of approximately 10%, significantly higher than that found in this study. These studies were all undertaken relatively close to the edge of the belt or in the case of Rwanda, in a country where epidemics have been reported. This suggests that transmission readily occurs in a zone adjacent to the edge of the meningitis belt and climate primarily modulates the incidence of meningitis by reducing the frequency with which colonization results in disease. However, the low carriage rate in western Zaire, an area of year-round high absolute humidity approximately 1700 km from the edge of the belt, suggests that there is also some impact on transmission. Whether this is due to a direct effect on the viability of airborne meningococci or by maintaining nasopharyngeal colonization resistance which then reduces the reservoir of potential transmitters is unclear. Reports of experiments which have attempted to examine the survival of meningococci under varying levels of humidity have been inconclusive [3].

In summary, western Zaire would appear to be in the centre of a hypoendemic zone for meningococcal disease with a very low potential for epidemic spread. The persistently high absolute humidity found in the Congo basin appears to correlate well with borders of this zone. The low prevalence of meningococcal carriage suggests that these climatic factors may prevent meningococcal disease by reducing colonization and/or transmission rather than by purely excluding co-factors which facilitate invasive disease. A larger study is required to confirm this finding.

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